Varinder S. Kanwar
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Proceedings of International Conference on Innovative Technologies for Clean and Sustainable Development (ICITCSD – 2021)

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Preface

With the advent of the concept of sustainable development, we citizens could not ignore the catastrophic effects of depleting natural resources, festering waste dumps and the subsequent pollution. Increasing population worldwide creates the need to build more infrastructure and develop more resources, and therefore our environment is under continued deterioration with different types of impact, including depletion of major resources such as air, water and soil, and destruction of ecosystem. There is a need to understand that true development cannot be achieved by putting resources and ecology at risk. We need to adopt sustainability in our progress and growth. Sustainability is often defined as a set of environmental, economic and social conditions in which the society has the capacity and opportunity to maintain and improve its quality indefinitely without degrading the quantity, quality or availability of natural, economic and social resources. Civil engineers must take the lead in applying sustainability to selection, planning, design, construction and maintenance of various elements and components of infrastructure. Sustainable design requires a complete assessment of the design in place and time. Sustainable engineering practice should meet the human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste and material management while conserving and protecting environmental quality and the natural resource base, essential for future development. Civil engineers can contribute solutions to sustainable development by adopting cleaner technology and green design principles. Commitment to this challenge requires that civil engineers acknowledge their professional obligation, extend their knowledge base and participate in all levels of policy decisions.

This international conference, held on October 14 and 15, 2021, achieved its aims by establishing long-term linkages between the user industries and the providers of clean technologies and sustainable materials. The conference has created awareness and appreciation among academicians, scientists, researchers and practitioners from various disciplines and sectors about developing and implementing sustainable practices and technologies that minimize the impact on our environment. Deliberations on new initiatives in latest technologies in the field of infrastructure development and maintenance took place. This helped participants and regulators to formulate concrete strategies with optimal utilization of available resources for developing these technologies, and consolidating the suggestions, strategies and recommendations made during the conference and disseminating the knowledge on the conference themes.

We would like to extend our deep-felt thanks to Dr Ashok K. Chitkara, Chancellor of Chitkara University; Dr Madhu Chitkara, Pro-Chancellor of Chitkara University; and Dr S.S. Patnaik, Director NITTTR Chandigarh for supporting us at all fronts. We are thankful to all keynote speakers, reviewers, IT team members and the team at Springer for their full support and cooperation at all the stages of the publication of this book. We wish to extend our special thanks to the contributing researchers/authors and all those who supported this conference for making it a milestone in the area of sustainability.

We do hope that this book will create awareness and appreciation amongst academicians, scientists, researchers and practitioners from various disciplines and sectors about the need and the new initiatives towards sustainable infrastructure development. The comments and suggestions from the readers and users of this book are most welcome.

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Abbreviations

μ S/cm	Microsiemens per Centimetre
10M	Morality
3D	Three Dimensional
3D Printing	3 Dimensional Printing
5G	Fifth Generation
AAR	Alkali Aggregate Reaction
AASHTO	American Association of State Highway and Transportation Officials
ABS	Acrylonitrile Butadiene Styrene
ACBFS	Air Cooled Blast Furnace Slag
ACI	American Concrete Institute
AFRP	Aramid Fibre Reinforced Polymer
AHEW	Amine Hydrogen Equivalent Weight
AI	Artificial Intelligence
Al_2O_3	Aluminium Oxide
Al^{3+}	Aluminium Cation
ALOS	Advanced Land Observing Satellite
AN	Aadhaar Number
ANN	Artificial Neural Network
ANS	Aadhaar Number System
ANSYS	Analysis of Systems
AOP	Advanced Oxidation Processes
API	Application programming interface
ARCGIS	Aeronautical Reconnaissance Coverage Geographic Information System
ASME	American Society of Mechanical Engineers
ASP	Activated Sludge Processes
ASR	Alkali Silica Reaction
ASSOCHAM	Associated Chambers of Commerce and Industry of India
ASTM	American Society for Testing and Materials
AUI	Application User Interface

AVHRR	Advanced Very High-Resolution Radiometer
B.A.	Brick Ash
BBMB	Bhakra Beas Management Board
BC	Bacterial Cellulose
BCM	Billion Cubic Metre
BFRP	Basalt Fibre Reinforced Polymer
BG	Reinforced Bagasse
BIS	Bureau of Indian Standards
BOD	Biochemical Oxygen Demand
BS EN	British Standard European Norm
BU	Ballot Unit
BZ	Benzamine
C	Celsius
C	Carbon
C&D Waste	Construction & Demolition Waste
C.A	Coarse Aggregate
C/C	Cement Concrete
C/E FAHS	Carbon/Epoxy Facings Aluminium Honeycomb Sandwich
C19P	Covid-19 Pandemic
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
C_4AF	Tricalcium Aluminoferrite
Ca	Calcium
CA	Coarse Aggregate
Ca^{2+}	Calcium Ions
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
CAS	Conventional Angle Steel
CBR	California Bearing Ratio
CBRI	Central Building Research Institute
CC	Calcined Clay
CCB	Conventional Clay Bricks
Cd	Cadmium
CEB	Compressed Earth Block
CEC	Cation Exchange Capacity
CETP	Central Effluent Treatment Plant
CF	Carbon Footprint
CFF	Carbon Fibre Fabric
CFRP	Carbon Fibre Reinforced Polymer
CFS	Cold Formed Steel
CH	Calcium hydroxide
CHIRPS	Climate Hazards group Infrared Precipitation with Stations
CII	Confederation of Indian Industry
CL	Contact Less

CLC	Cement Lime Concrete
Cm	Centimetre
CM	Cement Mortar
CMC-BC	Carboxymethyl Cellulose-Bacterial Cellulose
CMU	Concrete Masonry Units
CNT	Carbon Nanotubes
CO_2	Carbon Dioxide
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COD	Chemical Oxygen Demand
CONWEP	Conventional Weapon
COVID	Coronavirus Disease
CPCB	Central Pollution Control Board
CPU	Hybrid Carbon Fibre Polyurea
Cr	Chromium
Cr_2O_3	Chromium Oxide
CS	Compressive Strength
CSB	Conventional Solid Bricks
CSEB	Compressed Stabilized Earth Block
C-S-H	Calcium Silicate Hydrate
CSV	Comma Separated Values
CT	Carbonation Test
CTM	Compression testing machine
Cu	Copper
CU	Control Unit
Cu	Copper
CuO	Copper Oxide
DC	Direct Current
DFS	Differential Free Swell
Dia	Diameter
DIF	Dynamic Increase Factor
DIN	German Institute for Standardization
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
DOES&T	Department of Environment, Science & Technology
DSAS	Digital Shoreline Analysis System
DSGXNS	Distributed SGX Network System
DT	Destructive Test
DTGA	Differential Thermogravimetric analysis
DY	Direct Yellow
E Waste	Electronic Waste
EC	Embodied Carbon
ECI	Election Commission of India
EDC	Endocrine Disrupting Chemicals
EDTA	Ethylenediamine Tetraacetic Acid

EE	Embodied Energy
EEW	Epoxy Equivalent Weight
EF	Environmental Flow
EKR	Electrokinetic Remediation
EOF	Electro-osmotic Fluid
EPFO	Employee Provident Fund Organization
EPR	End Point Rate
eq	Equivalent
ER	Electoral Roll
ES	Expansive Soil
ETM	Enhanced Thematic Mapper
ETP	Effluent Treatment Plant
Eu	Europium
EVM	Electronic Voting Machine
EWS	Economically Weaker Sections
F.A	Fine Aggregate
F/M	Fineness Modulus
FA	Fly Ash
FA	Fine Aggregate
FA	Fly Ash
FA	Fine Aggregate
FDC	Flow Duration Curve
FE	Finite Element
Fe	Iron
FE	Finite Element
Fe_2O_3	Ferric Oxide
FEA	Finite Element Analysis
FEM	Finite Element Method
FIB	International Federation for Structural Concrete
FICCI	Federation of Indian Chambers of Commerce and Industry
FM	Fineness Modulus
FNR	False Negative Rate
FRP	Fibre Reinforced Polymer
FRP	Carbon Fibre Reinforced Polymer
FTIR	Fourier-Transform Infrared Spectroscopy
g	Gram
GEE	Google Earth Engine
GFRP	Glass Fibre Reinforced Polymer
GGBS	Ground-Granulated Blast Furnace Slag
GGBS	Ground-Granulated Blast Furnace
GHG	Greenhouse gases
GIS	Geographical Information System
GJ	Giga Joule
GoI	Government of India
GPC	Geopolymer Concrete

GPS	Global Positioning System
GSA	Groundnut Shell Ash
GTP	Gross Pollutant Traps
G-VA	Global Voting Application
GWP	Global Warming Potential
H_2SO_4	Sulphuric Acid
H^+	Hydrogen Ion
H_2O	Water
HCl	Hydrogen Chloride
HDS	Hydrodynamic Deflective Separation
HIPS	High Impact Polystyrene
HPC	High Performance Concrete
HRS	Hot Rolled Steel
HSC	High Strength Concrete
HUDCO	Housing and Urban Development Corp Ltd
ICE	Inventory of Carbon & Energy
IMD	India Meteorological Department
INR	Indian Rupees
IoT	Internet of Things
IRT	Infrared Thermography
IS	Indian Standard
IS	Indian Standard
ISA	Indian Standard Angle
ISA	Indian Standard Angle
ISE	Index of Scenic Evaluation
ISO	International Organization for Standardization
ISSB′SA′	South African Interlocking Standard Interlocking Brick
ISSB′T	Tanzanian Standard Interlocking Brick
J	Joule
JK Cements	Jammu and Kashmir Cements
JNNURM	Jawaharlal Nehru Urban Renewal Mission
JP	Japanese Paper
JSCE	Japan Society of Civil Engineers
JSW	Jindal South West
K	Kelvin
$K_2Cr_2O_7$	Potassium Dichromate
K_2O	Potassium Oxide
KCL	Potassium Chloride
Kg	Kilogram
Km/sec	Kilometre per Second
Km/sec	Kilometre per Second
KN	Kilo Newton
KNN	K Nearest Neighbour
KOH	Potassium Hydroxide
KWH	Kilo-Watt Hour

l	Clear Span
LANDSAT	Land Remote-Sensing Satellite (System)
LBE	Load Blast Enhanced
LCA	Life Cycle Assessment
LHC	Lime-Hemp Concrete
Li/Na_2O_e	Lithium Alkali Molar Ratio
LiCl	Lithium Chloride
LIG	Low Income Groups
$LiNO_3$	Lithium Nitrate
$LiSO_4$	Lithium Sulphate
LL	Liquid Limit
LOI	Loss on Ignition
LVDT	Linear Variable Differential Transformer
M	Molarity
M – Sand	Manufactured Sand
M_{40}	Mix Ratio
M-60	Grade of Concrete
MAT	Material
MC	Municipal Corporation
MDD	Maximum Dry Density
MDOF	Glass Fibre Reinforced Polymer
M_G	Mixes with Waste Crushed Glass with Different Percentages
MG	Malachite Green
Mg^{2+}	Magnesium Cation
MGD	Million Gallons per Day
MgO	Magnesium Oxide
$MgSO_4$	Magnesium Sulphate
Min	Minute
MK	Metakaolin
ml	Millilitre
mm	Millimetre
Mn^{2+}	Manganese Ion
MnO	Manganese Oxide
MNRE	Ministry of New & Renewable Energy
MODIS	Moderate Resolution Imaging Spectrometer
Mol.	*Molarity*
MoSPI	Ministry of Statistics and Program Implementation
MoUHA	Ministry of Housing & Urban Affairs
MP	Micro Plastics
MPa	Mega Pascal
MSL	Mean Sea Level
MSW	Municipal Solid Waste
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MSWP	Municipal Solid Waste Processing

MT	Metric Tonnes
MTCC	Microbial Type Culture Collection and Gene Bank
MW	Municipal Waste
MWCNT	Multi Walled Carbon Nanotubes
N	Normality
N/mm^2	Newton/Millimetre Square
N_2O_3	Nitrogen Trioxide
Na_2CO_3	Sodium Bi Carbonate
Na_2O	Sodium Oxide
Na_2SiO_3	Sodium Silicate
Na_2SiO_3	Sodium Silicate Oxide
Na_2Sio_3	Sodium Silicate Solution
Na_2SiO_3	Sodium Silicate Gel
NAAQS	National Ambient Air Quality Standards
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
NaOH	Sodium Hydroxide Solution
NaOH	Sodium Hydroxide
NBA	National Biodiversity Board
NCR	National Capital Region
NDT	Non-Destructive Test
NDT	Non-Destructive test
NDVI	Normalized Difference Vegetative Index
NDWI	Normalized Difference Water Index
NFA	Natural Fine Aggregate
NGO	Non-Governmental Organization
NGT	National Green Tribunal
Ni	Nickel
NiO	Nickle Oxide
NOAA	National Oceanic and Atmospheric Administration
NRC	Normal Reinforced Concrete
NRI	Non-Resident Indian
NSC	Normal Strength Concrete
NSM	Normal Strength Material
NZ	Naturally Available Zeolite
OECD	Organization for Economic Co-operation and Development
OH	Hydroxyl Ions
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
P_2O_5	Phosphorus Oxide
Pa	Pascal
PA	Process Analysis
Pa	Pascal
PAN	Personal Account Number
PANI/BC	Polyaniline /Bacterial Cellulose

Pb	Lead
PCA	Principal Component Analysis
PCBC	Phosphate Containing Bacterial Cellulose
PCC	Plain Cement Concrete
PE	Poly Ethaline
PETG	Polyethylene T-filament Glass
PETT	Polyethylene Terephthalate
pH	Potential of Hydrogen
PI	Plasticity Index
PL	Plastic Limit
PLA	Polylactic Acid
PM	Particulate Matters
PMAY	Pradhan Mantri Awas Yojana
PNG	Portable Network Graphics
POP	Persistent Organic Pollutants
PP	Polypropylene
PPC	Pozzolanic Portland Cement
PPC	Portland Pozzolana Cement
PPC 53	Portland Pozzolana Cement 53 grade
PPE	Personal Protective Equipment
PPM	Parts per Million
PPP	Public-Private Partnership
PS	Polystyrene
PVC	Polyvinyl Chloride
PW	Plastic Waste
PwC	Price Waterhouse Coopers
R1	Replicate 1
R2	Replicate 2
R3	Replicate 3
RAY	Rajiv Awas Yojana
RB	Reactive Blue
RBC	Rotating Biological Contactors
RC	Reinforced Concrete
RC	Strut and Tie Model
RCC	Reinforced Cement Concrete
RCC	Reinforced Cement Concrete
RDF	Reduced Derived Fuel
RDS	Respirable Dust Sampler
Rel	Release
RH	Rebound Hammer
RHA	Rice Husk Ash
RN	Rebound Number
RVRF	C19P-RVS Voters Registration Framework
RVS	Remote Voting System
S.P	Super Plasticizer

S1B1	Sample 1 Block 1
S1B2	Sample 1 Block 2
S1B3	Sample 1 Block 3
SAFIR	South Asia Forum for Infrastructure Regulation
SARsCOV2	Severe Acute Respiratory Syndrome Coronavirus 2
SBM	Swachh Bharat Mission
SBM-U	Swachh Bharat Mission Urban
SCC	Self-Compacting Concrete
SCM	Supplemental Cementing Materials
SCM	Supplementary Cementitious Material
SD	Social Distancing
SDF	Severity-Duration-Frequency curves
SEC	Soil Electrical Conductivity
Sec	Second
SEM	Scanning Electron Microscope
SF	Steel Fibres
SFRC	Steel Fibre Reinforced Concrete
SFRP	Steel Fibre Reinforced Polymer
SG	Specific Gravity
SHCC	Strain Hardening Cementitious Composites
SiO_2	Silicon Dioxide
SiO_2	Nano Silica
SIS	Scrap Iron Slag
SKUAST-K	Sher-e-Kashmir University of Agriculture Sciences and Technology of Kashmir
SMB	Stabilized Mud Blocks
SO_3	Sulphur Trioxide
Sp. Gr.	Specific Gravity
SPI	Standard Precipitation Index
STP	Sewage Treatment Plant
STS	Split Tensile Strength
SVM	Support Vector Machine
T	Time
t	Ton
TCI	Trumboo Cement Industries
TDF	Time scale-Duration-Frequency
TDS	Total Dissolved Solids
TDS	Total Dissolved Solid
TES	Textile Effluent Sludge
TGA	Thermogravimetric Analysis
TiO_2	Titanium Dioxide
TM	Titration Method
TMF	Time Scale-Magnitude-Frequency
TN	Total Nitrogen
TNDT	Thermal Non-Destructive Testing

TNT	Trinitrotoluene
TP	Total Phosphates
TPR	True Positive Rate
TSDF	Treatment, Storage, and Disposal Facility
TSS	Total Suspended Solids
TTDC	Tamilnadu Tourism Development Corporation
UAE	United Arab Emirates
UAV	Unmanned Aerial Vehicle
UCS	Unconfined Compressive Strength
UIDAI	Unique Identification Authority of India
UPV	Ultrasonic Pulse Velocity
US	United States
USGS	United States Geological Survey
UT	Union Territory
UTM	Universal Testing Machine
UV	Ultraviolet
VA	Voting Application
VOC	Volatile Organic Compounds
VS	Voting System
VSDU	VVPAT Status Display Unit
VVPAT	Voter Verifiable Paper Audit Trail
W	Watt
W/C	Water Cement Ratio
WA	Water Absorption
WAS	Weathering Angle Steel
WCG	Waste Crushed Glass
WLR	Weighted Linear Regression
WMO	World Meteorological Organization
WPOP	Waste Plater of Paris
WSUD	Water Sensitive Urban Design
WTE	Waste to Energy
WWTP	Wastewater Treatment Plant
XRD	X-Ray Diffraction
XRF	X Ray Fluorescence
Z	Scaled Distance
Zn	Zinc
Zn	Zinc
ZnO	Zinc Oxide
δ	Maximum Mid-height Displacement
ϴ	Support Rotation

Contents

About the Editors and Contributors

Editors

Varinder S. Kanwar is vice chancellor of Chitkara University, Himachal Pradesh; he holds a PhD in civil engineering, an ME in structural Engineering from Thapar University Patiala, a postgraduate diploma in rural development from IGNOU and a BE in civil engineering. Dr Kanwar carries more than 25 years of research, teaching and administrative experience. He is a fellow of the Institution of Engineers, senior member of IEEE, and life member of ISTE, ICI, IGS and IRC. He has authored 5 books and published 40 research papers in national and international journals as well as presented 17 research papers in conferences. He has guided three ME and seven PhD students, filed nine patents, and completed four government-funded research project worth more than 1.85 crore INR, seven such projects are ongoing. His major research areas are health monitoring of structures and alternate construction materials.

Sanjay Kumar Sharma is working as professor and head of the Department of Civil Engineering, NITTTR, Chandigarh. He has more than 30 years of experience in teaching, curriculum development and research. He completed his BE (Civil) from HBTI, Kanpur, and ME and PhD from Punjab Engineering College, Chandigarh. His research work focuses on utilization of waste in concrete, utilization of green materials in construction, repair and rehabilitation, and non-destructive testing of structures. He has guided about 15 PhD and several MTech students and has more than 150 publications to his credit. He is also involved in projects related to repair and rehabilitation, and stability of structures. Dr Sharma is co-author of a book on building defects and maintenance management.

C. Prakasam is an associate professor in the Department of Geography, School of Earth Sciences, Assam University (A Central University), Diphu Campus, Diphu, Karbi Anglong, Assam, India. His areas of expertise are engineering geomorphology, water resources management, slope engineering and geospatial engineering. Dr Prakasam obtained his MTech in GIS and remote sensing applications from Bharathidasan University, Tamil Nadu, India, and his PhD in the field of remote sensing and GIS application from the University of Burdwan, West Bengal. After completed his PhD, he worked as a postdoctoral research scholar under DST purse fellowship in same university in the field of fluvial geomorphology and geospatial technological applications. He has over 13 years of teaching, research and administrative experience. Dr Prakasam has authored 3 books and published more than 50 articles in various national and international journals of repute and edited books. He has presented more than 50 papers in different international and national conferences and seminars. Dr Prakasam is also an editorial board member and reviewer for many international and national journals (e.g., Springer and Elsevier).

He completed eight projects funded by different government agencies (DST, New Delhi, and DOEST, Shimla) worth of around 1 crore INR. He is a life member of the Indian Institute of Geomorphologists, The Indian Geographical Society, Indian Association of Hydrologists, Indian Society for Technical Education, Indian Society of Geomatics, Society of Geoscientists & Allied Technologists, Indian Geological Congress, Indian Society of Remote Sensing, International Association of Engineers, The Institution of Engineers (India), The Indian Society for Hydraulics, Indian Geotechnical Society, and Indian Society of Earthquake Technology.

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Chapter 1
Effect of Lime and Brick Ash Inclusion on Engineering Behaviour of Expansive Soil

Ajay Pratap Singh Rathor, Harshil Bhatt, and Deepak Pathak

Abstract Many major states of India have large deposits of expansive soil. We all know how difficult it is to work with expansive soil due of its unpredictable shrinkage and swelling behaviour. This uncertain behaviour causes major uplift pressure and stresses on the structure overlying on it. The presence of the mineral montmorillonite is responsible for the expansive soil's behaviour. Soil stabilization is the technique which is used to deal with problems associated with expansive soil. This research aimed to utilize industrial waste brick ash (that is produced during the production of bricks) in stabilization of the expansive soil with Lime. Brick ash can significantly improve the engineering characteristics of expansive soil.

Keywords Expansive Soil · Lime · Brick Ash · Soil Stabilization

In order to obtain the efficient results, lime was added to the expansive soil in proportions of 2%, 4%, 6%, 8%, and 10% in this study. The optimum results were recorded at proportion of 6% lime. Further brick dust was added with expansive soil and 6% lime mix specimen to provide better strength to expansive soil. 10%, 20%, 30%, and 40% brick dust was added to the mix specimen (expansive soil and 6% lime). The optimum results were recorded at the proportion 30%.The results show that after adding the lime and brick dust in the proper amounts, the engineering features of expansive soil improve significantly.

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1.1 Introduction

It is always a challenging task to deal with expansive soil for construction purpose. There are alternate significant volume changes in expansive soil which is very problematic for structures during and after the construction. To deal with such expansive soil conditions, soil stabilisation is a standard methodology that can improve geotechnical properties of expansive soil. There are physical and chemical methods of soil stabilization, and both the methods have its significance. Compaction and strength characteristics of expansive soil can be improved by using various chemical stabilizers (Phanikumar and Raju 2020). There are many conventional soil stabilizing agents like lime, cement etc which has high positive impact on the characteristics of expansive soil (Sharma et al. 2018). In current scenario the industrial waste is also a big problem for environment, so to sustain pollution free environment, the waste utilization and recycling of products is also in the focus. There are many industrial wastes that can be used separately or with any other stabilizing agent like lime or cement as a soil stabilizing agent such as fly ash, brick ash, pond ash, Kota stone slurry, quarry dust etc. and these industrial wastes has significant impact in altering the engineering properties of weak soils (Ikeagwuani et al. 2019; Indiramma et al. 2020). The expansive soil is stabilised using lime and brick ash in this study. On the addition of lime in expansive clay, lime reacts with clay minerals and produces pozzolanic products such as C-S-H gel (calcium silicate hydrate) and calcite (Akula and Little 2020; Cheng et al. 2018; Falah et al. 2018). These pozzolanic compounds are attributed with improving soil engineering properties. Brick ash is also a viable solution for modifying engineering features of expansive soil such as swelling and strength.

1.2 Material Used in Study

1.2.1 Soil

In this investigation, expansive clay is used. The soil was collected from a nearby region in Kota, Rajasthan, India (Borkhera Area).

1.2.2 Brick Ash

The brick ash used in this investigation obtained from a production area near Kota, Rajasthan, India.

1.2.3 Lime

Lime for this study was obtained from a local market in Kota, Rajasthan, India.

1.3 Experimental results

The results obtained by performing various laboratory tests on ES are shown in Table 1.1.

1.3.1 Atterberg's limits

Consistency limits were calculated by performing the laboratory tests as described in Indian standard for the mix specimen of expansive soil and lime. The proportion of Lime was kept 2%, 4%, 6%, 8% and 10% as shown in Table 1.2 (Fig. 1.1). The test was conducted in the laboratory as per (Bureau of Indian Standards 1972, 1985).

1.3.2 Differential Free Swell Test (DFS Test)

In the laboratory, a differential free Swell analysis was carried out according to Indian Standards. (Bureau of Indian Standards 1977). The value of differential free swelling index for expansive soil was 47.06% and after addition of the lime it was decreased up to 3.64% for the proportion of 10% lime. According to the findings, using a lime content of up to 10% can lower the DFS index of expansive soil by up to 92.27%. Figure 1.2 shows the decrease in DFS index of expansive soil as the lime content is increased (Table 1.3).

Table 1.1 Geotechnical properties of expansive soil

S. No.	Property	Value
1	Plasticity Index (P.I.)	21.18
2	Plastic Limit (P.L.)	20.44
3	Liquid Limit (L.L.)	41.60
4	Specific gravity (G)	2.71
5	Max. Dry Density (Υ_d)	1.68 kg/cm^3
6	O.M.C. (Optimum Moisture Content)	18.33%
7	Free Swell Index	47.06%
8	CBR %	2.13
9	Unconfined Compression Strength	2.12 kg/cm^2
10	Swelling Pressure	1.14 kg/cm^2

Table 1.2 Consistency limits for ES and mix specimen of ES & lime

Test specimen	L.L.	P.L.	P.I.
E.S.	41.60	20.44	21.18
E.S. + 2% lime	38.54	18.96	19.61
E.S. + 4% lime	34.73	15.66	19.07
E.S. + 6% lime	30.16	13.62	16.51
E.S. + 8% lime	27.75	11.74	16.02
E.S. + 10% lime	23.87	9.22	14.66

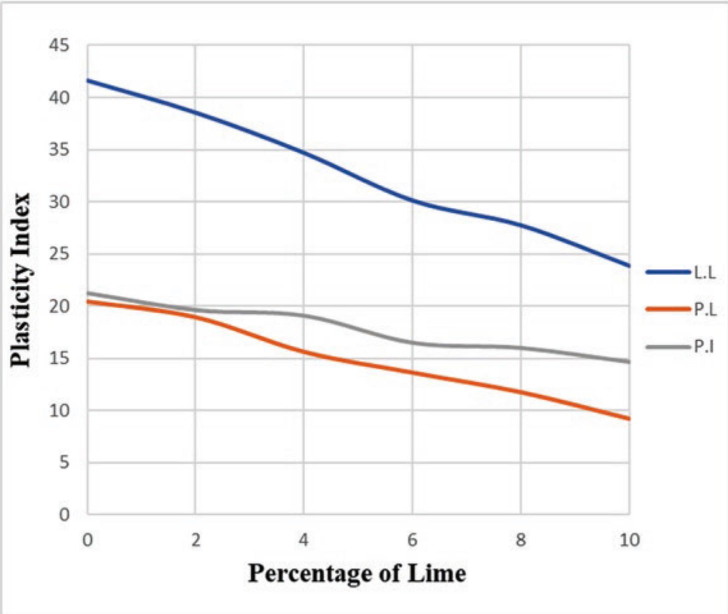

Fig. 1.1 Consistency limit for ES and mix specimen of ES & lime

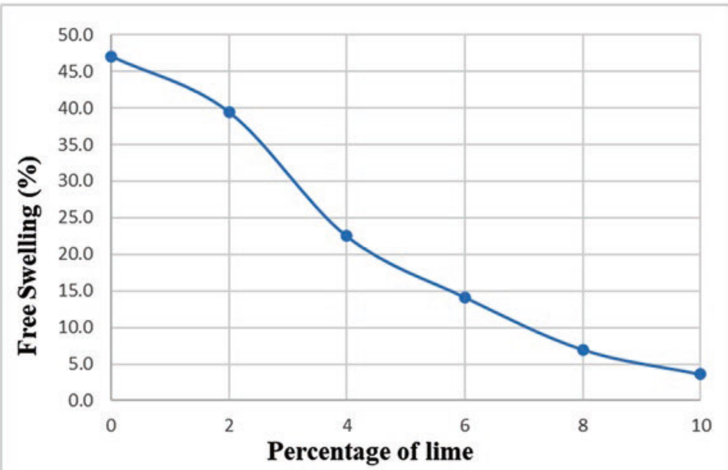

Fig. 1.2 DFS for expansive soil and mix specimens of ES & lime

1.3.3 Swelling Pressure

The consolidometer test was used to determine the value of expansive soil's swelling pressure as well as a mix specimen of expansive soil and limeas per. The value of swelling pressure for expansive soil was reduced when the quantity of lime was increased. Swelling pressure for expansive soil was measured at 1.14 kg/cm^2, and following treatment with 10% lime, it was reduced to 0.12 kg/cm^2 (Table 1.4 and Fig. 1.3).

1.3.4 Standard Proctor Test

In the laboratory, a standard proctor test was processed to calculate the MDD&OMC of expansive soil and a mix specimen of expansive soil and lime. The test was performed as per (Bureau of Indian Standards 1980).The results of standard proctor test are shown in Table 1.5. The MDD of soil was 1.68 kg/cm^3, but when the quantity of lime was increased to 10%, the MDD was reduced to 1.57 kg/cm^3.The OMC of soil was found to be 18.33%, and by increasing the proportion of lime in ES to 10%, the OMC was found to be 22.17%.

Table 1.3 DFS for ES and mix specimens of ES of lime

Particulars	Vol. of soil kerosene final reading	Vol. of soil in water final reading	Free Swell Index	Degree of expansiveness	Percentage change
Expansive soil	17	25	47.06	High	–
E. S. + 2% lime	19	26.5	39.47	High	−16.12
E. S. + 4% lime	20	24.5	22.5	Moderate	−52.18
E. S. + 6% lime	20.5	23.4	14.15	Low	−64.16
E. S. + 8% lime	21	22.9	7.01	Low	−68.84
E. S. + 10% lime	22	22.8	3.64	Very low	−92.27

Table 1.4 Swelling pressure for expansive soil with lime

Mix proportion	Swelling pressure value (kg/cm^2)	Percentage decrement
Expansive soil	1.14	–
Expansive soil + 2% lime	0.56	49.12
Expansive soil + 4% lime	0.45	60.52
Expansive soil + 6% lime	0.25	78.07
Expansive soil + 8% lime	0.18	84.21
Expansive soil + 10% lime	0.12	89.74

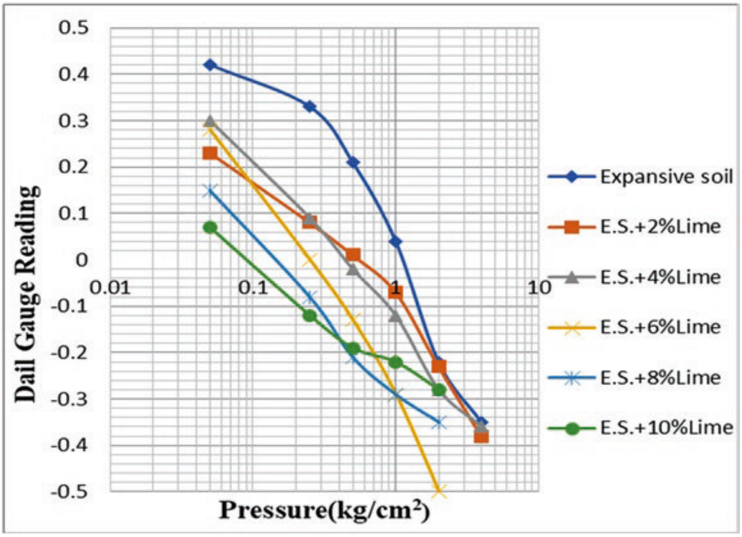

Fig. 1.3 Variation of swelling pressure for ES and mix specimens of ES & lime

Table 1.5 Standard proctor test for ES and mix specimens of ES & lime

Test specimen	MDD(kg/cm^3)	OMC (%)
E.S.	1.68	18.33
E.S. + 2% lime	1.66	19.38
E.S. + 4% lime	1.62	20.54
E.S. + 6% lime	1.60	21.35
E.S. + 8% lime	1.58	21.88
E.S. + 10% lime	1.57	22.17

Because of the chemical reaction and soil-lime mechanism, the OMC was enhanced by increasing the amount of lime in the soil. The floc formation happens, and the enlarged particle size leads the increased void ratio. A lower MDD and a higher OMC result in a higher void ratio (Fig. 1.4).

Brick ash was added to the mix specimen of expansive soil and 6% lime to improve the MDD of the soil. The brick ash percentages were taken as 10%, 20%, 30%, and 40%. The MDD of the mix consisting of expansive soil and 6% lime was enhanced to 1.76 kg/cm^3 by increasing the amount of brick ash to 40%. It was also observed that by increasing the proportion of the brick ash up to 40%, the OMC can be decreased up to 14.2% (Table 1.6 and Fig. 1.5).

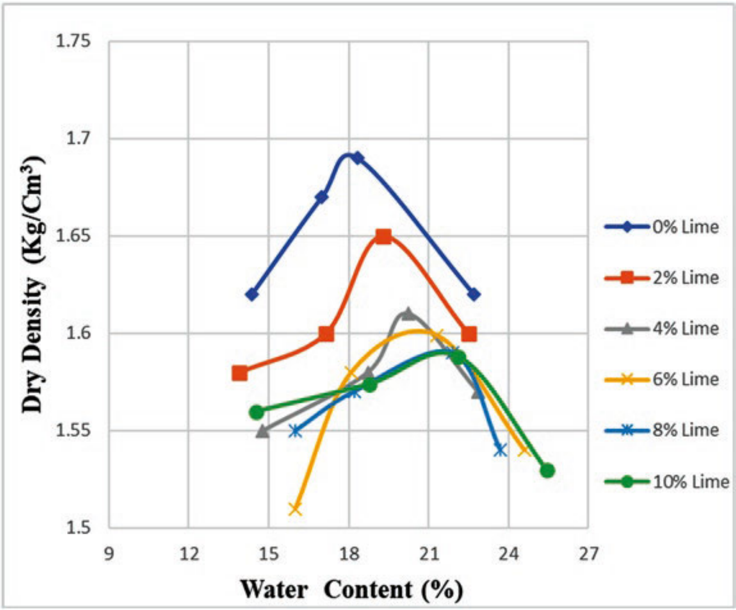

Fig. 1.4 Standard proctor test results for ES and lime

Table 1.6 Standard proctor test results for ES with 6% lime and varying percentage of brick ash

Test specimen	MDD(kg/cm^3)	OMC (%)
E.S.	1.68	18.33
E.S. + 6% lime	1.60	21.35
E.S.+ 6% lime + 10% B.A.	1.65	16.4
E.S. + 6% lime + 20% B.A.	1.68	15.9
E.S. + 6% lime + 30% B.A.	1.73	14.6
E.S. + 6% lime + 40% B.A.	1.76	14.2

1.3.5 Unconfined Compression Test (UCS Test)

The objective of this experiment was to determine the compressive strength as well as shear strength of clayey soils in undrained state. Soil sample was soaked for 3 days (Table 1.7). The test was performed in the laboratory as per (Bureau of Indian Standards 1991).

The UCS value of expansive soil was 2.12 kg/cm^2, and the value of compressive strength decreased after increasing the lime percentage in the expansive soil by 8% due to soil crystalline structure rearrangement (Fig. 1.6).

In order to further increase the value of UCS, brick ash was added to expansive soil with 6% lime specimen. As per the results obtained, the value of UCS was increased up to addition of 20% brick ash. The value of UCS was decreased for 30% & 40% brick ash due to the dilatancy effect (Table 1.8 and Fig. 1.7).

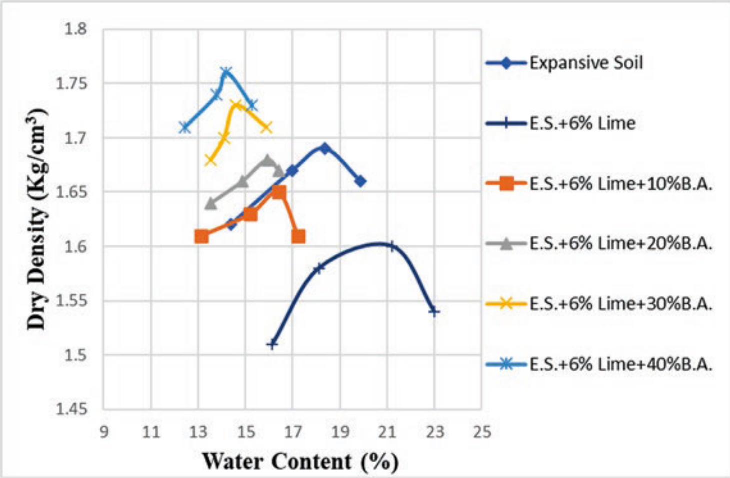

Fig. 1.5 Standard proctor test results for ES with 6% lime and varying percentage of brick ash

Table 1.7 Results of UCS test for ES and mix specimens of ES & lime

Test specimen	UCS (q_u) (Kg/cm^2)	Percentage increment
Expansive soil	2.12	–
ES + 2% lime	3.02	42.45
ES + 4% lime	3.62	70.75
ES + 6% lime	4.15	95.75
ES + 8% lime	4.32	103.77
ES + 10% lime	3.58	68.86

Table 1.8 Results of UCS test for ES with 6% lime and varying percentage of brick ash

Test specimen	UCS (q_u) (Kg/cm^2)	Percentage increment
Expansive soil	2.12	–
ES + 6% lime	4.15	95.75
ES + 6% lime + 10% B.A.	4.42	108.49
ES + 6% lime + 20% B.A.	4.54	114.15
ES + 6% lime + 30% B.A.	4.25	100.47
ES + 6% lime + 40% B.A.	3.89	83.49

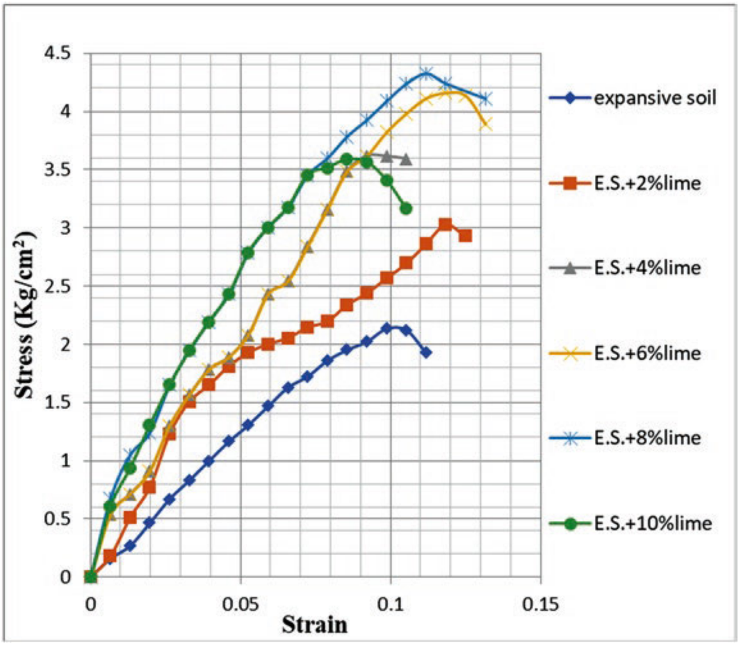

Fig. 1.6 UCS test results for E.S. & lime

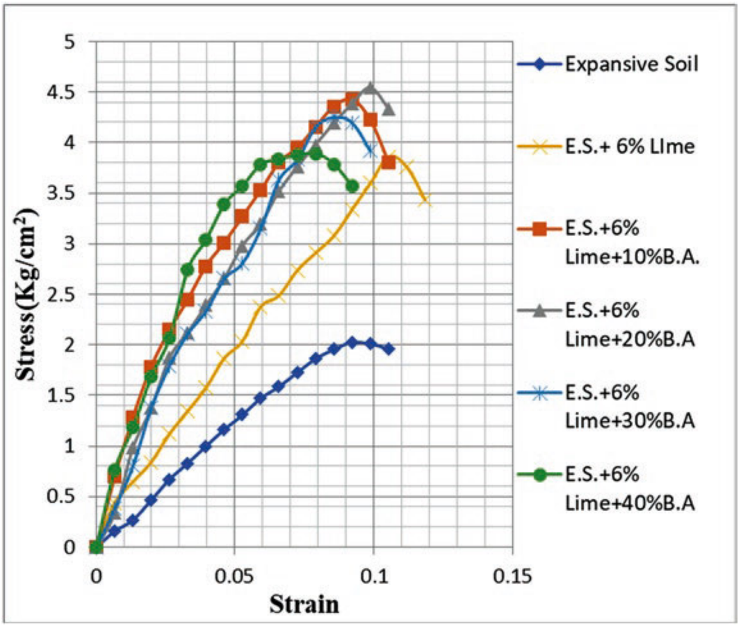

Fig. 1.7 UCS test results for expansive soil with 6% lime and varying percentage of brick ash

Table 1.9 CBR test results for ES and mix specimens of ES & lime

Mix proportion	CBR %	Percentage increment
Expansive soil	2.13	–
Expansive soil + 2% lime	4.48	110.32
Expansive soil + 4% lime	5.54	160.09
Expansive soil + 6% lime	6.07	184.97
Expansive soil + 8% lime	7.21	238.49
Expansive soil + 10% lime	7.97	274.17

Table 1.10 CBR test results for ES with 6% lime and different percentages of brick ash

Mix proportion	CBR %	Percentage increment
Expansive soil	2.13	–
Expansive soil + 6% lime	4.48	110.32
E.S + 6% lime+ 10% B.A.	6.34	197.65
E.S + 6% lime+ 20% B.A.	8.04	277.46
E.S + 6% lime+ 30% B.A.	9.25	334.27
E.S + 6% lime+ 40% B.A.	10.46	391.07

1.3.6 California Bearing Ratio Test

CBR values for expansive soil were 2.13% and 2.02%, respectively, for 2.5 mm and 5 mm penetration. By further increasing lime percentage in soil the value of CBR was increased up to 7.97% as mentioned in below Table 1.9. Test was performed in the laboratory as per (Bureau of Indian Standards 1987).

In order to improve CBR value, Brick ash was added to the expansive soil with 6% lime. It was discovered that increasing the proportion of brick ash raised the value of CBR. The highest CBR value was calculated for the 40% brick ash (Table 1.10).

1.4 Conclusions

1. It can be concluded that after adding lime in expansive soil, the consistency limits can be improved.
2. The degree of expansiveness of expansive soil can be altered from very high to very low. It can be decreased up to 92.27%.
3. The swelling pressure of expansive soil can be reduced by adding lime. Swelling pressure can be reduced up to 89.74% by adding the lime up to 10%.
4. It can be concluded that after adding the lime up to 10% in the expansive soil the MDD of soil decreases and OMC increases. It can also be deduced that by adding

brick ash to the expansive soil and lime mix, MDD of expansive soil can be enhanced.

5. Adding lime to expansive soil might increase its UCS value. In order to further increase the Value of UCS brick ash can be added. For best outcomes, a 20% dose of brick ash is recommended.
6. It can be concluded based on the results that the value of CBR can be improved by adding lime in the expansive soil. Brick ash can be included along with the expansive soil and lime mix to improve CBR results.

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Chapter 2
Know Your Daily Rainfall in Any Location in India- A Web-Based Approach Developed in Google Earth Engine

R. Boopathi, Madhavi Ganesan, and V. Naresh

Abstract Urban planners, farmers, academicians, researchers, and students particularly in agricultural and water resources field require daily rainfall information for their study or project preparation. To make this information available for them, a web-based application was developed using Google Earth Engine (GEE). GEE is a tool for analysing geospatial information and a cloud-based computing system. A java script code is compiled in the GEE platform in conjunction with the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) dataset which is used in the application as a base to download the daily rainfall for any region in India with a resolution of 5.5 × 5.5 km. The methodology adopted is used to derive daily rainfall information for certain coastal locations and other major cities in India. Chennai city receives 60% of Annual Rainfall during October, November, and December with an average annual rainfall of 1440 mm whereas Mumbai city receives 97% of Annual Rainfall during the months of June, July, August, and September with an average annual rainfall of 2837 mm. The information for rainfall estimation will be useful to farmers for estimation of farm pond storage capacity, practicing irrigation engineers of government body to determine the check dam storage levels etc., CHRIPS data is however 75–80% precise to the actual measured rain gauge readings due to bias. If bias correction is carried out, then one would be able to get an accurate estimation of rainfall.

Keywords Google Earth Engine · Rainfall · Web application · Monsoon · Flood

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2.1 Introduction

Due to continuing COVID'19 pandemic situation, researchers and college students find it extremely difficult to undertake field visit to the site or project region for their data collection. One primary data for Water Resources Engineering researchers and students is the daily rainfall information, which forms the basis for the study and analysis of water resources. To make this information available for the people who is in need of daily rainfall, a web-based application was developed using Google Earth Engine which is described below. The Google Earth Engine (GEE) is an online domain with java script providing earth spatial-temporal series satellite imagery and vector data, cloud-based computing, and access to software modelling and procedures for processing such data. The current era of digitalization and data driven for all scientific aspects will help a common man in understanding the pattern of rainfall and importance of harnessing the rainfall at the place to make use of it for the utilization of rain water. In this way, the paper will be very great importance to all the people who are dependent on the rainfall for their source.

The data source is a collection of over 40 years of satellite imagery for the entire geographical location of earth, with many places having repetitive data for the whole period or once in two weeks, and with a sizeable group of daily and sub-daily information as well. The data available in the GEE platform is from multiple satellites, such as the complete Landsat series; Moderate Resolution Imaging Spectrometer (MODIS); National Oceanographic and Atmospheric Administration Advanced very high-resolution radiometer (NOAA AVHRR); Sentinel 1, 2, and 3; Advanced Land Observing Satellite (ALOS) etc. As a water resources professional , one can use GEE tool for varied applications such as to determine the Cropping Intensity (Single, Double and Multiple), Water Body Mapping to calculate area and seasonal changes, Crop pattern change and Productivity, Assessment of Land Use and Land Cover Change, Water budgeting (Rainfall, Evaporation from Water, Interception loss, Evapotranspiration from Vegetation), Watershed Mapping – up to micro watershed level, Flood Modelling, Deriving Normalized Difference Vegetative Index (NDVI) and Normalized Difference Water Index (NDWI) calculations and Preparation of Contour maps of the watershed.

In the present paper we discuss on how to download the web-based rainfall information for any region inside India as a CSV or PNG file format and its allied applications. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a global rainfall dataset with 30+ year which has been used in this analysis. CHIRPS incorporate 0.05 degree resolution (5.5 km approx.) satellite imagery with ground-based station data to create gridded rainfall time series suitable for seasonal pattern and seasonal drought monitoring. Using CHIRPS as a baseline data, a Java script is written in the Google earth engine to download the rainfall data for the last 11 years from January 2009 to March 2021which can be used to download rainfall for any region or location in India.

2.2 Materials and Methods

Earth Engine is a web domain for scientific study and conception of geospatial datasets, for academic, non-profit organizations, business and government users. The difference between Google Earth and Google Earth Engine is that while Google Earth enables you to explore about the world by interacting with a simulated globe image and can view satellite images, maps, topography, 3D buildings, and much more, the Google Earth Engine on the other hand is a tool for analysing geospatial information. Once you have signed up with your google account in the following address https://earthengine.google.com/, the screenshot pop ups as shown in Fig. 2.1, where you can write the Java script you would like to work on. In our study, using CHRIPS dataset that is available in the global dataset directory of google earth engine, the daily rainfall web application script was written and using geometry tool the boundary is clipped to Indian administrative boundary; after running the code the output data will be shown as a chart file for the region selected, from where we can download the chart file as CSV (comma-separated values – MS-Excel file) or as an image in PNG (Portable Network Graphics). The methodology adopted is shown below (Fig. 2.2).

2.3 Results and Discussion

The two coastal cities of India (Mumbai and Chennai) which receives two different seasonal rainfall was taken for analysis. Mumbai receives its rainfall mostly from South West Monsoon during June to September and Chennai receives its bulk of rainfall from North East Monsoon during October to December. Using the web

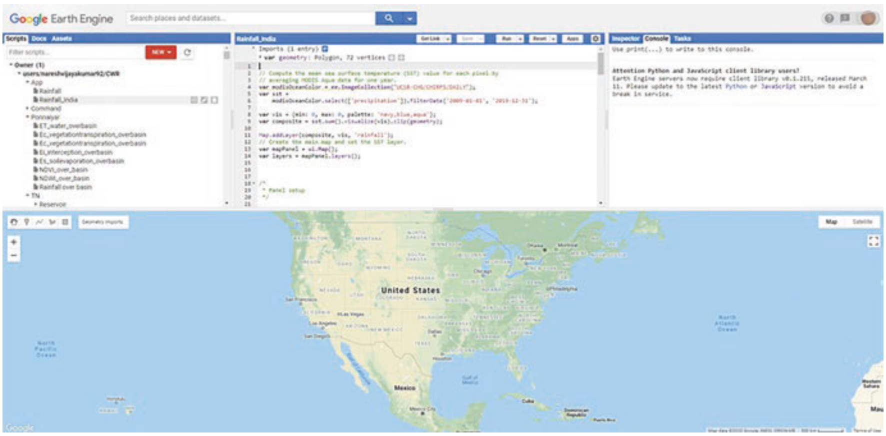

Fig. 2.1 Google Earth Engine platform. (Source: Author)

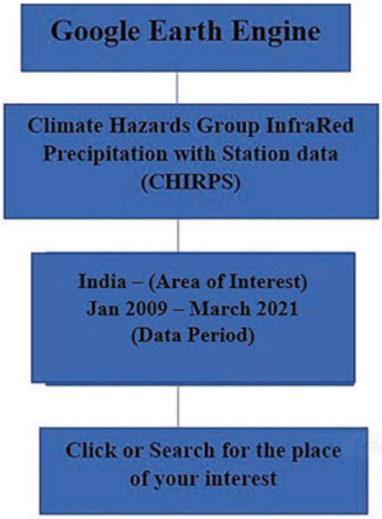

Fig. 2.2 Methodology flowchart. (Source: Author)

application, the daily rainfall for the above two locations was downloaded and analyzed. Also, for some mega cities in India, the daily rainfall was downloaded, and the daily data was converted into monthly average over the period (2009–2020) and the results were analyzed as monthly average as shown below.

1. Bangalore
2. New Delhi
3. Kolkata
4. Hyderabad
5. Trivandrum

Chennai receives 60% of Annual Rainfall during October, November, and December largely from the North East Monsoon and the average annual Rainfall for Chennai works out to 1440 mm. The maximum single day rainfall was recorded on 16th November 2015 with 191 mm. November 2015 is recorded as the wettest month of the last 100 years with 1113.80 mm of rainfall. Way back in 1918 Chennai has received 1088.40 mm which remains maximum till date. Normal life affected due to high rise of water level in Coovum river, Adyar river, Buckingham Canal and Kosasthalaiar river basin which passes through the Chennai city as a result of surplus water released from Chembarambakkam, Redhills and Poondi reservoir during 17.11.2015 and 01.12.2015 which are the water bodies for Chennai drinking water supply (Figs. 2.3, 2.4, and 2.5).

Mumbai receives 97% of Annual Rainfall during the months of June, July, August, and September predominantly from the South West Monsoon. The average annual Rainfall for Mumbai works out to 2837 mm. The maximum single day rainfall in Mumbai was recorded as 355 mm on 01st July 2019 followed with the second highest single day recorded rainfall on 23rd July 2014 with 255 mm. The monthly average rainfall for other few cities is shown below (Tables 2.1 and 2.2).

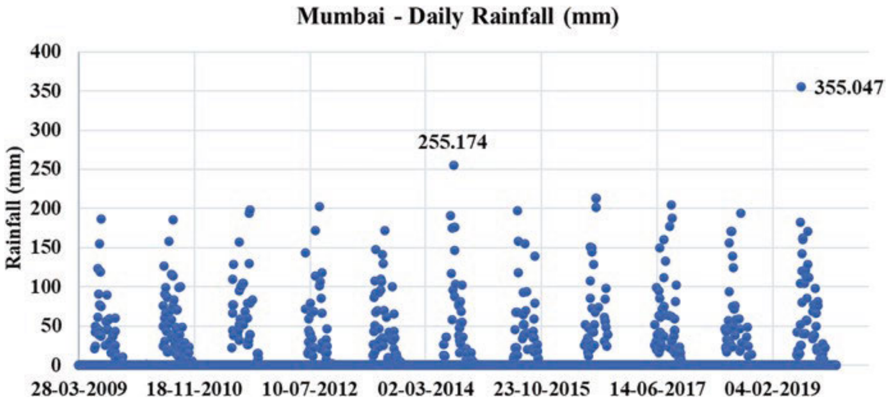

Fig. 2.3 Mumbai daily rainfall chart. (Source: Author)

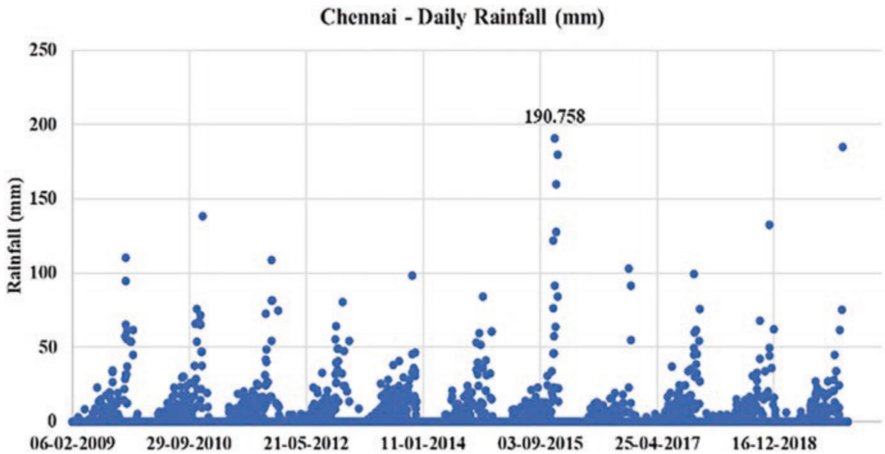

Fig. 2.4 Chennai daily rainfall chart. (Source: Author)

Delhi receives 86% of Annual Rainfall during the months of June, July, August, and September predominantly from the South West Monsoon. The average annual Rainfall for Delhi works out to 1440 mm. Hyderabad receives 89% of Annual Rainfall during the months of June, July, August, September, and October from the South West and North East Monsoons and the average annual rainfall for Hyderabad works out to 812 mm. Bangalore receives 86% of Annual Rainfall during the months of May, June, July, August, September, and October from the South West Monsoon and as well as from the North East Monsoon and the average annual Rainfall for Bangalore works out to 1061 mm. Kolkata receives 76% of Annual Rainfall during the months of June, July, August, and September predominantly from the South West Monsoon and the average annual Rainfall for Kolkata works out to 1750 mm. Trivandrum receives 87% of Annual Rainfall during the months of May, June, July,

Fig. 2.5 Chennai flood condition. (Source: Author, Dec 2015)

Table 2.1 Monthly average rainfall (mm)

M	D	K	T	H	B
Jan	20.29	10.22	12.2	4.91	0
Feb	23.49	27.2	18.03	4.35	1.56
Mar	18.17	25.29	22.63	7.21	14.86
Apr	11	50.74	115.86	25.3	65.93
May	28.53	154.97	198.79	29.52	153.08
Jun	91.17	262.84	332.82	114.91	101.77
Jul	229.97	409.65	171.17	165.51	122.8
Aug	276.7	365.59	166.17	184.42	177.59
Sep	179.13	290.63	180.53	159.13	213.24
Oct	15.4	125.32	310.16	98.95	145.67
Nov	1.75	14.84	236.64	14.4	50.51
Dec	8.76	12.24	62.05	2.9	14.3

M month, *D* Delhi, *K* Kolkata, *T* Trivandrum, *H* Hyderabad, *B* Bangalore

August, September, October, and November both from the South West Monsoon and North East Monsoon and the average annual Rainfall for Trivandrum works out to 1827 mm. As can be seen, the rainfall pattern namely the start and ending follows closely the monsoonic movement within the country and the cities located near the coast getting more rains than those which are located far inland.

Table 2.2 Average annual rainfall (mm)

Places	Annual rainfall (mm)
Delhi	904.36
Kolkata	1749.53
Trivandrum	1827.06
Hyderabad	811.5
Bangalore	1061.29

2.4 Application of Daily Rainfall

Daily rainfall data can be used for a number of different applications as stated above. Herein, its application to two typical cases are detailed:

1. To determine the Rainwater harvesting structure capacity for a House or any type of building:

Download the chart of daily rainfall data developed for the area of interest; from the chart the single day maximum daily rainfall in millimetres for 12 years could be determined. From this maximum 11 values, determine the maximum of maximum of rainfall and let us assume this as 100 mm. Calculate the area of the catchment of the house or the roof top area, assume it to be 2400 ft^2 or 223 m^2. The total runoff generation will then be 22.3 m^3; taking 10% as interception and flow losses, the balance is 20 m^3. This water can be stored in a well. Locate the well at the lowest elevation level of the house or building so that the runoff from the rainfall naturally drains into the well. Assuming the depth of the well to be 3 m, based on the capacity the diameter of the well calculated to be 3 m.

2. To construct a dugout farm pond which will be a potential source of water harvesting structure in the low rainfed areas.

The maximum of maximum daily rainfall in millimetres could be determined using the chart for the area of interest as described above. Let us assume this to be 80 mm; let us assume the area of the farm to be 1 acre or 4047 m^2. The total potential rainfall from the farm area will be 324 m^3; taking 40% as infiltration or seepage losses, the net available runoff for pond storage will be 194 m^3. If we assume the depth of the pond to be 2.5 m, and width of the pond is half the size of its length, the calculated length works out to be 12.5 m and width as 6.25 m.

2.5 Conclusion

The downloaded daily rainfall for the last 12 years doesn't restrict its use only to the above applications; it could be used widely by the researchers and the students for their own need-based analysis; the CHRIPS data is however 75–80% precise to the actual measured rain gauge readings. One who uses this web application for their scientific purpose should do an error or bias correction with the rain gauge station data available at that location.

2.6 Web Application Link

https://nareshvijayakumar92.users.earthengine.app/view/rainfall-indiawebapp

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Chapter 3
IoT- Based Innovative Technological Solutions for Smart Cities and Villages

Kriti Aggarwal and Gulshan Goyal

Abstract In recent decades, the term Smart City has emerged which has been further extended to villages in the past few years. In India, a major population still lives in rural areas. There are many technological and infrastructural factors that influence the development of these areas. The main aim behind making cities and villages smart is to provide a high-quality lifestyle to the people living in these areas, further leading to the development of a smart, sustainable and self-reliant nation. The rapid evolution of information and communication technologies, popularly known as ICT, and other information-sharing technologies are revolutionizing the smart city concept with the dawn of the Internet of Things (IoT). The term "smart" refers to the implementation of the Internet of Things and other technologies to automate and sustain things and systems. Therefore, the Internet of things has garnered a lot of attention over the past few years. The reason for its high importance lies behind its concept of data transfer via minimal human interaction through the objects called "things" which are connected over the internet network. Many researchers and developers have been continuously exploiting the applicability of the Internet of Things to provide smart and sustainable solutions for all sectors. Today, the need for an internet connected world has strengthened tremendously due to the ongoing COVID-19 pandemic. Thus, it has become even more important to look into and explore IoT-based innovative technological solutions while developing applications and systems for smart cities and villages. The present paper surveys the role and relevance of IoT-based innovative technological solutions for the operation of smart, sustainable cities and villages. The paper also discusses some major advantages of integrating these solutions in order to provide efficient and sustainable management.

Keywords Smart cities · Smart villages · Internet of Things (IoT) · COVID-19 · Urban and rural development · Sustainable solutions · Green IoT · Smart management

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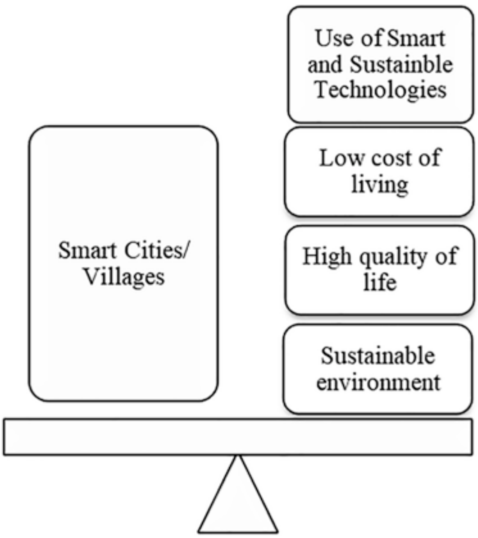
3.1 Introduction

The concept of “smart cities and villages” has developed in recent years. The phrase “smart city/ village” refers to emerging businesses that use information and communication technology (ICT) in a sustainable manner by connecting them with urban functions (Bibri 2019). The idea of smart city or a smart village refers to the application of smart technologies such as IoT, social computing, cloud computing, fog computing, and green computing in order to provide better amenities and to improve people’s lifestyles. This notion of development through smart technology is urgently needed as the population continues to expand and evolve to the point where there is a scarcity of both resources and services for the people. Some of the four objectives of smart cities and villages are summarized in (Fig. 3.1) (Hammi et al. 2018a).

Smart cities and smart villages, popularised in India, are the result of a combined effort by the government and people to improve lifestyles and ensure economic growth. The need for smart living, especially in rural areas like villages, stems from the population distribution factor in the country. Even though the urban population of India has been steadily increasing, this growth has been inherently unsustainable. Many major cities lack core infrastructure and rapid urbanisation has further led to mismanagement of resources. The smart city mission in India was hence launched officially by the government in order to bind data and technologies like the Internet of things, social computing, etc. together to improve the infrastructure of the cities. Under this mission, many researchers and scholars have dedicated themselves to developing reusable and replicable solutions to solve various problems, ranging from planning and resource management to environmental and social suitability. Various cutting-edge concepts like smart meters, e-governance, intelligent traffic

Fig. 3.1 Balancing different goals through the use of smart and sustainable technologies



management systems, and smart waste management systems have hence been established in various parts of the country. Furthermore, despite its size, the number of urban developers accounts for only 31 percent of the total population. of the remaining people still live-in rural areas (Kemp 2021). Hence, following the success of the mission, the government has now decided to try and harness these technologies for the villages.

In contrast to the notion of a smart city or village, sustainability was originally proposed in 1987 and has since gained widespread acceptance. It is founded on four pillars or aspects: economic sustainability, environmental sustainability, social sustainability, and technological sustainability (Keeble 1988). A more modern definition (Kennedy et al. 2007) defines a sustainable place, city or village as "an entity whose intake of material and energy resources, as well as waste disposal, do not exceed the capacity of the city's surrounding environment". In practice, in order to integrate sustainability into smart development, both the use of urban as well as rural resources must match the availability of natural resources (Belli et al. 2020). Excessive usage of resources creates a situation where the needs of the present as well as future generations are in danger.

The growth of smart, sustainable cities and villages is dependent on various technological and infrastructural parameters. However, amongst other technologies being used for the development of smart cities, the internet of things has emerged as a founding stone. The Internet of things refers to a network of physical objects called things. These physical devices share data with each other over the internet network (Gillis 2021; Guillemin and Friess 2009).

Today, the Internet of things (IoT) is one of the major and most widely researched domains. IoT services range from entertainment, healthcare, education to banking, fitness and various other industries. The term "smart city and village" in itself is an extended application of the Internet of things, which focuses on making cities and villages smart, sustainable and self-reliant. Thus, researchers and developers have been continuously exploiting the applicability of the Internet of Things to provide smart and sustainable solutions for all sectors. Today, the COVID-19 pandemic has created an irrefutable need for an internet connected world. This has further increased the importance of IoT-based innovative technological solutions for developing applications and systems for smart cities and villages. Section 3.2 of the present paper discussed the growth of IoT and its relevance in digital India. IoT-based Smart and Sustainable Solutions are discussed in Sect. 3.3 in detail. Lastly, Sect. 3.4 concludes the paper with future scope.

3.2 Growth of Internet of Things

The concept of the IoT first emerged in the early 2000s. Since then, the popularity and demand for IoT have risen tenfold in the past few years. This rise was a result of the introduction of fast-growing internet technologies ranging from 2G to 5G. Many reports have predicted that by 2022, approximately 14.6 billion IoT will

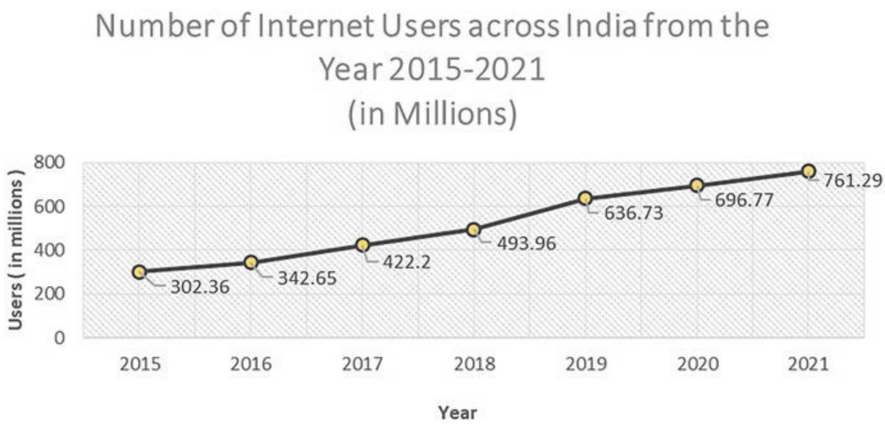


Fig. 3.2 Year-wise internet users across India from the year 2015–2021 (in Millions) [10]

be connected to networks all over the world (Statista 2020). Even in India, there has been a sharp rise in the number of internet users. The increase in the number of internet users from the years 2015–21 (Fig. 3.2) (Kumari 2020).

The number of users have increased from the year 2018 to the year 2021. This is the result of the COVID-19 global pandemic. While there were only 493.96 million internet users in the year 2018, today there are almost 761 billion people online.

With the advent of IoT in India, Industry 4.0 (the next level industrial revolution), has arrived. In addition to the new "Digital India" project announced by the government, IoT is also playing a very important role in transforming and developing smart cities. The major IoT-based technologies for the development of smart as well as sustainable solutions are discussed in further sections.

3.3 IOT Based Smart and Sustainable Solutions

As discussed in the previous sections, IoT paradigm is one of the key aspects guiding technological evolution and development of smart sustainable cities and villages. IoT uses plethora of internet connected devices help to adapt and change the behavior of the environment in which the citizens live. This results enhancement of both rural and urban development.

The key areas of focus for IoT based smart sustainable cities and villages, can be divided into two major areas one of which is sustainability, and the other is smartness and automation. The classification of IoT solutions can be done into two sections that are technology-based division of the solutions as well as application-based division of the solutions. Some of the IoT based smart sustainable solutions for cities and villages can be seen in Table 3.1.

Both the technological and Application based solutions of IoT are further discussed in detail in the sub Sects. 3.3.1 and 3.3.2.

Table 3.1 IoT technologies & applications for development of smart sustainable city and villages

IoT Technologies for implementing smart and sustainable solutions	IoT applications for implementing smart and sustainable solutions
Artificial Intelligence for further reducing the human interaction of the IoT devices	Smart Automation solutions for effective Waste Management and cost reduction
IoT enabled UAVs for leveraging aerial solution to solve the problem of smart cities and villages	Nurse Drone- a Smart UAV based Hospital Management Application of IoT solutions to Combat Covid -19
Social Computing as a powerful tool to collaborate with people worldwide	Smart Education Solutions for Villages and Cities
Smart Grids to ensure intelligent power consumption and managing energy efficiency demands in villages	Sustainable Mobility via smart parking systems as well as smart traffic management systems to help save gas
Green IoT as way to ensure sustainability along with the application of intensive computing IoT technology to provide smart sustainability	Energy Efficient Buildings to promote sustainable infrastructure for development of smart cities and villages
Edge computing for affordable data processing and decreasing bandwidth consumption	Smart Agriculture using sensor technology in villages

3.3.1 Smart Technologies for Smart and Sustainable IoT Solutions

Six major emerging technologies used to leverage the Internet of things for the development of smart, sustainable solutions are discussed in brief below:

Artificial Intelligence (AI) It is the replication of human cognition in machines trained to think and act human-like. The ability of artificial intelligence to rationalise and execute actions that have the best chance of attaining a given goal is its ideal characteristic. AI in smart city development can play a critical role in urban planning, development, and management. AI uses connected devices to gather and analyze data for enhancing infrastructure and public utilities. Artificial intelligence, Internet of Things (IoT) devices along with cloud-based services are used in smart cities (Xiao et al. 2018). With access to and control over their homes and other activities that improve their living experience, AI in IoT helps to make societies more secure and liveable.

IoT-Enabled UAVs Unmanned aerial vehicles (UAVs) are remotely operated autonomous or quasi devices that help in aerial data collection. IoT-enabled UAVs can aid in the development of smart management solutions capable of remote data transmission throughout the network of things. Because of the integration of multiple hardware and software technologies, specialised industrial applications may be developed and these UAVs can be deployed even in human-inaccessible and disaster-prone locations. As a result, they may be widely employed to build long-term applications in smart, sustainable cities and villages (Parameswaran and Whinston 2007). UAVs have several uses in smart cities, including traffic control, agricultural operations, parcel delivery, disaster management and so on.

Social Computing Social computing is a new computing model that begins with the study of human behaviour and their interaction with the environment and computational systems, and is based on the creation or recreation of social conventions and social context (Xu et al. 2014). This is done through the use of software and IOT and technology like blog posts, social media sites, instant messaging applications and many more. IoT-enabled integration of solution computing technologies enables entertainment and communication in smart, sustainable cities. Some of the components of social computing are discussed below:

- *Entertainment and social networking:* social computing has eliminated the idea of boredom to a huge extent by providing a lot of entertainment and networking opportunities to people through social media like Instagram, YouTube, LinkedIn, Facebook, etc. (Hammi et al. 2018a, b). It has not only provided general entertainment but has also allowed people to send and connect with others who have the same interests. Some common areas for networking can be job finding, online-dating and marriages, reading groups and instant messengers.
- *Tourism:* With the help of 360-degree technologies, augmented reality, computer vision, Google maps, etc., tourism opportunities are ever growing. People can easily do home tours and promote their cities.
- *Business*: With the advance of social networking, many new businesses and start-ups have reverted to e-business platforms for business transactions and promotion of products. With the advent of Web technology, even persons with modest means may begin engaging in economic transactions with one another. It has also increased the reach and improved the quality of business by allowing people, all across the world, access to various products and services on online platforms.

Smart Grids for Cities & Villages The Smart Grid is a component of an Internet of Things architecture that may be used to remotely monitor and regulate everything from traffic lights to early detection of events such as power outages. The Smart Grid achieves this via a network of power lines, smart meters, distribution automation, sensorsand other components spread across the villages and cities (Shaw 2019). All of these smart grid technologies contribute to efficient IoT energy management solutions. These solutions presently do not exist in the existing framework. The smart grid is envisioned as the next generation of electric infrastructure for smart villages. Smart grid advantages include high dependability and resilience, greater intelligence and optimal control, decentralised operation, increased operational efficiency, more effective demand management, and improved electricity quality. All of these anticipated shifts, however, carry with them a plethora of problems and possibilities.

Green Internet of Things (G-IoT) Energy-saving IoT or Green IoT is a relatively new concept that has gained traction in recent years. The vast number of high-performance and complex devices linked to the IoT system uses a significant quantity of energy. As a result, the issue of energy consumption in IoT-based systems is a major research priority, especially when it comes to villages. Green IoT refers to the challenge of lowering the power consumption of IoT devices in order to establish environmental sustainability for IoT systems (Gutberlet 2018). Green IoT autonomously as well as smartly contributes to the sustainability of smart cities and villages in a collaborative approach (Tahiliani and Dizalwar 2018). Governments and many organisations across the globe are making significant efforts to promote the significance of reducing energy usage and carbon emissions, as well as emphasising the Green IoT for smart villages & cities.

Edge Computing Smart sustainable city and village applications demand real-time analytics services. Hence, IoT generates a significant volume of data, which must be processed and evaluated before use. Edge computing is computation that occurs at or near the location of either the client or the data source, resulting in decreased latency and bandwidth savings (Arasteh et al. 2016). This data source might be an Internet of Things (IoT) device. This allows IoT data to be collected and analysed at the device's edge instead of being sent back to a data centre or cloud to help discover trends that start actions faster, such as anomaly detection for predictive maintenance. IoT devices' capacity to use computational power is becoming increasingly important as a way of swiftly evaluating data in real-time.

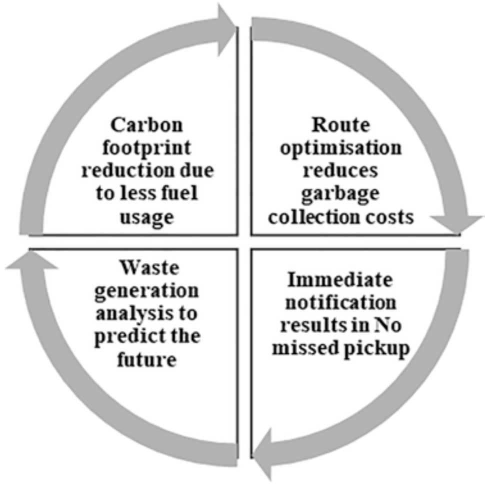
3.3.2 Smart and Sustainable Applications

Smart and Effective Waste Management Solutions With the population increasing day by day, the amount of garbage being generated per day is also increasing. Hence, collection of garbage in urban and rural areas requires large number of resources(Mathews and Gondkar 2017). Moreover, for the people living on the city outskirts and in villages, it can be a costly process which leads to the problem of open dumping. The use of IoT devices such as sensors etc., can decrease the needless expenditures caused by inefficiencies in garbage collection operations. Route optimization is one of the most prevalent IoT use cases in trash management. Four key benefits of using IoT-based waste management solutions are described in (Fig. 3.3).

Nurse Drone Smart Nurse is a UAV-based Hospital Management Application of IoT solutions to Combat COVID-19. The system is named "SMART NURSE" as it can perform the duties of nurse without coming in direct contact with patients. Moreover, it can also perform additional operations like area surveillance and sanitization. This can help to revolutionise and automate the work of hospitals in smart villages and cities. The Smart Nurse idea proposed in this section performs two tasks: live monitoring of patients and medical and food delivery. The flowchart for the proposed system of Smart Nurse for live monitoring of patients is given in (Fig. 3.4).

Sustainable Mobility via Smart Parking and Road Traffic Management One of the major goals of a smart, sustainable city or village is to ensure the saving of natural energy resources and to provide automation for tasks. Smart parking and

Fig. 3.3 Key advantages of using IoT-based trash management solutions in smart villages and cities



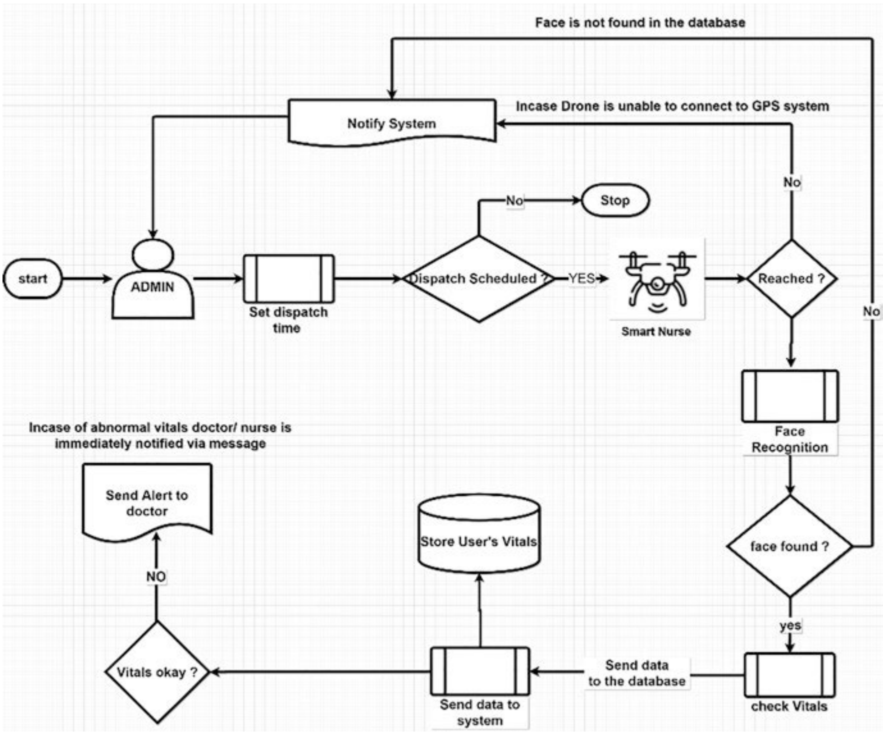


Fig. 3.4 Smart Nurse for live monitoring of patients. (Rashandeep et al. 2021)

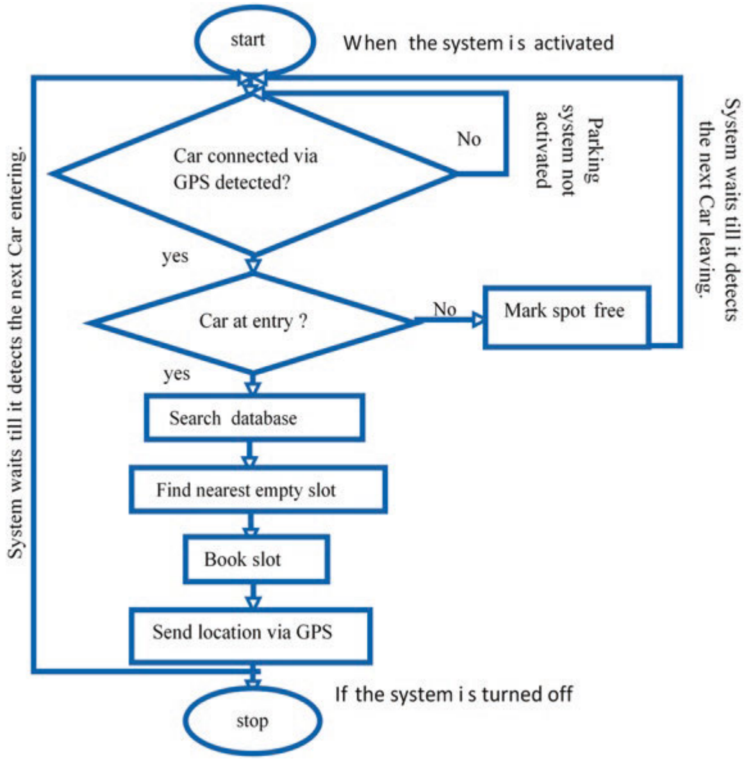


Fig. 3.5 A flowchart representing methodology of a smart parking system. (Kriti and Gulshan 2021)

traffic management systems not only help people to find the location earlier, but by doing so, they allow them to save a lot of gas and petrol (Arasteh et al. 2016). Both the Smart traffic Management system and Smart Parking make use of GPS monitoring systems to find the location they desire. A simplified flow diagram shown in (Fig. 3.5) explains one of the possible working methodologies of the smart parking system.

Smart Education Solutions for Villages and Cities Providing uninterrupted quality education is an important. However, Covid-19 has made things difficult for students. Even before covid-19, providing education in villages and rural areas was a problem. IoT offers a new learning model that bridges the gap between the physical and virtual worlds. Lack of infrastructure, facilities, unavailable or hard to reach educational institutions all these problems can now be solved with the help of IoT. Some of the available IoT solutions are:

- *IoT-based e-learning apps*: They can contribute to the creation of a virtual classroom in which many students from various classrooms in different regions may easily study. An IoT-based e-learning system can foster competition among local and foreign students. This creates a mixed classroom setting. This system includes course material, interface design, digital archives etc. This may be accomplished through the use of a mobile app.

- *Smart Virtual Learning (SVL):* A SVL solution can assist in leveraging smart, long-term studies while remaining at home. The idea behind the SVL system is derived from several stand-alone ideas like social computing, virtual reality applications, smart classrooms, and smart e-learning. The main aim of a Smart Virtual Learner is to provide education to everyone in an interactive and engaging manner. It can often be seen that, for practical subjects, online teaching can get difficult and often hard to accomplish. Smart Virtual Learners can help instructors construct interactive study modules and practical implementation of courses. Furthermore, technologies like virtual and augmented reality can help transform traditional 2D study sessions into a 3D real-time study environment. IoT-based social computing applications can further assist in the streaming of these modules in real time across the world via social media platforms.

The whole concept of Smart villages and cities center around how well they can use the smart resources. Education is one the most important issues. IoT connects various technologies such as the Internet, mobile devices, and smart gadgets. It can hence be used to educate people in Villages and cities. Moreover, village schools can be outfitted with VCD, LCDs, projectors, automatic attendance recorders etc. transforming them into Smart schools Mathews and Gondkar 2017). With the use of smart Education systems, receiving quality education will become free from any physical or financial limitations like wealth, geological location etc.

Energy Efficient Buildings According to a survey conducted by the UN Environment Programme, both office and residential buildings consume around 60% of the world's power (UNEP 2009). The concept of smart buildings is being investigated at all stages of the building life cycle, with a focus on the construction, design, and operational phases. In many cases, a smart sustainable building combines the features of a green building. The operational stage of a commercial grid is the most technologically advanced procedure that allows various building functions to communicate with one another. Different controllers and sensors may be used to govern the functioning of various systems, such as air conditioning, lighting, and security etc. This decreases energy usage while also increasing safety and security and improving personal interior comfort for the inhabitants. Smart energy-efficient buildings learn from past experiences to make more effective real-time decisions to optimize quality and performance while consuming the least amount of energy. Implementing these buildings may save up to 30% of the water and 40% of the energy used, as well as 10–30% of the overall building maintenance expenses (European Committee 2009). This can prove to be one of the biggest boons, when it comes to use of IoT in Rural areas and villages.

Smart Agriculture Solutions Agriculture is the backbone of Indian villages. However, villages face many problems like water shortage, in accurate weather predictions etc. Use of smart agriculture solutions like sensor-based irrigation systems and remote satellites systems can hence prove to beneficial in villages. Even in the cities, indoor farming solutions like AeroFarms and Bowery Farming can be implemented. These solutions rely on carefully regulated conditions to cultivate the finest plants possible. IoT sensors are an excellent type of technology to help with environmental control. Farmers can enhance their crop-growing techniques by collecting and analysing data on anything from moisture in the soil to light and the quality of air.

3.4 Conclusion & Future Scope

The present paper talked about the role and importance of IoT for constructing smart and sustainable cities and villages in India. Some of the technological applications use of Artificial Intelligence and based technologies, use of Social Computing as a means of connecting people living in villages and cities to the rest of the world, Smart Grids, Green IoT as a means to reduce energy consumption of IoT application and use of edge computing for affordable data processing and decreasing bandwidth consumption were discussed. While AI and UAV can open doors to new IoT services, Smart Grids, Green IoT and edge computing can help realise IoT for not just smart cities but also for smart Villages. The present paper also talked about some problem specific applications like smart waste management systems to reduce garbage collection costs, the use of Smart Nurse Drone for remote patient monitoring in hospitals, SVL systems to provide remote education in cities and villages, smart parking systems for traffic prevention, Energy Efficient Buildings for saving electricity and Smart Agriculture solutions for farmers. IoT offers a huge scope for the introduction of new services in smart cities and smart villages. However, integration of these solutions can serve as a challenge due to lack of infrastructural and technical skills in cities and villages. The avenue for further research is hence recognizing these challenges and developing these IoT solutions in order to minimize the challenges.

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Chapter 4
A Review on Utilization of E-Waste in Construction

Neeraj Kumar and Anjali Jaglan

Abstract When an electronic or electrical device like cellular phones, computers, printers, washing machines, refrigerators, etc. reaches the end of its service life, its disposal results in the creation of electronic waste (e-waste). In 2019, about 53.6 Mt. of e-waste was generated worldwide, and it is estimated to reach 74.7 Mt. by 2030. The rapid up-gradation in science and technology, short product life cycles, and very few repair services contribute to the generation of the copious amount of e-waste. The disposal of this copious amount of e-waste is huge concerning matter regarding the environment. In addition, the presence of noxious substances such as lead, cadmium, beryllium, mercury, dioxins, etc. makes it challenging to dispose of them. The present research work presents a comprehensive review of the previous studies and examinations carried out to find an effective way to utilize e-waste in construction practices. The study finds that recycling e-waste in construction can be a suitable alternative to minimize e-waste while offering new sustainable waste management strategies.

Keywords E-waste · Construction · Concrete · Recycling

4.1 Introduction

Electronic products play a vital role in the everyday life of an ordinary person. Some of the daily used electronic gadgets like cellular phones, computers, television, printers, washing machines, refrigerators, etc., have made human life more convenient and productive. Electronic products are being more integrated into health, transportation, security systems, and energy generators, making them a

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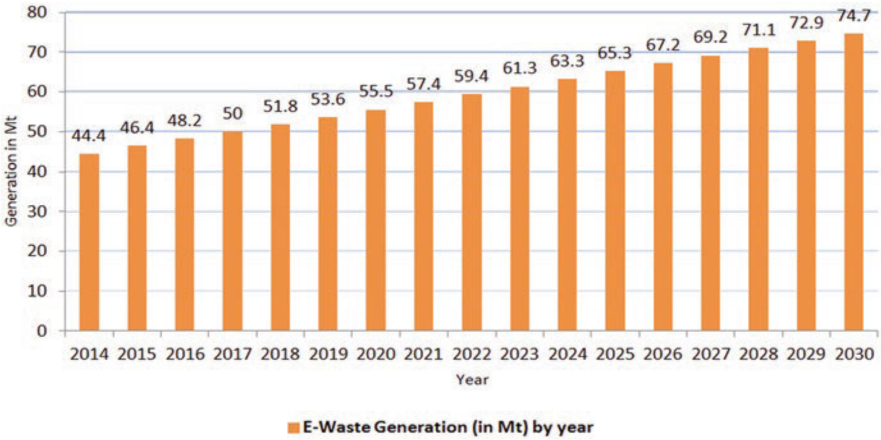

Fig. 4.1 E-waste generation scenario

significant component of modern civilization (Parajuly et al. 2019). With the rapid progress in technology, the insatiable desire of the consumer for new-fashioned and ultra-high-tech products has led to a tremendous boost in the production and consumption of these electronic and electrical devices (Tan et al. 2016; Cruz-Sotelo et al. 2017; Islam and Huda 2020). Even serviceable old products are just discarded due to the continuous consumer mindset to switch over to the advanced products as per the latest trend followed worldwide (Hamsavathi et al. 2020). Electronic products have a short service life, decreasing due to the rapid up-gradation in the product's design and features (Kang and Schoenung 2005). Moreover, the options for repairing the damaged products are also limited (Marinello and Gamberini 2021). Thus, due to the disposal of old, damaged, and non-usable electronic products, e-waste or electronic waste is generated.

Globally, the world created around 53.6 million metric tons (Mt) of e-waste in 2019, and it is projected to reach about 74.7 Mt. by 2030, as shown in Fig. 4.1 (Forti et al. 2020). On the other hand, recycling efforts are falling behind the global rise of e-waste generation. The amount of e-waste generated and recycled by different continents in the world in 2019 is shown in Table 4.1. It can be observed from Table 4.1 that only 9.29 Mt. of electronic scrap was recycled out of 53.6 Mt.

The construction activities entail a large-scale depletion of natural resources, which leads to the scarcity of natural resources. Several researchers have attempted to use e-waste in the construction sector for several years to lessen the burden on the natural resources and safeguard the environment from this dangerous waste. A comprehensive review has been done in the present research study on the usage of electronic waste in various construction practices.

Table 4.1 Amount of e-waste generated & recycled by different continents (Forti et al. 2020)

Region	E-Waste generated (in MT)	Amount recycled (in MT)
Asia	24.9	2.9
Americas	13.1	1.2
Europe	12.0	5.1
Africa	2.9	0.03
Oceania	0.7	0.06
Total	**53.6**	**9.29 (17.3%)**

Table 4.2 Different categories of e-waste (Forti et al. 2020)

S. No.	Category of e-waste	E-waste products
1.	Temperature Exchange Equipments	Heat Pumps, Air Conditioners, Refrigerators, Freezers
2.	Screens & Monitors	Laptops, Tablets, Monitors, Notebooks, Televisions
3.	Lamps	High Intensity Discharge Lamps, LED Lamps, Fluorescent Lamps
4.	Large Equipments	Dish-washing Machines, Clothes Drying Machines, Washing Machines, Copying Equipment, Electric Stoves, Photovoltaic Panels, Printing Machines
5.	Small Equipments	Microwaves, Toasters, Vacuum Cleaners, Scales, Electric Shavers, Ventilation Equipments, Radio, Video Cameras, Calculators, Electronic Toys, Small Electrical Tools, Small Monitoring & Controlling Devices
6.	Small IT & Telecommunication Equipments	Pocket Calculators, Routers, Telephones, Mobile Phones, Printers, Personal Computers, Global Positioning System devices (GPS).

4.2 Different Categories and Components of E-Waste

E-waste is typically comprised of electronic appliances or gadgets discarded after completing their useful life (Sinha-Khetriwal et al. 2005). Table 4.2 shows that e-waste can be classified into six main categories according to the report of Global E-Waste Monitor 2020 (Forti et al. 2020).

E-waste is one of the most intricate waste categories to handle due to its continuously changing features and specificities (Borthakur and Singh 2020). The kind and model of the electronic product, the manufacturer, the date of production, and the garbage age all influence the composition of e-waste (Mmereki et al. 2016). It may include metals like iron and steel (steel chassis, cases, and fixings), aluminium (heat sinks, electrolytic capacitors, all electronic goods that uses power), copper (component leads, copper wires, printed circuit boards, wires); plastics (circuit boards, cables, computer mouldings); glass; rubber; wood; ceramics and concrete (Widmer et al. 2005; Luhar and Luhar 2019). Some e-waste consists of hazardous components like lead (printed circuit boards, light bulbs, televisions), cadmium (batteries,

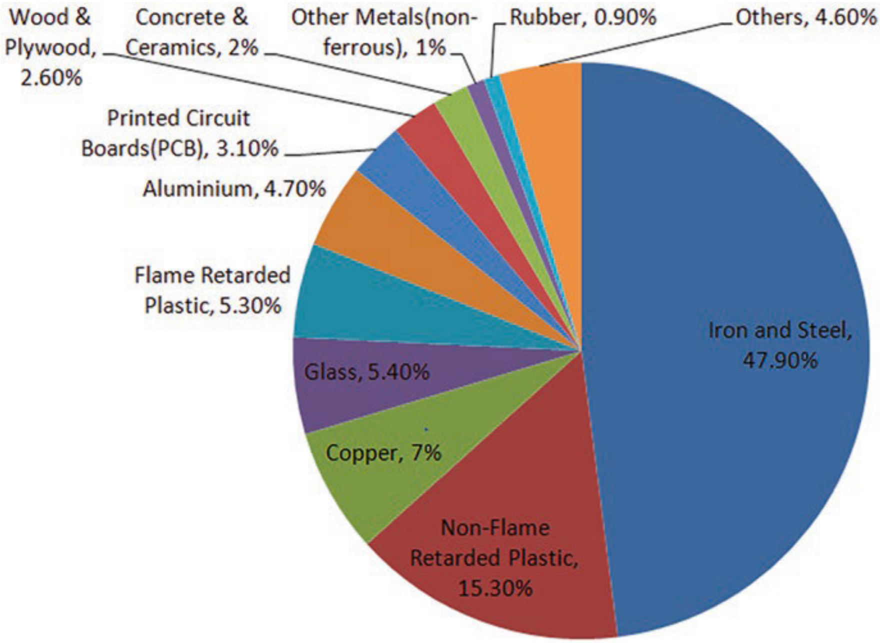

Fig. 4.2 Constituents and % contribution in e-waste. (Widmer et al. 2005)

switches, cell phones), mercury (sensors, thermostats, monitors), chromium (hard disc parts, cables, monitors), beryllium (X-Ray machines, circuit boards, power supply boxes), dioxins (generators, capacitors, electric motors), polychlorinated biphenyls (capacitors, motors, coolants), and many others (Mmereki et al. 2016; Widmer et al. 2005; Luhar and Luhar 2019; Perkins et al. 2014). The e-waste also includes some precious metals like gold, silver, platinum, palladium, copper, cobalt, etc. (Sinha-Khetriwal et al. 2005; Widmer et al. 2005; Luhar and Luhar 2019; Perkins et al. 2014). Thus, waste from electronic products is very diverse (Needhidasan et al. 2014). The generalized range of constituents and their contribution in percentage in e-waste is as shown in Fig. 4.2 (Widmer et al. 2005).

4.3 Environmental Impact of E-Waste

4.3.1 Effects on Soil

The perilous components present in this waste adversely affect the properties of soil near the dumping sites and e-waste recycling facilities. The soil, plants, vegetation, and even groundwater get contaminated with heavy metals like cadmium, mercury, lead, etc., present in the electronic waste debris (Pradhan and Kumar 2014; Tang et al. 2010; Luo et al. 2011). The most common technique of disposal is to dump e-waste on land. The soil fertility gets polluted, which is hard to recover since the composition of e-waste alters the soil's overall properties. The practice of e-waste dumping influences groundwater's characteristics, changing its nature such that it cannot be used for any other civilian applications (Hamsavathi et al. 2020).

4.3.2 Effects on Water Bodies

E-waste recycling has also been discovered to have polluted water tables (Cayumil et al. 2016; Zheng et al. 2013). Wu et al. (2015) investigated the neighborhood of an e-waste processing plant to study the contamination level of ponds and well waters by the hazardous constituents present in e-waste. The findings showed the acidification and contamination of pond water with lead and cadmium. Furthermore, toxins from e-waste infiltrate local water bodies, posing a threat to aquatic life (Huang et al. 2014; Someya et al. 2010).

4.3.3 Effects on Air

When e-waste is discarded at a dumping site, especially a landfill, it is often burnt to diminish the enormous volume of e-waste. However, the burning of this diverse type of waste results in the release of harmful pollutants such as cadmium, mercury, dioxins, furans, etc., into the environment (Luhar and Luhar 2019; Xiao et al. 2014). The adverse effects on air from e-waste are more dangerous for people who manage this scrap (Caravanos et al. 2011), although contamination may spread thousands of kilometers beyond dismantling and recycling sites.

4.3.4 Effects on Human Health

Electrical and electronic devices are an intricate mix of many small individual parts containing toxic substances (Needhidasan et al. 2014). Humans can be exposed to electronic scrap either directly through recycling or indirectly through environmental exposure. Some heavy metals found in this type of waste are hazardous to humans. For example, lead that is present in printed circuit boards, light bulbs, televisions, computer monitors, etc., affects the nervous system, reproduction system, circulatory system, bones, kidneys, and child's psychological growth. Mercury, which is found in sensors, thermostats, monitors damages the liver, lungs, kidney, and brain. Some e-waste contains constituents like beryllium, cadmium, and chromium, which are carcinogenic (Luhar and Luhar 2019; Kumar et al. 2017).

4.4 Recycling of E-Waste

The sheer amount of trash generated by electrical or electronic equipment is becoming a matter of huge concern. Recycling is the key to minimize this massive amount of e-waste. The most common and efficient method of recycling the e-waste is 'Reuse'. The act of reusing is the ideal choice to give the used products to any knowledgeable person or donate these products to a recognized needy individual or group (Luhar and Luhar 2019). However, these old types of equipment have a limited life and will eventually be discarded as waste after serving their service life (Lakshmi and Nagan 2011). After exploring all the available options of reuse, the recycling process becomes the new focus. It includes the dismantling of the electronic devices into various parts, followed by their separation. Thus, the reusable, valuable, and toxic materials are separated from the electronic scrap (Gollakota et al. 2020). The reuse of materials from electronic scrap results in preserving the natural resources. In addition, the recycling process reduces the burden on land resources, which otherwise would be used only for dumping the electronic scrap. Therefore, the recycling sector plays a significant role in minimizing environmental degradation caused by the unsafe disposal of this toxic trash (Luhar and Luhar 2019; Kumar et al. 2017).

4.5 Utilization of E-Waste in Construction

4.5.1 In Mortar

Ban et al. (2005) utilized aggregates obtained by grinding Printed Circuit Boards (PCB) waste as a sand substitute in the mortars. The mortar containing PCB waste showed 12% lesser compressive strength than the standard mortar after a curing period of 7 days. However, the difference in strength dropped to 10% after a curing period of 4 weeks. Furthermore, the difference in weight and compressive strength were recorded to evaluate the durability of the PCB added (20% by weight) mortar and the control mortar. These results suggested that recycling PCB waste as a sand replacement material in mortar requires a longer curing time.

Ling and Poon (2011) employed the Cathode Ray Tubes (CRT) glass to substitute sand in a mortar. The substitution of river sand by acid-treated CRT glass ranged from 0 to 100% with an increment of 25%. The workability of CRT glass added mortar was found to be 190 mm as compared to the standard mortar with a workability value of 120 mm. In addition, for every 25% increase in CRT glass substitution value, the hardened density of sample mortar increased by around 3%. However, the other parameters such as water absorption, mechanical strength properties showed a declining trend with the percentage increase in usage of CRT waste.

Wang et al. (2012) investigated the usage of non-metallic powder, recovered from PCB waste, in cement mortars by assessing the physical and strength characteristics of the cement mortar samples. The non-metallic e-waste powder was supplanted as an admixture in cement mortar samples, with powder to cement (m_p/m_c) ratios ranging from 0% to 25% by weight. The test findings indicated that the strength parameters decreased when the mp/mc ratio in cement mortar increased. The incorporation of e-waste powder into the mortar increased the air content but reduced the density of the hardened mortar. However, the water retention characteristics of the hardened mortar improved due to the inclusion of e-waste into the mortar.

Wang and Meyer (2012) examined the feasibility of replacing sand with high-impact polystyrene (HIPS) in cement mortar. The sand was replaced by HIPS in the percentage ranges of 10, 20, and 50%. The percentage decrease in compressive strength was 12, 22, and 49% for the corresponding increase of 10, 20, and 50% in HIPS content in mortar. Similarly, the percentage decrease in split tensile strength was 1.5, 11, and 20% for the corresponding increase of 10, 20, and 50% in HIPS content in mortar. In addition, the results depicted that thermal conductivity reduced by 87, 69, and 44%, respectively, with a 10, 20, and 50% increase in e-waste incorporation in mortar. Furthermore, when the amount of HIPS in the mortar increased, the dry bulk density of the mortar decreased. Hence, the mortar containing HIPS content can be used in applications of light or medium weight concrete.

Ling et al. (2012) utilized CRT glass-based aggregates as a substitute material of sand in cement mortar in varying percentages of 25, 50, 75, and 100%. The strength properties of the mortar mixes prepared with varying percentages were then compared to the strength values of the standard mortar. The flexural and compressive strength values dropped as the amount of glass component in mortar specimens increased. However, all the mortar specimens containing e-waste aggregates showed flexural strength values of more than 4 MPa and compressive strength values of more than 30 MPa, indicating their usefulness in most building-related construction applications.

Meanwhile, Hui et al. (2013) first replaced 25% of cement content with fly ash (FA) and ground granulated blast furnace slag (GGBFS). Then, untreated CRT glass in crushed form was used to supplant sand in a quantity of 0, 25, 50 & 75%. The mechanical properties, and wet density of the mortar mix improved as the amount of CRT glass in the mortar increased. Furthermore, mortars with GGBFS exhibited slightly higher wet density and mechanical characteristics for a given substitution range of CRT glass-based sand than mortars with fly ash.

Makri et al. (2019) attempted to use e-plastic aggregates derived from liquid crystal display (LCD) screens to replace sand in cement mortar in varying percentages of 2.5, 5.0, 7.5, 10.0, & 12.5%. The compressive strength results of specimens containing 2.5, 5.0, 12.5% of e-plastic aggregates in cement mortar decreased. However, an increase of 15.4% and 7.8% was observed in compressive strength for cement mortar containing 7.5% and 10% of e-plastic aggregates, respectively. On the other hand, the modulus of elasticity decreased as the substitution level increased, indicating that the specimens became less elastic despite their acquired strength. The test results for physical properties such as porosity, water absorption, and density further supported this conclusion.

Ouldkhaoua et al. (2020) developed a self-compacting mortar by utilizing e-waste as a sand substitute and metakaolin (MK) as cement substitute material. The e-waste aggregates used in this study were prepared from Cathode Ray Tube (CRT) waste. The substitution range for e-waste aggregates was 0–50% (by weight) with an increment of 10%. The cement was replaced by metakaolin in the percentage ranges of 5, 10, and 15%. The results of the slump flow test were in the recommended range of 300 to 330 mm. The results showed that 90-day compressive strength rises by 7.27% for a combination of (10MK + 50CRT) compared to the control mixture (0MK + 0CRT). In all, the addition of 10% metakaolin to the CRT mixtures enhanced the strength properties.

Merlo et al. (2020) conducted experimental investigations to find the feasibility of using polyvinyl chloride (PVC) waste obtained from electronic wires and cables to produce mortars. The PVC waste was used to replace aggregates with a 5% incremental increase up to 20%. However, when the replacement percentage increased, the mechanical characteristics, such as compressive and flexural strength, began to decline. Nevertheless, the cement mortar made with PVC provides ample mechanical properties for the works demanding nonstructural applications. Hence, PVC waste offers a sustainable solution in preserving natural resources.

Recently, Kakria et al. (2020) studied the potential of utilizing non-metallic fractions, recovered from the debris of PCB waste, as a substitute for fly ash and metakaolin for making geopolymer mortars with varying fly ash and metakaolin ratios (100-0, 90-10, 80-20, 70-30, and 60-40). The fly ash was subsequently replaced with e-waste by 5, 10, 15, and 20% for each mix. It was observed that a combination of 55% fly ash +30% metakaolin +15% e-waste showed optimized results for compressive strength results. The sorptivity and water absorption values for this combination of geopolymer mortar mix observed at 56 days were 38.5% and 35.6% lower than that of the control mix, respectively. Thus, the consumption of e-waste in the geopolymer mortars can prove to be a suitable sustainable solution for recycling PCB waste.

The details of the previous studies on the usage of e-waste in mortar mixes have been summarized in Table 4.3, which shows the feasibility of incorporating e-waste as sand replacement material, as admixture in concrete mortars, and as a fly ash replacement in geoploymer mortars.

4.5.2 In Concrete

Kumar and Baskar (2015) conducted investigations to explore the possibility of incorporating e-plastic waste as supplementary material to supplant coarse aggregates. The e-plastic waste aggregates supplanted coarse aggregates up to 50%. The experimental observations depicted that the inclusion of e-plastic waste reduced the workability and density of the concrete. Furthermore, the increase in the usage of e-plastic concentration in the concrete mix decreased its strength properties. Nonetheless, the study suggests that the coarse aggregates can be replaced up to

Table 4.3 Details of previous studies on the e-waste utilization in mortar mixes

References	E-Waste source	% used	Utilization type	Properties evaluated	Remarks
Ban et al. (2005)	PCB	10, 20, 40	Sand	CS, DU	CS increases with curing time. In durability evaluation, 20% of e-waste added mortar showed comparable results to standard mortar at later curing stages.
Ling and Poon (2011)	CRT Glass	25, 50, 75 & 100	Sand	W, D, WA, CS, FS	W and D increases while WA, CS, and FS decreases with increase in e-waste replacement level
Wang et al. (2012)	PCB	5, 10, 15, 20, 25	Admixture	AC, WR, D, CS, TS, FS	Strength parameters exhibited very slight reductions up to 15%
Wang and Meyer (2012)	HIPS	10, 20, 50	Sand	CS, TS, TC, D	Inclusion of e-waste decreases the strength properties, but enhances the thermal conductivity
Ling et al. (2012)	CRT Glass	25, 50, 75, 100	Sand	CS, FS	Addition of e-waste to the concrete mixes gave satisfactory results
Hui et al. (2013)	CRT Glass	25, 50, 75	Sand	CS, FS, E, D	Presence of FA and GGBFS enhances the performance of e-waste substituted mortars
Makri et al. (2019)	LCD Screens	2.5, 5.0, 7.5, 10, 12.5	Sand	CS, E, PO, WA, D	Increase in CS observed for 7.5% and 10% e-waste substitution
Ouldkhaoua et al. (2020)	CRT Waste	10, 20, 30, 40, 50	Sand	CS, FS,	10% addition of metakaolin enhanced the strength properties
Merlo et al. (2020)	PVC Waste	5, 10, 15, 20	Sand	CS, FS	CS & FS decreases, although mortars with PVC waste can be used in nonstructural applications
Kakria et al. (2020)	PCB	5, 10, 15, 20	Fly Ash	CS, WA, S	CS improved by the addition of e-waste; maximum strength obtained for 30% FA + 15% E-waste combination

CS compressive strength, *DU* durability, *W* workability, *D* density, *FS* flexural strength, *WA* water absorption, *AC* air content, *WR* water retention, *TS* tensile strength, *TC* thermal conductivity, *E* elasticity modulus, *PO* porosity, *S* sorptivity

30% by e-waste aggregates to achieve characteristic strength, and about 40–50% replacement can be recommended for works requiring nonstructural applications.

Alagusankareswari et al. (2016) incorporated e-wastes as fine aggregates replacement (10, 20, and 30%) in a concrete mixture. The strength parameters of e-waste incorporated concrete mixtures were evaluated, and the findings were compared to a standard concrete mix. All of the characteristics of the concrete mix deteriorated with the increased usage of e-waste in it. The compressive strength of concrete mixtures containing 10, 20, and 30% e-waste dropped by 7.6, 21.47, and 26.11%, respectively. Similarly, for 10, 20, and 30% e-waste substitution levels, the splitting tensile strength was reduced by 1.67, 20.98, and 38.98% compared to the conventional concrete mix, respectively. The flexural strength results for conventional concrete were 16.67, 40.5, and 42.86% higher than the concrete containing e-waste at 10, 20, and 30% substitution levels. Furthermore, the self weight of the concrete mix decreased with the increased usage of e-waste in it. Hence, the resulting concrete finds its application in lightweight concrete structures.

In an investigation by Sabău and Vargas (2018), the coarse aggregates were replaced by e-plastic aggregates reclaimed from old computer housing with quantity percentages of 40, 50, and 60% for a control concrete mixture of 21 MPa compressive strength. The increase in the volume of e-plastic aggregates in the concrete mixtures decreases its density and compressive strength. The compressive strength and density were reduced by 44% and 22% for a concrete mixture containing 60% e-plastic aggregates in comparison to the control concrete mix, respectively. In addition, a cost analysis results demonstrated that 15% savings on cost per m^2 of masonry wall could be achieved by utilizing concrete made with e-plastic aggregates compared to the traditional concrete.

Hamsavathi et al. (2020) used e-waste from CRT Plastics to supplant coarse aggregates in the proportions of 5, 10, 15, 18, and 20% by weight. They found that 15% e-waste replacement showed excellent compressive strength and flexural strength. Furthermore, the study results revealed that the inclusion of e-waste certainly reduces the density of the concrete mixes, benefiting applications requiring lightweight concrete. Thus, the research study recommends the usage of e-waste aggregates as a feasible alternative material to replace coarse aggregates for preparing concrete for nonstructural applications.

Kalpana et al. (2020) employed powdered e-waste as a substitution to sand in the range of 0–25% (by weight) for M30 concrete. The e-waste-containing mixes (up to 20% substitution) showed lower split tensile strength than the standard concrete; though, the 25% e-waste substituted mixture showed strength values comparable to the standard mixture. However, the concrete mixture with 20% e-waste exhibited better flexural and compressive strength than the standard mixture.

Kurup and Kumar (2017) added fibers to the concrete, obtained from waste electrical cables, at 0.6, 0.8, and 1.0% of the cement weight to produce fiber reinforced concrete. In addition, silica powder was also used to replace 10% cement volume to improve concrete performance. The examined results depicted that the ideal fraction for incorporating fibers made from e-waste is 0.8%.

Lakshmi and Nagan (2011) examined the effect of e-waste partial substitution as coarse aggregates (0–24% with an incremental increase of 4%) on the pattern of strength values. The strength was found to decrease for all levels of the substitution in contrast to the control mix. The addition of 10% fly ash to cement was then used to counteract the declining effect of e-waste substitution on the strength of concrete. The combination of 12% e-waste aggregates and 10% fly ash showed a compressive strength value of 29.79 MPa, higher than the strength value of 28.79 MPa of the control mix. Overall, the strength gain of e-waste substituted concrete was adequate, and it was determined that 12% of e-aggregates particles might be used as an aggregate replacement without causing long-term harm.

Chunchu and Putta (2019) employed waste e-plastic to supplant fine aggregates in the range of 10–40% (by volume) for making self-compacting concrete (SCC). The fly ash was also used to supplant 30% of cement content for all the SCC mixes. The performance of concrete mixes was assessed in terms of sorptivity, porosity, and water absorption, and it was found to be satisfactory for an e-waste substitution value of 30%.

Suchorab et al. (2020) examined the effect of the inclusion of Polymer Optical Fibers (POF) scrap in the form of small fibers of 15–20 mm length and 1 mm diameter on the concrete properties. The fibers were incorporated into the concrete mix at 1, 2, and 3%. The bulk density of the concrete decreases, while water absorption and porosity increase with the increased usage of e-waste fibers content. The bulk density decreased by 11.6%, while water absorption and porosity increased by 14.8% and 55.1%, respectively, for the concrete mixture containing 3% fiber volume compared to the standard mixture. Incorporating e-fibers in concrete mixtures negatively affected compressive strength; however, a positive effect on flexural and tensile strength was observed. For the maximum addition of 3% fiber content to the concrete mix, the compressive strength was lowered by 24.9%, but flexural and split tensile strength did rise by 22.0% and 16.36%, respectively, compared to the standard mixture. Accordingly, this concrete found its application in the structural elements subjected to tensile and bending forces, preferably than the elements subjected to the forces of compressive nature.

Evram et al. (2020) conducted experiments to examine the effect of e-plastic waste and waste marble dust (MD) as aggregate and cement replacement, respectively, on the concrete properties. The natural aggregates were replaced by e-plastic waste up to 40% by volume. In addition, cement was replaced by MD up to 15% by weight. The experimental results demonstrated that the concrete mixes with e-plastic waste as aggregates showed reduced split tensile strength, compressive strength, elasticity modulus, and toughness than the control mix. On the other hand, permeability increased with the e-plastic content in concrete. However, the experimental study revealed that the concrete mixes containing e-plastic aggregates showed better strength and performance with the inclusion of MD. The effect of inclusion of MD was more evident at 15%.

Ullah et al. (2021) noted the effect of incorporating e-wastes aggregate as coarse aggregate substitution (0, 10, 15 & 20%) in the concrete mixtures by evaluating its workability, mechanical properties, and durability characteristics. The examined results depicted that the workability increases while the mechanical strength reduces with the increased usage of e-waste aggregates in the concrete mixture. However, in durability tests such as abrasion resistance, alternate wetting and drying, and sorptivity coefficient, the experimental findings indicated the efficacy of e-waste incorporated concrete.

Recently, Ali et al. (2021) used e-plastic aggregates to substitute sand (at 10, 15, and 20%) in the concrete mix. The workability increased but the compressive and tensile strength reduced by 22% and 29% compared to the control concrete. Silica fume was then added to the mix as a substitute for cement at the same proportion as the e-plastic sand to enrich the strength properties of the concrete. For a 20 percent substitution of e-waste plastic sand and silica fume, the compressive and tensile strength reductions were only 4.7% and 1.1%, respectively. Thus, the study demonstrates an effective way to utilize e-waste to produce an eco-sustainable concrete mix.

Table 4.4 presents a detailed summary of the previous studies on the consumption of e-waste in concrete, showing that e-waste can be utilized in concrete in various ways.

Table 4.4 Details of previous studies on the e-waste utilization in concrete

References	E-Waste source	% Used	Utilization type	Properties evaluated	Remarks
Kumar and Baskar (2015)	E-Plastic	10, 20, 30, 40, 50	Coarse Aggregates	W, D, CS, ST, FS	Characteristic strength can be achieved up to 30% substitution of e-plastic waste aggregates
Alagusankareswari et al. (2016)	Discarded E-Waste	10, 20, 30	Sand	CS, ST, FS,	E-waste substitution decreased the strength properties
Sabău and Vargas (2018)	Computer Housings	40, 50, 60	Coarse Aggregates	W, D, CS	Workability increases while density and compressive strength decreases with the increase in e-waste substitution
Hamsavathi et al. (2020)	CRT Plastic	5, 10, 15, 18, 20	Coarse Aggregates	CS, FS	Addition of e-waste aggregates can be done up to 15%
Kalpana et al. (2020)	Discarded E-Waste	10, 15, 20, 25	Sand	CS, ST, FS	20% e-waste substitution improved the compressive and flexural behavior
Kurup and Kumar (2017)	Electrical Waste Cables	0.6, 0.8, 1	Fibers	W, D, CS, ST, FS	0.8% addition of e-waste fibers gave optimum results
Lakshmi and Nagan (2011)	Discarded E-Waste	4, 8, 12, 16, 20, 24	Coarse Aggregates	CS, DU, P, WA	Addition of 10% fly ash enhanced the properties of concrete mixtures containing e-waste
Chunchu and Putta (2019)	E-Plastic	10, 20, 30, 40	Sand	WA, S, PO	30% of e-plastic substitution can be done to produce flow-able and durable concrete

(continued)

Table 4.4 (continued)

References	E-Waste source	% Used	Utilization type	Properties evaluated	Remarks
Suchorab et al. (2020)	Fiber Optic Cables	1, 2, 3	Fibers	D, WA, PO, CS, ST, FS	3% fiber addition improved flexural strength and tensile strength
Evram et al. (2020)	E-Plastic	10, 20, 30, 40	Aggregates	CS, ST, E, T, P	15% addition of MD enhanced the performance of concrete containing e-plastic aggregates
Ullah et al. (2021)	E-Waste Plastic	10, 15, 20	Coarse Aggregates	W, CS, ST, AR, S, WD	Addition of e-waste enhanced the durability properties
Ali et al. (2021)	CRT Glass	10, 15, 20	Sand	W, CS, ST	Addition of silica fume in same substitution range as the e-waste provides satisfactory results

W workability, *D* density, *CS* compressive strength, *ST* split tensile strength, *FS* flexural strength, *P* permeability, *DU* durability, *WA* water absorption, *S* sorptivity, *PO* porosity, *AR* abrasion resistance, *WD* alternate wetting and drying, *E* elasticity modulus, *T* toughness

4.6 Conclusion

The extensive use of electrical and electronic devices in various applications has resulted in the worldwide generation of a copious amount of e-waste (electronic waste). The e-waste composition is very diverse, containing reusable material, valuable metals, and hazardous materials. The presence of hazardous components in e-waste is a matter of environmental concern. Thus, there is a considerable need to recycle or reutilize this tremendous amount of e-waste. Several research studies indicated that e-waste could be effectively consumed in the construction industry. The following major outcomes can be drawn from this review:

- It can be concluded from Table 4.3 that e-waste can be consumed as a sand replacement material or as an admixture in cement mortars.
- The density and basic strength properties decreased with the increased usage of e-waste; however, these properties can be enhanced by introducing fly ash, GGBFS, etc., as binder replacement in mortars. In addition to cement mortars, e-waste found its application in geopolymer mortars too.
- It can be seen from Table 4.4 that e-waste reclaimed from various sources can be used for substituting aggregates in concrete. The e-waste can also be introduced as small fibers in concrete. The fundamental strength properties and durability characteristics were found within the acceptable limits, indicating the practical and effective usage of e-waste in concrete for sustainable construction practices.

Thus, the enormous amount of e-waste can be managed by consuming it into construction practices, which helps to minimize this hazardous waste, and helps in preserving the natural resources, save landfill spaces, and preventing environmental degradation.

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Chapter 5
Water Sensitive Urban Design (WSUD) for Treatment of Storm Water Runoff

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Abstract Limited water availability and steadily increasing urban population have resulted in higher water demand, particularly in urban areas. Water scarcity or poor quality can lead to adverse health effects, water-borne diseases, and even casualties if the event is acute. For effective water management, the treatment of wastewater and its reuse plays a crucial role. A substantial volume of water received as rainfall runs off unutilized, contaminating the receiving water bodies in many cases. The first rain scavenges pollutants and flushes contaminants from the catchment making the water non-usable without treatment. Some treatment units like gross pollutant traps (GPT), wetlands, rain-garden, vegetated swales, etc., are the significant components of Water Sensitive Urban Design (WSUD) and can be used to remove the physical-chemical impurities from storm water runoff. These units have been used to remove the suspended/floating impurities, organic load (BOD), nutrients (nitrogen and phosphorus), heavy metals, hydrocarbons, and even pathogens (coliforms). There has been a wide application of WSUD in developed countries, but it is relatively less popular in developing/poor countries due to several factors. India, the second most populous country of the world with only 2.4% of geographical area, receives non-uniformly distributed precipitation (3880 BCM) mostly during 3–4 months of monsoon, and requires a strong and effective WSUD for conserving water. Suitable technique of WSUD can be applied individually or in combination depending upon the quality of runoff and feasibility of treatment. Design considerations such as type of vegetation and hydraulic conductivity of filter needs attention initially before its application. The lower operation and maintenance cost, no energy input, and formation of non-toxic metabolites make it sustainable. An effective

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WSUD not only conserves water, it also favours improved urban hygiene, better air quality, carbon sequestration, and healthy ecology.

Keywords Stormwater · Runoff · Water sensitive urban design · Urban water management

5.1 Introduction

A very limited quantity of freshwater is available to us, hence, it is said that the water will become as valuable as crude oil in the present century, forcing us to think of its efficient management and usage so that water of acceptable quality is available to all and not only to specific group of population (Rezaei et al. 2017). The usage of fresh water is increasing everyday with the increase in population and demand, and when fresh water once used becomes wastewater and it cannot be reused until it is given some treatment. This causes the scarcity of the water for humans, animals, and plants. In past, several studies were also done to estimate the world's water budget. It was estimated that 1338×10^6 km^3 of water is stored in ocean which is salty; and freshwater lakes, rivers, and streams have approximately 0.0072% of world's total stock of water (≈93,000 km^3) while the precipitation on land is of the order of 119×10^3 km^3/year (Shiklomanov 1993). India is the world's second most populous country with approximately 2.4% of the geographic area, and receives annual precipitation of about 3880 BCM (Billion Cubic Metre) (Extraction of Groundwater 2020). The precipitation is not received uniformly in India, making few places receive excessive rainfall and others receive scanty/scarce rainfall. Hence, it can be said that water is deficit in India because of the limited resources of freshwater. Also, the rainfall which is received on earth, first satisfies the infiltration capacity (leading to interflow) of ground, fills the undulations (pits and ditches) on ground and it is affected by land use/cover before it become storm water surface runoff (Wang et al. 2021). Although rainwater is the purest form of water, during the path traversed by runoff, it takes along the impurities and gets contaminated (Pipil et al. 2022). Despite being contaminated, the strength of impurities in storm water runoff is far less than the domestic/municipal wastewater. Therefore, the surface runoff can be treated to make use of storm water most efficiently to reduce the load on the existing water resources and bridge the gap between the demand and supply of the freshwater. Moreover, the annual average temperature is increasing, resulting in the change in the climate and disturbed pattern of rainfall. There is an urgent need to design the water sensitive mechanisms and techniques in order to treat and reuse the contaminated storm water runoff. For this purpose, several techniques and methods are being used in developed countries like United States of America, New Zealand, and Australia, which include gross pollutant trap (GPT), vegetated swales, rain garden wetlands, tree pits, etc. Such techniques have been implemented locally or as a centralized unit in these countries (Beza et al. 2018). These techniques and methods can also be used in India depending upon the prerequisites and requirement of the individual method are satisfied (Hoban 2018).

5.2 Water Sensitive Urban Design (WSUD)

In last few decades, a new method for sustainable water cycle management was introduced in many developed countries, known as Water Sensitive Urban Design (WSUD), and since then, it has been modified by professionals in many other parts of the world till date to achieve more efficiency towards removal of the impurities from stromwater runoff (Argue 2004). There is a wide gap between the developed and developing countries in terms of the development and functioning of such treatment units. The techniques and the methods can be combined with each other to achieve the desired level of pollutant removal. In addition to this, guidelines have been developed over a period of time to plan and design these WSUD units depending upon the local climate, catchment characteristics, environmental and local community considerations, etc. Considering the above mentioned scenario, WSUD can be broadly classified depending upon the functionalities and scale as Household Scale, and Urban Development Scale.

These WSUD can have one or more functionalities and it can also have one or more configurations. Its functionalities include, but not limited to, storm water quality management, flood control, rainwater harvesting, biodiversity, etc. These treatment units can be configured as a stand-alone unit, or combination of one or more units in either series or parallel, or sequences can also be inter-changed, since, it was observed that single WSUD unit are not able achieve the targeted or desired degree of treatment of storm water runoff (Sharma et al. 2018). The storm water quality management and flood control can be achieved by filtration, sedimentation, adsorption, rainwater harvesting, flow volume attenuation, biodegradation and uptake by plants, detention, retention, etc. so that it can find its utility for the purpose of domestic or industrial use, irrigation, ground water recharge, etc. (Argue 2004).

The quality of treated storm water from WSUD units can be classified (Lewis et al. 2015) on the basis of effectiveness and application of treatment as:

- Primary: Removal of floating, suspended ($d > 0.1$ mm) impurities through sedimentation tanks, gross pollutant tank (GPT), trash rack, etc.
- Secondary: Removal of relatively finer suspended impurities by sedimentation and filtration through swales, infiltration basin, porous pavement, etc.
- Tertiary: Removal of dissolved and micro impurities through adsorption and biological degradation, uptake by plants through bio-retention system, wetlands, etc. (Table 5.1).

The criteria on the basis of which a WSUD is selected depends upon the following (Fewkes 2012):

Table 5.1 Functions of various WSUD techniques

WSUD technique	Various functions performed				
	Flow rate reduction	Water quality management	Flood management	Rainwater harvesting	Biodiversity improvement
Gross Pollutant Trap		✓			
Trash Rack		✓			
Swales	✓	✓	✓	✓	✓
Raingarden	✓	✓		✓	✓
Wetlands	✓	✓	✓	✓	✓

– Reduction in total suspended solids (TSS), removal of total nitrogen (TN), and removal of total phosphates (TP).
– Prevention of mixing of storm water runoff with sewer water.
– Groundwater recharge.
– Development of amenities along the WSUD treatment units.
– Prevention of flood by WSUD in urban area.
– Enhancement and improvement of ecosystem and biodiversity with WSUD.

The WSUD methods that have been used in many developed countries along with the mechanism involved, advantages and the limitation are discussed below:

5.2.1 Primary Treatment Unit

5.2.1.1 Gross Pollutant Trap (GPT)

Gross Pollutant Trap (GPT) is a WSUD treatment method in which the floating impurities such as plastics, leaves, branches, and other anthropogenic litter, suspended impurities like sand and silt are removed from the stromwater runoff. The selection of size or number of GPTs depends upon the catchment area from where the runoff will be received by it. Hence, GPT helps in retaining the floating litter and debris from the storm water runoff through screening and it can remove the solids of dia d > 5.0 mm through impaction/gravity settling. GPTs can be installed on the existing drainage system that conveys storm water with the objective to prevent the entry of litter into the waterways at the initial stage. Hence, it can also be used as the pre-treatment unit for many other treatment units, such as wetlands (Hoban 2018).

There are various types of GTPs and they all have different mechanisms for the removal of impurities from storm water runoff. They come in various style and configurations such as Trash Racks, Litter Control Devices, Baffled Wall (Fig. 5.1), Circular Screens or Hydrodynamic Deflective Separation (HDS) Devices, Catchpit Grates, etc. Few of these GPT work on sedimentation for removal of suspended impurities through gravitational force, other work on the physical screening

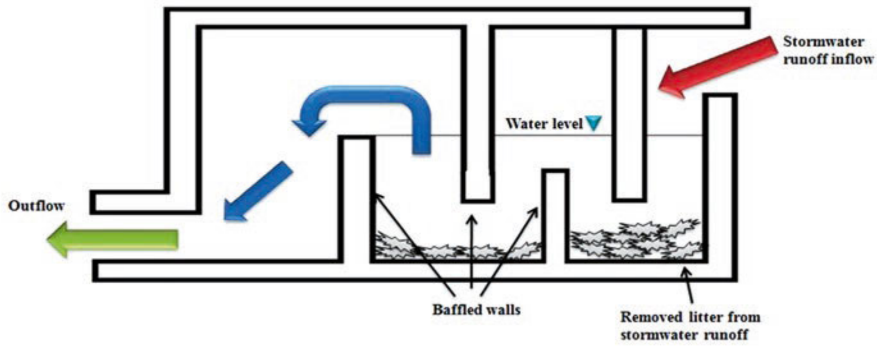

Fig. 5.1 Sectional view of a baffled wall type Gross Pollutant Trap (GPT)

separation, while, HDS works on hydrodynamic of physical impurities using centrifugal force.

5.2.1.2 Trash Rack

It is a type of GPT in which coarse metal screens facing towards the flow of storm water runoff are provided. The screens are made of parallel vertical metal bars with design specific centre-to-centre spacing. It can also be provided with a built-in trash collection unit. It physically removes the floating anthropogenic impurities/ litter like plastics, bottles, paper, newspapers, etc. since, the clear opening between the screens are kept smaller than the trash in storm water runoff, and thus, prevents them from further entering and going downstream into the treatment system. Hence, they are recommended in high litter area and it results in storm water quality management (Hoban 2018) (Fig. 5.2).

5.2.1.3 Hydrodynamic Deflective Separation (HDS)

Hydrodynamic Deflective Separation (HDS) is also a type of GPT is used to separate out the sediments, debris and litter from the storm water runoff through its continuously deflecting system. The incoming storm water runoff is allowed to pass through a system of screens provided at the centre of HDS to separate out the debris and litters, and it is collected at the sump at the centre from where it is removed later on. The incoming storm water runoff is acted upon by the centrifugal force, making a vortex, and treated storm water runoff exits the outlet (Hoban 2018).

Hence, GPT can prevent a significant portion of impurities to enter the downstream treatment units such as wetlands. They do not increase the water level in upstream side since they do not block the flow of storm water runoff. However, it cannot remove the sediments having dia smaller than 5.0 mm. When it reaches the maximum capacity, the trapped debris can be remobilized. Poor maintenance

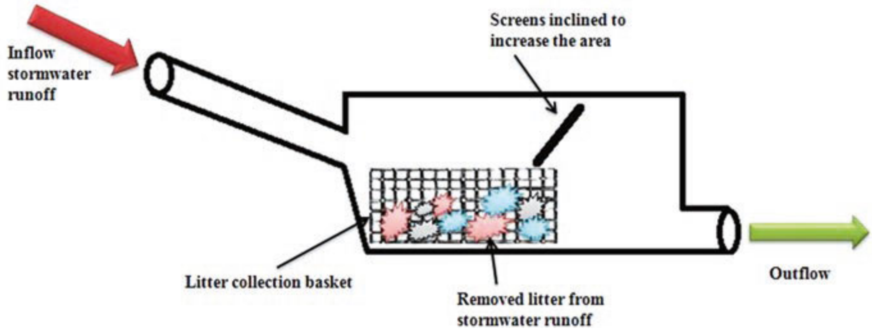

Fig. 5.2 Sectional view of a trash rack

reduces the working efficiency of the trap system and it can increase the pollutant such as phosphorus, nitrogen, COD and TSS in downstream side (Walker et al. 1999). They are usually unattractive and can cause odour problem due to poor maintenance that leads to decomposition of the wet organic litter and anaerobic conditions (Abood and Riley 1997). Its performance depends upon rainfall and runoff characteristics. It can also cause health hazards to the workers handling the waste. In order to prevent these limitations, it is recommended to clean the GTP fortnightly or after 10 mm downpour (Hunter 2001).

5.2.2 Secondary Treatment Unit

5.2.2.1 Vegetated Swales

Instead of providing the pipes to convey the storm water runoff, vegetated swales or bio-swales or swales can be provided along the side of the road. The road acts as the catchment area from where the storm water runoff is received into the swales. They are provided with a longitudinal bed slope of 1–4% in order to carry the runoff to the next treatment unit through a system of underlying perforated pipes or it can infiltrate the storm water runoff to ground through its sides that reduces the cost of laying storm water drains (Bligh Tanner 2014). Flatter slopes can cause water logging, thus, steeper slopes are preferred as they can convey the storm water runoff more easily. The steeper slopes can be balanced with the natural ground slope by providing the drop structures within the swale. They are provided with the bed of sediments and gravels with a suitably selected vegetation species. They can be provided in the road median or next to road shoulder, reducing the cost of land allocation (Fig. 5.3).

The pollutants that are present over the surface of the road over a period of time are flushed with storm water runoff due to cross slope (camber) provided on the road. These impurities enter the vegetated swale where the suspended impurities are removed by filtration due to small voids present between sediment particles

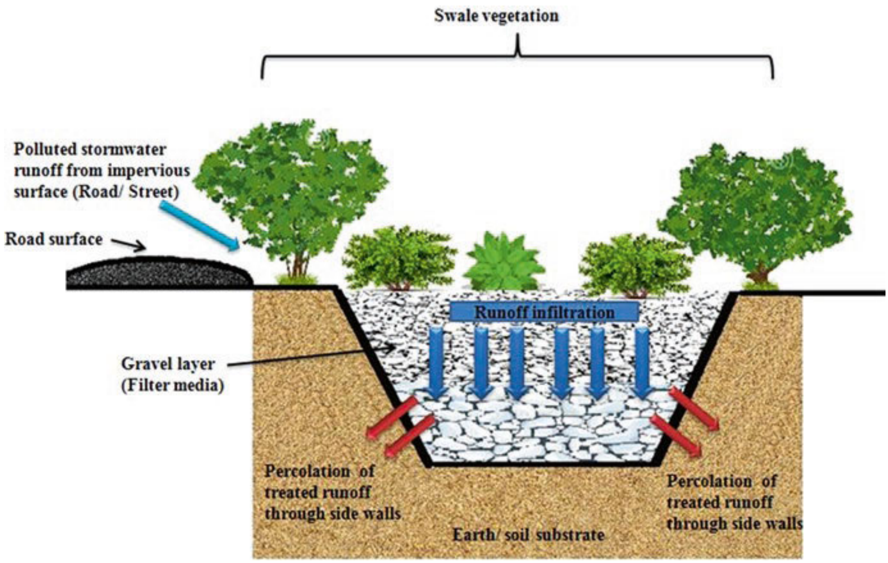

Fig. 5.3 Sectional view of an established Vegetated swale

in substrate bed. Once the voids traps suspended impurities, the filtration is enhanced as the void size further decreases and helps in removal of further finer suspended impurities. The sediments also remove the impurities through adsorption. Vegetation species up takes the dissolved impurities from storm water runoff for their metabolic activity and translocate them in various parts of vegetation (Haritash at el. 2017).

It provides better aesthetics, landscaping and increases the green cover along the roads and streets due to vegetation. They are passively getting irrigated through strom water runoff. The green cover helps in reducing the temperature of the urban area. Its operation and maintenance cost is low (Hoban 2018). It can effectively remove the TSS and TP from storm water runoff (Barrett et al. 1998). In addition to this, it takes more time (≈5 years) for treatment system to get well established and till then it requires more maintenance cost. It generally fails in removing the total nitrogen (TN) from the storm water. Wilting of vegetation can be seen in case of limited supply of the storm water runoff during dry seasons (Lloyd et al. 2002).

5.2.2.2 Raingarden

Raingarden is a type of storm water treatment technique in which the strom water runoff is allowed to enter this system which performs filtration through the media made up of sand and gravel layers; sorption, and denitrification (anaerobic conditions at bottom), etc. Nutrient uptake by plant takes place which has vegetations to suit the local climate (Hoban 2017). The filtered runoff is collected at the bottom of

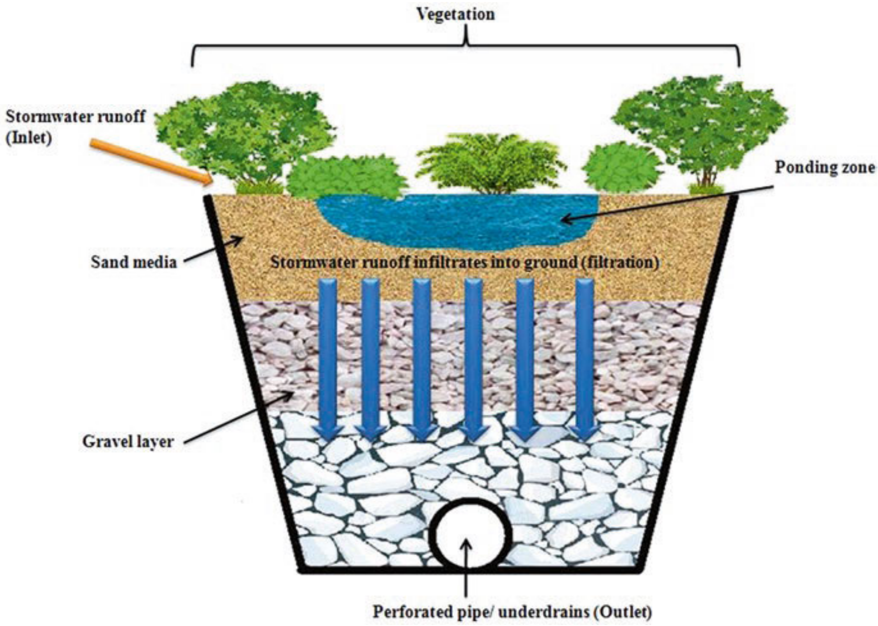

Fig. 5.4 Sectional view of a Raingarden

raingarden through perforated pipes, allowing it to further go downstream towards the next treatment unit. Also, the ponding above the raingarden provides additional treatment to runoff (Fig. 5.4).

The vegetation prevents erosion of the media and breaks media through its growth, thus, preventing the clogging. The vegetation survives with the residual moisture in the filter media during extended dry periods. The filter media allows the percolation of the runoff into ground and prevents flooding and adds to attenuation of flow. Thus, the filter media shall be so selected keeping in mind that its hydraulic conductivity reduces with time and it should be able to hold the water for vegetation growth.

Due to the presence of different type of vegetation, it enhances the aesthetics and landscaping of the urban area, helps in restoring the ecology, and augments the biodiversity. Vegetation prevents the soil erosion caused due to storm water runoff. In addition to this, it removes the pollutants such as phosphates, TSS, and heavy metals from the runoff satisfactorily (Fletcher et al. 2007). However, the filter media gets clogged with time, thus, the hydraulic conductivity of the raingarden reduces significantly with time. Water loving weed herbs can also infest which is unavoidable, and thus, use of weedicide and herbicide can cause further pollution due runoff. The vegetation can experience wilting due to long dry periods and lack of storm water runoff (Hoban 2018).

5.2.3 Tertiary Treatment Unit

5.2.3.1 Wetlands

Wetlands are unique type of ecosystem that remains submerged for most of the time in year, retains the storm water runoff over a relatively larger area and releases the treated water slowly in the downstream direction for further treatment and use. It has shallow depth of water having a wide variety of vegetation which include emergent, floating, or submerged type vegetation. The variable concentration of pollutants enters the wetland with storm water runoff where wetland vegetation acts upon it for its metabolic activities, and also, adsorption of pollutants takes place by sediments present in wetlands. Pollutants are acted upon by removal mechanisms such as sedimentation, filtration, adsorption, biodegradation, and plant uptake (Fisher and Acreman 2004). This helps in reducing the suspended impurities, dissolved impurities, reduces biochemical oxygen demand (BOD) from the domestic and storm water runoff.

Constructed wetlands can be used to remove the pollutants and they have provided the promising pollutant removal efficiency. It has shown upto 86% and 85% of phosphates and nitrogen removal efficiency, respectively, using wetland sp. *Phragmites* and *Canna lily* (Haritash et al. 2015; Nandakumar et al. 2019; Pipil et al. 2021). The nutrients present in the wastewater are taken up by the plant species, moves from root zone with the water for its metabolic activities to other parts of plant and gets accumulated resulting in translocation of nutrients (Haritash et al. 2017). This not only results in change of phase of pollutant, but also, acts as the sink for them and it is not released into the environment.

Wetland can improve the ecology of certain area and it can act as the habitat for various species flora and founa. It can be clubbed with the recreational activities like pathway, resting areas, etc., and hence, it can act as the place for enlightening the community and educate people, professionals, and provides the scope for scientific research. It can improve the aesthetics and landscaping of urban area. It can hold a very huge volume of water over large area that can be used to facilitate irrigation and ponding of water receives further treatment. This water over a large area get pretreatment and percolates into the ground helping the rainwater harvesting function. It can provide the storage at the end that acts as flood routing method and prevents flooding. It acts as the sink for pollutants, such as heavy metals and nutrients from the storm water runoff (Coleman 2007). Wetland also helps in carbon sequestration that removes the carbon from the atmosphere, produces biomass products that can be used for thatching, conserves the soil, etc. However, wetlands remain submerged in water for most of the time, thus, it is susceptible to get attacked by aquatic weeds. It has limited and poor access for maintenance as it remains submerged in water for most of the time. The upstream flow of the sediments and litter cannot be controlled and it enters the wetland (Table 5.2).

Table 5.2 SWOT Analysis of various units used in WSUD system

Type of treatment unit	Strength	Weakness	Opportunity	Threat
Gross Pollutant Trap (GPT)	Operates on gravity, centrifugal force; Does not affect the upstream flow; Expected pollutant removal performance; No energy is required;	Visually unattractive; Litter can remobilize; No removal of sediments smaller than 5.0mm; Poor maintenance leads to poor performance; Barrier to flora and fauna migration;	Better design opportunities; Research opportunity in developing countries;	Organic impurities causes odour problem; Health hazard to person cleaning the trash;
Vegetated Swales	Better aesthetics along the roads; Improved landscape; Improves water quality downstream; Prevents soil erosion; No energy is required;	Takes time to stabilize; Increased cost of maintenance in developing stage; Fails to remove total nitrogen; Reduced hydraulic conductivity causes impurities to bypass;	Various vegetation species can be used in different geographical areas; Can be used successfully in developing countries;	Difficult to retain moisture; Revegetation required after dry period; Hydraulic conductivity reduces;
Raingarden	Improved aesthetics; Attractive landscaping; No energy is required; Prevents soil erosion;	Hydraulic conductivity reduces with time; Storm water runoff can bypass them during high intensity rainfall;	Selection of new species can be identified; Can be used in developing countries;	Difficult to retain moisture in dry period; Wilting of vegetation can be seen;
Wetlands	Improves aesthetics; Augments biodiversity; Carbon sequestration; No energy is required; Improves groundwater level; Prevents flooding;	Larger area is required; Takes time to get fully established; Maintenance is difficult;	Can be used to provide water for irrigation, greenbelt and gardening on downside; Various combinations and configurations can be used in parallel, series or cascade;	Susceptible to shock from toxic impurities; Can be infested by weeds;

5.3 Conclusion

Development of urban environment needs an awakening and awareness not only among the community but also in the local law making agencies for promoting sustainable development in developing countries like India. Water is scarce and treatment of raw water for making it fit for domestic or industrial activity costs hefty money to government, even though not everyone is blessed to get safe drinking water. Along with this, the poor management of wastewater treatment is leading to pollution of freshwater resources. The dependence on freshwater resource can be reduced by making use of stromwater treatment for which the WSUD has been suggested and it is being used by many developed countries. WSUD consists of various types of methods and techniques for the removal of impurities from storm water runoff. All the methods and techniques vary in terms of its objective, application, function, mechanism of removal, and management practices. The selection of WSUD methods and techniques depend upon the local climatic condition and type of soil, slope of ground, local laws of authorities and governing bodies, presence of existing asset on site, etc. WSUD improves quality of the storm water runoff through reduction in floating, suspended, nutrient loading (phosphates and nitrates), and dissolved impurities, and it can prevent the flooding in urban area by providing detention and storage to attenuate the flow which in return helps in increasing the water capacity of the city. The storage reduces the dependence on other water resources for non-drinking purpose, such as irrigation. It also improves the green cover of urban area, helps in providing better quality of life, enhances ecology, and augments the biodiversity in terms of flora and fauna. These independent treatment techniques reduce the load on the existing conventional water treatment system and help in saving the additional cost of storm water drain laying. These techniques and methods do not need any source of energy for their operation and WSUD like wetland can act as the sink for the pollutants proves that the technique is sustainable in its approach. It has been proven effective in many developed countries, and can find a way in developing country like India in coming future.

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Chapter 6
Textile Industry Wastewater Treatment Using Eco-Friendly Techniques

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Abstract Sustainability is the need of the hour, and every industry on the planet is focusing on removing environmentally hazardous elements from its supply chain. Organic and inorganic products, heavy metals like chromium, nickel, arsenic, lead, etc.; formaldehyde compounds join the stream as dyes, alkali, softeners, salts, fixing agents, levelling agents, ammonia, among other auxiliaries. These compounds are more resistant to biodegradation due to their synthetic nature and complex aromatic structure. Untreated effluent water released into pools of water may pose a significant threat. It has the potential to disrupt the oxygen transport process at the water surface, increasing the turbidity, disruption of photosynthetic activity, and decreased sunlight availability to aquatic organisms. Hence, water quality suffers, as a result, rendering it unfit for human use. Due to increased water shortages and environmental restrictions, the textile industry thus, needs to switch to alternative wastewater treatment solutions that can help minimize the water footprint and maintenance costs. Several agricultural residues and organic wastes are now used as natural adsorbents in effluent streams to remove dyes and heavy metals. These materials are commonly used due to their ease of availability, the potential for adsorption, and reduced cost. Enzymes are an appealing choice for wastewater treatment for various reasons, including their biocompatibility, convenience, and simplicity of process control. Microbial dye degradation and decolorization is a more environmental friendly and cost-effective alternative to chemical decomposition. Dead cells are preferable for wastewater treatment because they remain unharmed by toxic waste and chemicals and do not pollute the environment by releasing toxins or propagating toxins. Since economy and sustainability have been driving forces in modern manufacturing, efforts are being made to manufacture textiles more effectively, with less water pollution.

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Keywords Textile sector · Sustainability · Wastewater treatment · Eco-friendly technique

6.1 Introduction

"Waterways have taken the brunt of economic development". However, it is no less important to internalise environmental costs in the midst of global climate change. Textile is a necessary material and an entity for human life. The term 'textile' signifies weaving, which comes from the Latin word 'texere'. Natural and synthetic fibres serve as the building blocks for the textile sector and are categorized based on textile fibres they utilize (Elliott et al. 1954). Plant sources such as hemp, linen, cotton, lyocell, ramie, and rayon derive cellulose fibres. Acetate, nylon, spandex, polyester, acrylic, polypropylene, and ingeo are synthetic fibres. Wool, angora, mohair, cashmere, and silk are examples of protein fibres derived from animals (Bledzki and Gassan 1999). Since sustainability is the need of the hour, every sector worldwide concentrates on removing environmentally dangerous aspects from their supply chain. The process of bleaching and dyeing textiles is one of the several components of the supply chain generating recalcitrant. Large volumes of dyestuffs are utilised in textile dyeing, and other industrial uses, and the extensive use of such chemicals is causing a threat to nature (Periyasamy and Militky 2020a, b). These compounds are more resistant to biodegradation due to their synthetic nature and complex aromatic structure. Untreated effluent water released into pools of water pose a significant threat. It has the potential to disrupt the oxygen transport process at the water's surface, increasing the turbidity, disruption of photosynthetic activity, and decreased sunlight availability to aquatic organisms. Hence, water quality suffers, as a result, rendering it unfit for consumption. China is the leading exporter of nearly all textiles, has an inside joke about telling the year's colour by looking at the hue of the rivers, portentous towards the untreated effluents mixed in with their rivers. The ample shreds of evidence of vibrantly coloured and chemical-foam-ridden waterbodies worldwide have shown a direct correlation between the garment sector and some of the world's significant water arteries facing crisis.

With the high sustainability waves, increasing water shortages, and environmental restrictions, the textile industry thus needs to switch to alternative wastewater treatment solutions that can help minimize the water footprint. Several agricultural residues and organic wastes are now used as natural adsorbents in effluent streams to remove dyes and heavy metals. These materials are widely utilised because of their quick access and adsorption potential and lower cost. Enzymes are an appealing choice for wastewater treatment for various reasons, including biocompatibility and convenience and simplicity of process control. The prospect of microbes decolorizing dyes has garnered a positive response. Microbial dye decolorization and degradation are low-cost ways of eliminating harmful contaminants from the environment. An alternative to chemical decomposition, it is more environmentally friendly and cost-effective. Dead cells are preferable for wastewater treatment because they remain unaffected by toxicants and chemicals and do not pollute the environment by releasing toxins or propagating toxins. Since economy and sustainability have been driving forces in modern manufacturing, efforts are being made to manufacture textiles more effectively, with less water pollution (Periyasamy and Militky 2020a).

6.2 Environmental Impacts of Textile Effluent

Textiles discharge enormous volumes of coloured water effluent in the water body without adequate treatment. Table 6.1 depicts the major pollutants in the wastewater discharge from each step, as indicated by Holkar et al.(2016). The effluent contains a significant amount of dyestuff with many toxic metals increasing the biochemical oxygen demand of the receiving water and reducing the reoxygenation process thus hampering the growth of photoautotrophic organisms (Ananthashankar 2013). Furthermore, the suspended solid concentrations in the effluents combine with oily scum and interfere with the oxygen transfer mechanism in the air-water interface.

Since dyeing process is crucial step where the colour along with different chemicals are added to the fibres. Some of these dyes and chemicals however become part of the textile industry effluent (Yaseen and Scholz 2019). Owing to dyes xenobiotic and wayward nature, toxic dye components mix with water bodies paving a way to enter the food chain. Benzidine-based azo dyes have been reported as carcinogens in the human urinary bladder and tumorigenic in experimental animals (Sudha et al. 2018). It leads to nuclear anomalies, splenic sarcoma, hepatocarcinoma in laboratory animals, and chromosomal aberrations in mammalian cells (Puvaneswari et al. 2006). The easy inhalation and solubilization of azo dyes in water cause rapid absorption by the skin, resulting in allergic reactions, cancer, eye irritation, etc. (Sudha et al. 2018). Metabolic oxidation of aromatic amine to reactive electrophilic species, produced during azo dye reduction, binds covalently to DNA. Table 6.2

Table 6.1 Characteristics of wastewater generated from textile industry

Textile process	Chemicals used/released
Desizing	Starch, glucose, enzymes, ammonia fats and waxes
Scouring	Caustic soda, waxes, soaps, waxes, soda ash, surfactants, pectin, oils
Bleaching	Hydrogen peroxide, chlorine, hypochlorite, sodium silicate, organic stabilizer and alkaline conditions
Mercerizing	Caustic soda
Dyeing	Chlorinated phenols, colour, acetic acids, metals, surfactants, salt, acidic/alkaline conditions
Printing	Solvents, formaldehyde, urea, colour, acids, metallic salts, starch
Finishing	Softeners, spent solvents, resins, chlorinated compound,and waxes

Table 6.2 Environmental impacts associated with textile effluent dyes

Textile dye	Environmental impact	References
Benzamine (BZ)-based azo dye	Carcinogenic to human urinary bladder and tumorigenic to laboratory animals	Manning et al. (1985)
Reactive brilliant red	Inhibit regulation and function of human serum albumin	Li and Wang (2010)
Malachite Green	Alterations in biochemical parameters and multi-organ tissue failure in MG-exposed fish	Srivastava et al. (2004)
Reactive Black 5	Decrease the activity of urease, restrict nitrogen uptake by plant, chance mutagenic, and carcinogenic	Dave et al. (2015), Gottlieb et al. (2003) and Topaç et al. (2009)
Congo red	Carcinogenic and mutagenic effect in *Bacillus sp.*	Gopinath et al. (2009)
Acid Violet 7	Inhibition of membrane lipid peroxidation and acetylcholinesterase activity, Chromosomal aberration in mouse	Ben Mansour et al. (2010)
Disperse Red 1 & Red 13	Mutagenicity in human beings, salmonella; activity and composition of microbial communities is affected	Chequer et al. (2015)

shows some commonly used textile azo dyes and the environmental impacts associated (Sarkar et al. 2017).

6.3 Limitations of Conventional Treatment Methods

Textile dyeing mills in India are often small-scale operations, are not able to put up a comprehensive Effluent Treatment Plant (ETP). Generally, the wastewater released from the textile sector undergoes various physio-chemical treatment. Oil and grease, gritty materials and suspended solids are removed via primary treatment, while the secondary treatment employs microorganisms under aerobic or anaerobic conditions. The tertiary treatment engages the use of processes like ion exchange, reverse osmosis, or electrodialysis. The significant limitation of the biological process is the presence of toxic heavy metals in the wastewater that inhibits the growth of microorganisms, further increasing the retention time. The high TDS content creates unfavorable conditions resulting in microbial inhibition of growth and development. The high concentration of solutes builds up high osmotic pressure preventing the smooth transport of water inside the cell. Retardation of biological growth thus leads to declined efficiency of the treatment system further affecting the BOD. Since, the textile wastewater is laden with heavy metals like mercury, arsenic, zinc, the microbial growth is hindered and becomes limited as the concentration of heavy metals keeps on rising because of the recycling of the biological cell materials. One of the key problems associated with the treatment of textile wastewater are the dye components. The recalcitrant xenobiotic compound is resistant to biodegradation rendering the conventional biological treatment approach less efficient. Thus, conventional techniques like coagulation-flocculation, foam floatation, etc. result in phase transfer of pollutants, resulting in another waste like spent carbon sludge that requires different elimination methods. The chemical oxidation is generally expensive as during attaining complete chemical degradation the treatment tends to become more and more resistant, furthermore demands more input of energy and chemical reagents, leading to an increase in the duration of the treatment.

6.4 Eco-Friendly Treatment of Textile Wastewater

Several physico-chemical decolorization procedures have been developed during the last two decades, but the textile industry has adopted only a handful. Their primary issue of implementation is attributed to their high cost, poor effectiveness, and inapplicability to a wide range of dyes. Physical and chemical treatments though is adequate for colour removal, demands more input of energy and chemicals than biological processes. They can concentrate pollutants into solid or liquid by-products that need additional treatment or disposal. Biological processes, on the other hand, effectively mineralize contaminants. Alternative methods of treating wastewater can be implemented for textile industry water.

6.4.1 Bioadsorption

Adsorption methods utilises the surface phenomena and a suitable interface to remove soluble organic contaminants from wastewater. The process depends on the particle size, adsorbent surface area, adsorbate-adsorbent concentration, temperature, contact time, and pH (Sachidhanandham and Periyasamy 2020). Generally, activated carbon is preferred as useful approach towards wastewater treatment because of high surface area (> 1000 m^2/g), porous structure and high adsorption capacity. However, its high capital problem for handling the spent carbon is its significant disadvantage (Fazal-ur-rehman 2018). Nowadays, several agricultural residues and organic wastes are used as natural adsorbents such as, powdered banana peel, cotton waste, neem, sawdust, peanut hull, coir pith, apple pomace, wheat straw, sugarcane dust, tree fern, wood, rice husk, bark, silk cotton hull, fruit stones. Agricultural wastes are readily available, primarily consisting of lignin, hemicellulose, and cellulose, which when combined act as effective adsorbents for a broad range of pollutants having functional groups such as phenols, carboxyl, methoxy, hydroxyl, etc. that are involve in pollutant binding to remove dyes (Table 6.3) and heavy metals in effluent streams (Hassanein and Koumanova 2010). They possesses several advantages such as high capacity and rate of adsorption, rapid kinetics and highly selective to wide range of concentrations thus serving excellent resources for environmental protection (Crini 2006).

Table 6.3 Specificity of bioadsorbents used in textile industry effluent

Bioadsorbent	Adsorbate	References
Peel waste of cotton Boll	Congo red, sunset yellow, tartrazine, methyl orange	Narasaiah and Mandal (2020)
Tea residue waste	Acid blue 25	Jain et al. (2020)
Water hyacinth, amazon natural waste	BF 4B Reactive red dye	Rigueto et al. (2020)
Coconut shell activated carbon	Maxilon blue GRL and direct yellow DY 12	Aljeboree et al. (2017)
Wheat husk	Heavy metals from RB 19 and RB 195 effluent	Vasu et al. (2020)
Activated surface of orange peels and banana	Reactive red dye	Temesgen et al. (2018)
Banana fibre and stem	Novacron Blue FN-R, methyl red, Malachite green	Khaleque (2016)

Use of Dead Biomass Biosorption using dead microbial cells is more favourable for wastewater treatment since dead organisms do not demand the constant need of nutrients and can be regenerated and utilised for multiple cycles. The utilisation of biomass offers advantages, particularly if the dye-containing wastewater is extremely hazardous. Dead cells are clearly preferred for wastewater treatment since they are unaffected by hazardous wastes and chemicals, and they do not contaminate the environment by releasing toxins or propagating. Fungal biomass obtain from fermentation processes is not pathogenic to humans and animals. Dead and dry biomass may be kept at room temperature for extended periods of time with no risk of putrefaction. This facilitates convenient operation and transportation. Dead biomass is also produced from known industrial processes as a waste product. Biomass adsorption functions if the environment for microbial growth and survival are not always favourable.

6.4.2 *Enzyme-Mediated Degradation*

Enzymes are a preferred feature for wastewater treatment for various factors, particularly their biocompatibility and ease and simplicity of process management. In some compounds such as azo dyes, the generation of electron-deficient groups makes it less susceptible to degradation (Solís et al. 2012). Enzymes like laccase, azo-reductase, and peroxidase & oxidase under adverse conditions have great potential to degrade diverse spectrum dyes having complex chemical structures. These enzymes can act both extracellularly and intracellularly (Singh et al. 2015). Enzymes have a broad substrate specificity catalysing the desired reaction of interest, are quickly immobilized in nature, and have a high effectiveness, on the other hand being biodegradable, they cause minimal environmental pollution. Under controlled conditions, enzymes can pace up the reactions involved in dye decolourization in industries and have the ability to work for longer after immobilization in suitable matrix. Bacteria have a high potential for dye degradation due to their varied and well-developed enzyme system (Popli and Patel 2015). Fungi are indeed a great source of dye degrading enzymes. Lignin degrading white-rot fungi has gained attention because of the ability to degrade wide range of recalcitrant organic compounds such as chlorophenol, polycyclic aromatic hydrocarbons, and various azo, heterocyclic and polymeric dyes (Sen et al. 2016). Microbial enzymes have advantages over other sources because of cheaper culture, maintenance cost, downstream processing, etc. The usage of enzymes depends on the specificity of the substrate and can be utilised efficient for pre-treatment of textile water.

6.4.3 Microbial Degradation

Microbial decolouration efficiencies are determined by adaptability and the activities of chosen micro-organisms. Bacteria, fungi, yeast, actinomycetes, and algae are some of the microorganisms have the ability to break down azo dyes. The mechanism of microbial degradation of azo dyes under aseptic conditions involves the reductive cleavage of azo bonds (-N $\equiv$ N-) with the help azo reductase, generating a colourless solution. Intermediate metabolites, aromatic amines formed further undergo aerobic or anaerobic treatment. Microbial dye degradation and decolorization is a cost-effective and eco-friendly alternative to chemical degradation. *Pseudomonas aeruginosa*, a bacterial strain, found capable of decolorizing 12 distinct dyes with varying degree of decolorization effectiveness. Dye degradation utilising isolated *Pseudomonas* species as biocatalysts has demonstrated that biological and combined treatment can provide a low-cost alternative approach for removing reactive dyes.

Use of Live Fungi in Decolourisation The fungal cell walls are made up of macromolecules that include carboxyl groups, amino groups, phosphates, lipids, sulfates, and hydroxides, serving as metal sorption sites. *Phanerochaete chrysosporium*, species are known to metabolise a spectrum of xenobiotics compounds. Fungi remove dyes primarily by absorption and an oxido-reduction process. Non-lignolytic fungus from the basidiomycete group, such as several *Aspergillus* species has been found to decolorize a variety of colours. In a nitrogen-poor medium, a strain of *Aspergillus sojae* decolorized the azo dyes Sudan III, Congo red, and Amaranth. Several other wood-rotting fungi, such as *Aspergillus fumigatus* and *Aspergillus oryza*, were more efficient than *Phanerochaete chrysosporium* at decolorizing a wide range variety of structurally diverse dyes.

6.4.4 Constructed Wetlands

Wetlands are special type of ecosystem that houses unique type of vegetation. It remains submerged in water for most of the time of the year. It could be either natural or man-made, known as constructed wetland. Constructed wetlands have been used to treat the wastewater in a most effective sustainable way making use of the wetland vegetation species that includes *Phragmites*, *Canna lily*, Cattail, Duckweed, etc. (Nandakumar et al. 2019; Pipil et al. 2021). They have been found to remove the nutrients like phosphates, nitrates and reduce biochemical oxygen demand (BOD) of the wastewater. The suspended and dissolved impurities from the wastewater can be removed from constructed wetlands. The suspended impurities are acted upon by gravity leading to sedimentation, whereas, the bed media or the substrate acts as the filter media to further remove the finer suspended impurities. The dissolved impurities such as nutrients and heavy metals are taken up by the plant for their daily metabolic activities. These impurities traverse the path from rhizosphere to branches and leaves of plant to translocate these dissolved impurities (Haritash et al. 2017). The plant changes the phase of the pollutant and it remains fixed over there. Not only this, but the wetland also helps in augmenting the biodiversity and carbon sequestration. There have been successful studies that were carried out in India in tropical conditions and there is always a scope for further improvement over previous studies (Haritash et al. 2015). The various configurations and combinations of the wetlands, such as series, parallel or cascading can be used to achieve the desired objective of waste removal from wastewater.

6.4.5 Advanced Oxidation Processes(AOP)

It was first used in water purification. AOPs are now significantly employed for treating wastewater because of its good oxidative capacity of the hydroxyl or sulfate radicals. The different types of AOP are ozonation, Photocatalysis, Fenton's Process, Photo-Fenton treatment, Ultrasonic Irradiation, heat/persulfate, UV/persulfate, Fe(II)/persulfate, OH-/persulfate, etc. (Verma and Haritash 2019). The iron catalyst is utilized to decompose peroxide in the Fenton's reaction and convert it into highly reactive hydroxyl radicals. The primary benefits of this method are its high removal performance, mild working conditions and non-toxic characteristics. Because of these benefits, the Fenton method is used for various industrial wastewater treatments, including olive-oil mill effluent, pharmaceutical wastewater, textile wastewater, cosmetic wastewater, and so on (Pipil et al. 2022; Sharma et al. 2016; Verma and Haritash 2020). The process can also eliminate the chemical oxidation demands in case of dyes. The typical Photo-Fenton's approach involves producing hydroxyl radicals ($HO^{\bullet}$) which subsequently oxidizes the organic molecule into water and carbon dioxide. Because iron species have a low solubility, considerable research has focused on iron free Fenton's process for H_2O_2 activation. Other elements such as chromium, bismuth, copper, cobalt, and aluminium can be used instead of iron to breakdown H_2O_2 into $HO^•$ in a photo Fenton-like oxidation (Krishnan 2017). Perovskite-type metal oxides have recently become more widely used in a variety of fields. Due to its chemical composition, excellent stability, and narrow bandgap characteristics, its appeal as a heterogeneous catalyst is steadily growing.

6.4.6 Sustainable Sludge Management

The generation of sludge and its safe disposal is a mounting global problem. Hence, its treatment and disposal is necessary towards the environment owing to its toxic nature. Anaerobic digestion is a standard treatment approach while dealing with textile sludge. The essential features of anaerobic digestion is production of methane, improved dewatering properties and mass reduction of the fermented sludge. The primary objective is to enhance biogas' commercial-scale production from textile sludge (Đurđević et al. 2019). Furthermore, the dewatering of sludge by inactive pathogens and anaerobic digesters enhances the production of biogas. In addition, the hydrolysis system transforms organic solids into soluble form, resulting in more easily biodegradable sludge (Velghe et al. 2013). Aerobic sludge digestion employs microorganisms in an aerobic environment to oxidize and decompose both the organic and inorganic content and reduce the volume of sludge. Although the treatment method is temperature-sensitive and demands more energy input, it does not produce by-products like methane.

6.5 Conclusion

India is the second most populous country in the world and also has very large installed capacity of industries. Thus, domestic and industrial wastewater production is very significant and needs sustainable methods and technologies to treat them.

- In order to reduce the dependence upon scarce freshwater resources, it is required to find a suitable, sustainable wastewater treatment approach so that the treated wastewater can be reused for industrial purposes and can reduce the impact on freshwater resources by their disposal into them.
- Among the various industries, the textile sector is one of the most important sectors contributing significantly to the economy of the nation; however, it is also causing water pollution. The textile sector consumes large volumes in processes like sizing, desizing, scouring, bleaching, dyeing, printing etc. The chemical processing of fabrics generates high-strength wastewater laden with toxic heavy metals, dyestuffs etc.
- The existing conventional treatment methods demand more chemicals adding to the non-biodegradable sludge with lethal synthetics, advocating the need to

foster sustainable treatment techniques. Bioadsorbentsmade from cotton-boll, clay, water hyacinth, coir, citrus peel waste, wheat husk, cotton-boll, chitosan, tea residue waste, and microorganisms are proven efficient to treat textile wastewater.

- In India, the modern AOPs are not being used on vary larger scale instead the sector is still relying on the outdated treatment units. Thus, the AOPs finds a scope in developing countries like India to achieve sustainable treatment methods for its industrial wastewater treatment.

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Chapter 7
Sustainable Treatment of Metal-Contaminated Soil by Electrokinetic Remediation

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Abstract Soil is among the most important natural resource that provides a wide range of goods and services. However, rapid expansion of heavy industries has led to intensive and unsustainable practices such as effluent discharge, mining, fuel combustion etc., which continues to increase contamination of soil. It is a serious issue as heavy metals are toxic even at low concentration and are resistant to biodegradation. Therefore, they affect all life forms via biomagnification, which necessitates the need to remediate such soils. There are various conventional technologies to remediate heavy metal-contaminated soils, but they have certain limitations in terms of reducing bioavailability of metals, removal efficiency, and high costs. This calls for an advanced and innovative alternative to reclaim contaminated soil that will provide economic and sustainable solutions. Electrokinetic Remediation (EKR) is one such developing, environmental friendly method discussed in this chapter which uses electric current to remove charged contaminants from soil. Optimization of EKR can result in reduced toxicity with very less disturbance to soil ecology and at low costs.

Keywords Heavy metals · Soil pollution · Electrokinetic Remediation · Sustainable treatment

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7.1 Introduction

Soil provides a wide range of ecosystem services and is regarded as the ultimate sink for pollutants since majority of the pollutants get incorporated into the soil causing soil pollution (Machender et al. 2010). Tackling soil pollution is challenging for many developed and developing countries owing to excessive discharge from mining, fibre or pharmaceutical, ore refining and smelting industries etc. into the environment, which contaminate extensive areas of soil resources and groundwater bodies (Saha et al. 2017). Unsustainable use of agricultural additives like fertilizers and pesticides, intensive cultivation, and land use change due to increasing population and urbanization, also contribute to soil pollution and land degradation (Cameselle et al. 2021; Karaca et al. 2019).

The heavy metals in the form of dust from mines, fuel combustion, industries and rainwater runoffs are introduced into the soil. They are the most frequent contaminants present in the soil because of their persistent and non-biodegradable nature that leads to accumulation in the soil. Since heavy metals are present in the environment for prolonged time, they tend to interact with their surroundings and may undergo speciation. The different chemical forms in which the metal occur influence its bioavailability and hence, its toxicity (Selladurai et al. 2015; Wuana and Okieimen 2011). Toxic metals at higher concentrations are carcinogenic, mutagenic, and thus, can affect the environment, reduce soil fertility, retard plant growth, and affect human health through bioaccumulation and biomagnification (Krishna and Govil 2007). Therefore, heavy metal toxicity is a threat to environment and public health, necessitating the need to remediate such contaminated soils. Increased metal and synthetic chemical inputs into the terrestrial environment as a result of industrialization, combined with poor environmental management in developing countries such as India, has resulted in widespread pollution of the soil (Machender et al. 2010). Although, remediation of soil is more complex than that of air and water and a hazard to human life, still soil pollution is largely overlooked due to gaps in existing knowledge of the subject or lack thereof, resulting in limited attempts for soil treatment.

7.2 Conventional Methods for Heavy Metal Contaminated Soil Remediation

Many traditional approaches for soil reclamation have been used in the past, based on the type of soil, pollutants to be removed, and cost effectiveness (Liu et al. 2018). Ex-situ remediation is a remediation in which contaminants are handled off-site, while, in-situ remediation involves on-site treatment (Sakshi et al. 2019). Physico-chemical methods such as in-situ soil flushing or soil washing; thermal processes, such as vitrification; and biological processes, such as bioremediation and phytoremediation, are some examples of remediation processes (Liu et al. 2018). Although these approaches have been shown to be commercially successful, there are several limitations to their application which are discussed below.

In-situ soil flushing or soil washing technique is used to remove metal pollutants from soil using an extraction fluid based on their solubility. Although it is a simple and cost-effective method, the chemicals used as fluids are toxic and can contaminate the soil. A study conducted by Wang et al. (2021) to remove lead (Pb) and Cadmium (Cd) revealed that Cd and Pb was removed by 75.7% and 60.6%, respectively, when treated with washing solution of 1% HNO_3 . However, decreasing pattern was observed in the pH of soil and soil microbial diversity, along with decreasing phosphorus and potassium availability. Another drawback of this technology is that the reagents are not delivered adequately in low permeability soils (Cameselle et al. 2013).

Vitrification, landfilling and drilling, soil excavation and other ex-situ techniques provide long-term solutions in a limited amount of time. Vitrification is a thermal process used to remediate soil by melting and immobilizing pollutants in soil. This approach requires extremely high temperature range of about 1600–2000 °C to transmit heat to the soil via molybdenum electrodes (Liu et al. 2018). Vitrification is a well-established and commercially available process. However, these are energy and money-intensive methods that can only be employed on a small area of land (Selladurai et al. 2015).

Biological approaches like bioremediation and phytoremediation are environmental friendly and cost effective way of removing contaminants from soil by natural processes. These are sustainable methods since no drastic modifications take place in the properties and texture of the soil after the treatment (Cameselle et al. 2013). Bioremediation is based on microorganisms' intrinsic degradative capability, which transforms pollutants into less hazardous molecules and, eventually, their end products (Sakshi et al. 2019). Phytoremediation, on the other hand, is a technique that employs plants for contaminant removal by containing or detoxifying toxins (Abioye 2011). In comparison to other remediation strategies, phytoremediation has proven to be effective for treating wide areas having less contaminant concentrations at a reasonable cost. It also helps in soil stabilization, reducing soil erosion, and increasing microbial activity (Cameselle et al. 2013). However, their use is restricted to the treatment of low-concentration metals and just one pollutant at a time. Furthermore, this technique is constrained to surface soil treatment with plant roots (Zhou et al. 2005).

These techniques focus on reducing toxicity by converting toxic to non-toxic metal form; reducing bioavailability by converting available to unavailable form; or removing contaminants by crop uptake. However, these procedures are site and contaminant specific, have limited applicability when applied to soils with low hydraulic conductivity, disturb soil ecology or are expensive, which is not economic or sustainable in long term. As a result, an effective technique to overcome majority of the limitations of above-mentioned techniques is required. The feasibility of EKR for the remediation of metal contaminated soils is examined in this study to bridge the gap between the efficiency of conventional treatment methods and the treatability attained. It is a cost-effective; time and energy efficient; and environmental friendly technique in the development stage.

7.3 Electrokinetic Remediation (EKR)

Electrokinetic Remediation (EKR) is an advance technique to treat polluted soil, especially fine grained soils with low hydraulic conductivity (Shin et al. 2017). It involves the use of low DC current to induce electric field in the soil positioned between electrodes across a cross section area of few centimeter squares (cm^2). The induced electric field influences the mobilization and migration of metal ions which exist in the soil pore to the oppositely charged electrodes from where they can be removed (Acar & Alshawabkeh 1993). The migration of metal ions due to electric field, has made possible the removal of heavy metals such as cadmium, cobalt, lead, zinc etc. with 85–95% removal efficiency (Yeung et al. 1997), while that of Nickel with 74.1% (Saleem et al. 2011). During EKR, major processes occur at the electrodes like electrolysis, and oxidation-reduction, and between soil and contaminants such as adsorption-desorption, and precipitation and dissolution (Acar & Alshawabkeh 1993). These key processes govern the mechanisms of ion movement through electro-osmosis, electromigration, and electrophoresis (Al-Hamdan and Reddy 2006). These processes are discussed in brief below.

7.3.1 Electrolysis

When an electric current is applied at the electrodes, hydrogen and hydroxide ions are generated due to electrolysis of water at the electrodes. Oxidation at anode results in hydrogen ion generation creating an acid front of pH 2 to 4, whereas, reduction at cathode produces hydroxyl ions causing alkaline environment or base front in the pH range of 10–12 (Acar & Alshawabkeh 1993).

$$\textbf{At Anode}: 2H_2 0 \rightarrow O_2 + 4H^+ + 4e^- \tag{7.1}$$

$$\textbf{At Cathode}: 4H_2 0 + 4e^- \rightarrow 2H_2 + 4OH^- \tag{7.2}$$

The primary ions (H^+ and OH^-) produced during electrolysis migrate to the cathode and anode, respectively causing variations in soil pH (Reddy and Shirani 1997). The hydrogen ion's ionic mobility is higher than that of the hydroxide ion; hence the H^+ would go faster into the soil (Pamukcu and Wittle 1992). As the acid front approaches towards the cathode due to the applied current, it dissolves metals into the pore fluid. Thus, the key mechanism that enables desorption of metal species is acidification of the soil due to hydrogen ions migrating from anode to cathode across the soil. While the hydroxide ions generated at the cathode form hydroxides with metals, thus precipitate out near cathode region. The adsorption/desorption mechanism is influenced by the clay mineral's surface charge density, the cationic species' properties and concentration, and organic matter percentage in the soil along with the pH as changes in pH of soil affect the migration and transport of contaminants (Acar et al. 1993; Cameselle et al. 2013). Elsayed-Ali et al. (2009) investigated the impact of pH on copper contaminated sand by using hydrochloric acid to regulate pH at the cathode region. Results showed that pH value of 2.6 was considered optimum. Above this pH, hydroxyl ions cause precipitation of copper, whereas below this pH, electro-osmosis decreases due to hydrogen production, which further decreases the transport of copper from anode to cathode.

7.3.2 Electro-Osmosis

The mass movement of soil pore liquid along with free ions under the action of electric field is known as Electro-osmosis (Acar and Alshawabkeh 1993). It is a complicated transport mechanism that is influenced by the solid surface's electric properties, the properties of soil pore fluid, and the soil-water interaction. Since soil clay particles have negative charge, electro-osmotic flow (EOF) is towards cathode. The electro-osmotic flow goes toward the anode in electropositive soil section (Cameselle et al. 2013). Under the action of electric field, EOF is primarily determined by the zeta potential and porosity of soil, while being unaffected by the pore size. The zeta potential can be defined as the potential difference between fixed layer of charged soil surface layer and the diffused layer of metal ions in the dispersion medium. It is a function of many factors influencing soil like the type of clay in soil, pH of soil, ionic contaminant concentration in soil, and temperature (Acar and Alshawabkeh 1993).

The role of electro-osmosis and electromigration in the total movement and transport of pore fluid and contaminant change is influenced by soil composition, moisture content, concentration of pore fluid, and electrolytic conditions. In silts and clays of low activity with high water content, maximum EOF is frequently achieved (Figueroa et al. 2016). Experiments carried out by Shin et al. (2017) concluded that the EOF increased with increasing water content in soil pore, but decreases when electrolyte concentration is increased. In contrast to montmorillonite, kaolinite clays with high anion retention capacity show a stronger electrolyte concentration impact. At low contaminant concentration, Electro-osmosis is the dominant mechanism; however, at higher contaminant concentrations, electromigration dominates the migration and transport of contaminants (Pamukcu and Wittle 1992).

7.3.3 Electromigration

The movement of ions under the applied electric current is known as Electromigration (Virkutyte et al. 2002). Ions which are present in the soil pore fluid migrate to the oppositely charged electrodes. The H^+ and OH^- generated at the electrode compartments also migrate along with the metal ions toward the opposite electrode (Pamukcu and Wittle 1992). The electromigration mechanism is influenced by ion characteristics like the size and charge on it (Cameselle et al. 2013). Because electromigration is applicable on both coarse and fine grained soil as it is not affected by pore size (Virkutyte et al. 2002). Shin et al. (2017) investigated the effect of moisture content on electromigration. High moisture levels were shown to increase the soil pore size that further improved ion electromigration in the soil. As a result, migration becomes a significant contributor to total flux.

7.3.4 Electrophoresis

The relative movement of charged particles in the stationary fluid when low direct current is applied to it is known as Electrophoresis. If fine particles, colloids, or bacteria have negative charges, they will migrate towards the anode, and if they have positive charges, they will migrate towards the cathode, while counter ions will move in the opposite direction (Yeung 2006). Mass transfer by electrophoresis is negligible in comparison to ionic migration and electro-osmosis in low permeability soil (Cameselle et al. 2013). This process is significant when surfactants are introduced in the pore fluid or when the technique is used to remediate slurries (Acar and Alshawabkeh 1993).

7.4 Limitations of Electrokinetic Remediation

Application of EKR for heavy metal removal has significant drawbacks that have been addressed among various researchers. The major constraint in the previous study is that commercial clays like kaolinite are used for the experiments (Acar & Alshawabkeh 1996), and they studied only individual contaminants (Gouri and Deepthy 2018). Thus, there is less knowledge of application of EKR on field soil with multiple contaminants (Al-Hamdan and Reddy 2006; Reddy et al. 2001). Other major limitation lies in the mechanism of EKR. The three essential processes cause accumulation of cations at cathode and anions at anode due to ion transport. Heavy metal ions and other cations are washed out of the soil with the effluent or deposited at or near the cathode due to the high pH conditions which obstruct their movement into the cathode compartment (Acar et al. 1993). Therefore, there is a need to develop certain processes to prevent precipitation such as, addition of acid to regulate the pH of cathode compartment. Besides, increase in hydrogen ions near anode limit the transport of other ionic species due to high ionic mobility of hydrogen. To overcome these limitations, it is essential to optimize the operating variables such as pH, processing fluid, voltage etc.

7.5 Enhancement and Optimization of EKR

Properties of the soil have a huge influence on EKR. Type of soil, soil composition, soil pH, and moisture content have been documented to impact the removal rates of heavy metal contaminants, as a result of pH change, hydrolysis, and oxidation-reduction reactions at the electrode compartments (Virkutyte et al. 2002). Apart from that, operating parameters such as type of electrodes, electrolytes composition and current density also influences the efficiency of electrokinetic remediation. Electrolyte solutions circulate through soil pore fluid during electrokinetic process, thereby governing the pH of soil. Various researchers have used different processing fluids as electrolytes to regulate the pH, increase conductivity and mobilize metal ions for their removal. Among them, mineral acids have shown the best results for metals like Cu, Pb, Cd and Zn where the removal efficiency is proved to be over 80% (Figueroa et al. 2016).

Electrodes like Graphite, titanium, gold, silver and platinum are the most appropriate electrodes for analysis as they resist anode dissolution (Virkutyte et al. 2002). Titanium alloy electrodes were used by Zhou et al. (2005) which showed higher electrolysis efficiency by titanium alloys when compared to other electrodes. For most soils, the distance between electrodes is maintained at 36 cm to increase cost effectiveness at it prevent soil overheating and shorten the duration of experiments (Virkutyte et al. 2002). However, the effect of changing the distance between electrodes revealed that maximum removal of heavy metals occurred when the distance between electrodes was 22 cm, except for Pb, which had the highest achievable removal occurred when distance was 14 cm (Johar and Embong 2015). The efficiency of electrokinetic remediation improves as the current density increases, which can be accomplished with increase in voltage gradient. Zhou et al. (2005) observed that copper ion transport and removal increased with increase in voltage. Increasing the current density, on the other hand, may result in higher energy costs (Wang et al. 2021). Wei et al. (2011) demonstrated the removal efficiency of cadmium at three different voltages 15, 25 and 35 V. It was concluded that 25 V was the optimized voltage at which maximum removal was achieved, by taking into account the type of soil, duration of treatment, and energy consumption.

To become more energy efficient, use of pulsating voltage instead of continuous was investigated by Mu'azu et al. (2016) that showed a significant decrease in the energy consumption. Zhou et al. (2018) compared the use of DC power with Solar Cells and concluded that the combination of solar energy with EKR is effective and feasible. Apart from adjusting the components of EKR, the efficiency can also be enhanced by coupling conventional techniques with EKR applications to overcome the limitations of the former. Studies have been carried out for EKR coupled with Bioleaching (Huang et al. 2015), Phytoremediation (Cameselle et al. 2013), and permeable membrane barriers (Virkutyte et al. 2002) for inorganic compounds; and Fenton's process and ultrasonication for organic compounds (Han et al. 2021). The coupling technique brings the advantage of both the processes and has proven to be more efficient in removing contaminants.

7.6 Conclusion

Soil pollution due to heavy metals is hazardous to the environment and human health. Therefore, adoption of an efficient treatment method is necessary to remediate such soil to sustain life on earth. EKR is an effective and sustainable technology for remediation of metal-contaminated soil. The major advantages of EKR over traditional methods are mentioned below:

- EKR is best suited to reclaim low permeable soils from organic and inorganic compounds over large areas in less duration. The use of low DC voltage is a cheaper alternative to transport and remove metal ions.
- During EKR, heavy metals get transfer to mobile phase, which is easy to treat following chemical precipitation, which is a cleaner approach since no secondary pollutants are formed.
- We can overcome the limitations of EKR by optimizing variables such as adjusting the pH of soil to avoid precipitation at cathode; adding suitable electrolytes to increase conductivity and moisture content of soil; and regulating voltage and current to maximize the removal efficiency.
- EKR can be optimized to become more energy efficient by using renewable sources such as solar cells, or by using pulsating voltage.

Thus, significant study should be conducted for analyzing and optimizing the operational factors to become successful in developing countries like India for the reclamation of heavy metal contaminated soil.

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Chapter 8
Eco-Restoration of Lakes and Water Sustainability in Urban Areas

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Abstract More than half of the world's population resides in urban and suburban areas. An increase in the rate of urbanization in recent years has put extreme pressure on the environment which has led to biodiversity loss and ecosystem degradation. The water bodies in urban areas have become primary source of sewage discharge which has led to poor water quality and issues like eutrophication. Therefore it is very crucial to maintain a healthy state of water bodies. The role of eco-restoration becomes critical in this regard. Eco-restoration techniques for improving the condition of water bodies across urban areas involve a mixture of physical (dredging, flushing, aeration, drainage etc.), chemical (clarification, adsorption, disinfection etc.) and biological (species management, microbial remediation, habitat restoration etc.) techniques which are implemented both within as well as outside the aquatic body. These practices are yet to be implemented more effectively in developing countries like India where the rate of urbanisation is fairly high. Eco-restoration holds key to treatment and reuse of water, thus, leading to water sustainability in urban areas. Further, such practices serve as primary solution for improving the health of water bodies which will not only help humanity to better adapt and respond to climate change but also in building a sustainable future.

Keywords Ecological restoration · Sustainable development · Lakes · Urban pollution

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8.1 Introduction

Humans have a close relation with nature. There has always been harmony between humans and nature which involves human beings following the laws of nature which prevent them from exploiting and degrading nature and its resources (Takeuchi 2010). Habitation is a basic need for human development. The places that were close to rivers and lakes were preferred for settlements by our ancestors. A major reason for this was crop cultivation. Development of any city highly depends on its rivers and lakes. The water from lakes aids in restoring groundwater aquifers and reducing the cases of droughts. Lakes provide shelter to many plants and animals which further provide food to many organisms (Natarajan et al. 2020). The relationship between cities and rivers is becoming complex day by day. Most of the lakes and ponds in urban areas are constructed manually. As a result, most of the urban water bodies have poor flow and low volume of water. Because of the poor structure and low maintenance of these water bodies coupled with poor self-purification capacity, the water quality keeps on deteriorating. It is very difficult for a water body to recover by itself once its quality has decreased (Cao 2020).

For people living in urban areas to have a good life, urban managers need to constantly purify the urban ecological environment. They also need to maintain small lakes and ponds (Natarajan et al. 2020). The development and restoration of urban water bodies not only helps in improving the economy but also improves the aesthetics of the city. Presently, the approach of restoration of water bodies in urban areas not only involves engineering techniques but also incorporates social, humanistic, and ecological concepts (Fang 2014). Proper planning of urban river channels can help cure the rivers while also contributing to the overall development of the city. Sustainable urban design focuses on the interaction between human's activities and their impact on the environment and then comes up with sustainable design structures that prevent the environment from degrading further. Due to climate change, cities need to have effective management designs to cope with future disasters. Conservation of water bodies and water cycle is very important to mitigate the harmful effects of climate change (Li et al. 2020). India is a country which is going through a period of transformation and development. This has increased the pressure on environment. Urban development has added to this pressure. As development of cities takes place, water quality is severely affected. The main reason for degradation of urban rivers is dumping of garbage, sewage discharge and industrial effluent in the water bodies (Pipil et al. 2021). This affects the physicochemical structure of the lake and also poses harm to the health of citizens. Since the last few years, the government has started to lay a lot of emphasis on urban water bodies and their conservation and restoration. The protection of native environment during implementation of eco restoration projects has also been prioritized by the government.

8.2 Sources of Contamination in Urban Water Bodies

Urban water bodies are being constantly degraded due to improper management and increased stress of high population. Urban water bodies are affected by five major problems. First, the problem of sediment pollution which enter by the erosion of soils, construction sites, urban land uses, airborne particulates, agricultural practices, and the weathering of rock (Williamson 1993; Pipil et al. 2022); second, pollution by heavy metals which increase greatly specifically from impervious sources such as roofs, pavements and roads (Shan et al. 2021). The main type of metal contaminants in waterways are copper, zinc, and lead but may also include other metals like nickel, arsenic, cadmium, chromium and mercury (Williamson 1993); third, semi volatile organic compounds which are emitted to the atmosphere from fossil fuel burning such as motor vehicle emissions and petroleum sources. They enter the urban water bodies as runoff from roads; fourth, nutrients which mainly include nitrogen and phosphorus which enter the water body from wastewater, from the breakdown of organic nitrogen in protein waste matter, the oxidation of the ammonia in urine, from detergents used in washing and laundering, and are also produced by organic breakdown (Nandakumar et al. 2019); fifth, pathogens such as faecal coliform which are a member of Escherichia coli (E. coli) which enter the water body either by attaching to soil particles or are freely suspended in water flow (Yeghiazarian et al. 2004). E. coli only indicates about the pathogenicity of water and is not a direct measure of disease causing organisms. The effect of pathogens on humans varies with the concentration and time of exposure and is generally not very harmful to most of the humans. Microorganisms can also cause groundwater pollution by seeping through the soil.

8.3 Techniques for Ecological Restoration of Lakes

Restoration of surface water bodies has been carried out in many countries by employing a mixture of various physical, chemical and biological techniques (Wu et al. 2001; Zheng et al. 2016; Liu et al. 2019). Before applying these techniques, the major pollutants present in the water body are identified along with their source. Restoration techniques are then employed to reduce their production rate which also involves treating the pollutants before they are released into the water body or directly by in-situ treatment in the aquatic body.

Table. 8.1 Physical techniques for ecological restoration of urban water bodies

S. No.	Restoration technique	Technical characteristics	Scope of application
1	**Dredging**	This method is effective in removing toxic sediments. It increases the depth of the water body along with reducing internal nutrient cycling.	Effective in removing bottom sediments of a water body.
2	**Flushing**	This technique reduces nutrients and chlorophyll content and makes the water body less turbid.	Effective in removing algae from the water body.
3	**Aeration**	This method helps in increasing the concentration of dissolved oxygen in lakes with anaerobic conditions.	Effective in improving overall quality of the water body.
4	**Drainage**	In this process, oxygen level is increased by pumping out oxygen-deficient bottom layer water by siphoning (Cachter 1976).	Effective in restoring eutrophic water bodies.
5	**River water supply**	In this method, water is supplied to the water body to improve its flow. Addition of extra water dilutes the pollutants in the water body and replenishes the water in river channels.	Effective in improving river water quality.
6	**Stabilization pond technology**	The technology consists of open basins which use natural low-lying land to excavate reservoirs.	Effective restoration technique to reduce pollution.
7	**Ecological bank protection**	This method uses boulders, stone crate tanks and aquatic vegetation to prevent erosion and promotes plant growth.	Effective method for water bodies with single habitat and low biodiversity.

8.3.1 Physical Techniques

Several physical techniques like dredging, flushing, aeration, stabilization pond technology, ecological bank protection etc. are employed for improving the water quality of the aquatic body by reducing the sediments, reducing the turbidity, removing excess nutrients, improving the flow of water and reducing the point and non-point source of pollution (Table 8.1). Physical techniques are often the first type of restoration techniques that are implemented during any ecological restoration project and are able to improve the water quality of the water body being restored with high efficiency.

8.3.2 Chemical Techniques

Chemical techniques involve various techniques that improve the physicochemical characteristics of the water body and are mostly used when the quality of water body has degraded immensely and immediate action is required for its restoration.

Table. 8.2 Chemical techniques for ecological restoration of urban water bodies

S. No.	Restoration technique	Technical characteristics	Scope of application
1	**Phosphorous removal**	Iron or alum salts are added in the water body which leads to formation of flocs leading to precipitation of phosphorus.	Effective for lakes with high eutrophication.
2	**Weeds and algae removal**	Weeds and algae are controlled by adding weedicides and algaecides in surface water bodies. Eg.-Atrazine, Fluoridone, Metribuzin WP, Glyphosate, Imazapyr etc. (Bhattacharya and Chakraborty 2019).	Effective for water bodies with high number of weeds and algae.
3	**Clarification**	This technique involves carrying out coagulation and flocculation and then employing clarification technique. Coagulants like alum are added to remove suspended and colloidal solids which also lead to formation of flocs. These flocs, after aggregation form larger flocs and settle at the bottom of a clarification tank which are later removed.	This process is very efficient for removing suspended solids, phosphorus, and organic matter from the water body.
4	**Adsorption**	Adsorption is done using activated carbon filters.	Effective in removing pollutants from the water body.
5	**Disinfection**	This process is carried out by adding chlorine or/and chloramines in water which kills the harmful microorganisms. Disinfection is also done by ozone and ultraviolet light.	Effective in killing microbes present in the water.

Techniques like adsorption, disinfection, clarification etc. are employed to regulate the concentration of certain chemicals in the water body. These techniques are effective in reducing the concentration of suspended solids, weeds, nutrients, phosphates and organic pollutants from the water body (Table 8.2).

8.3.3 Biological Techniques

Biological techniques are employed in addition to physical and chemical techniques to rapidly increase the species diversity in the water body. Techniques like species management, microbial remediation technology, habitat restoration technology etc. are employed which not only restore the habitats of organisms in the water body but also improve the structure and quality of water body by connecting several food chains with food webs (Table 8.3).

Table. 8.3 Biological techniques for ecological restoration of urban water bodies

S. No.	Restoration technique	Technical characteristics	Scope of application
1	**Biological treatment**	This process is carried out by using bio-filters, trickling filters, activated sludge processes (ASP), oxidation ditches, and rotating biological contactors (RBC). It removes 65% of volatile organic matter (Bhattacharya and Chakraborty 2019).	Suitable for improving the quality of water body.
2	**Species management**	Involves manipulating prey-predator relationships to control the population of harmful species e.g. zooplanktons are natural predators of algae.	It is important for habitat restoration.
3	**Microbial remediation technology**	It uses microbes to reduce pollutants concentration in the water body. It is a fast, easy and cost effective technique.	It is an efficient process for seriously polluted rivers.
4	**Habitat restoration technology**	Improves and repairs the habitats of aquatic species like fishes by repairing their spawning and feeding grounds. Fishways, deep trap-shoals, mounds and groins are constructed to improve the habitat.	It is efficient for water bodies with low biodiversity.
5	**Biological grid**	The water flow is reduced to provide a safe habitat for aquatic flora and fauna.	Suitable for habitat restoration.
6	**Vegetation restoration technology**	Introduction and adaptation of native resistant plants to revive the ecosystem functions; based on ecological principles.	It is suitable for river restoration.
7	**Revival of biological food chain**	This method is effective in restoring and connecting food chains to food webs and ensures a good habitat for microbes and fishes.	It is best fitted for water body restoration having low diversity.
8	**Fish restoration technology**	This method uses artificial fishing firewood and fish stocking to increase the habitat of fish and benthic organisms. This also helps in controlling algae and purifying the water body.	It is effective for the restoration of water bodies with low aquatic diversity.

8.4 Ecological Restoration Projects of Urban Water Bodies

River ecological restoration is a long and complex process. It starts from assessing the problems of the water body, planning and formulating the objectives for its restoration, implementation of various restoration techniques and finally evaluating the effect of restoration techniques by assessment of physicochemical and biological characteristics of the water body after equal intervals. The number of ecological restoration projects that have been carried out for water bodies in urban areas in different countries since the last decade have increased significantly and these projects have succeeded in improving the water quality and health of the respective water body. Four of these projects from countries like Japan, USA, South Korea and Scotland have been mentioned in Table 8.4 along with the pre and post-assessment water quality and biodiversity of the target water body.

Table. 8.4 Case studies of some restoration projects along with the pre and post-treatment water quality of the study area

Name of water body	Length/ catchment area	Techniques applied	Pre-treatment water quality	Post-treatment water quality	References
Izumi river, Japan	Length = 9.5 km	(a) River widening to increase the flow path, (b) Stabilization of slope and creation of green spaces in the river bank.	BOD = 10 ppm	BOD<5 ppm, detection of fishes like *Carassius* and Loach, appearance of 18 species of fish overall.	ARRN (2009)
Ythan river, Scotland	Catchment area = 680 km^2	(a) Removal of non-native conifer trees along the river bank, (b) Replanting native trees along the river and creation of buffer strips of 70 km along the river, (c) Flow diversification, bank stabilization using felled conifer trees, (d) Creation of pools using stones and boulders to create turbulence effects.	Algal cover = 31.4% in 2000, oxidized nitrogen = 2000 mg/L	Algal cover = 15% in 2003, decrease in orthophosphate concentration downstream, no increase in oxidized nitrogen levels.	Balls et al. (1995), OSPAR 2006 and Ythan project (2014)
Kissimmee river, USA	Catchment area = 7804 km^2	(a) Re-carving and reconnecting sections of the river destroyed during channelization, (b) Aeration.	DO = 2.3 ppm, Total phosphate = 170 ppb	DO = 4.9 ppm, Total phosphate = 12 ppb, increase in avifauna diversity, reduction in invasive fish population like bowfin and gar.	Colangelo and Jones (2005), Jones et al. (2012) and Colangelo (2014)

(continued)

Table. 8.4 (continued)

Name of water body	Length/ catchment area	Techniques applied	Pre-treatment water quality	Post-treatment water quality	References
Cheonggyecheon River, South Korea	Length = 10.92 km	(a) Redesign of urban stream after demolition of highway and construction of an embankment, (b) Controlling the flow of nutrients in the river by creating sewage lines, (c) Increase in the capacity of sewage treatment plant connected to the river.	Suspended solids >16 ppm, BOD >12 ppm, DO <4 ppm	Suspended solids <10 ppm, BOD <5 ppm, DO >6 ppm.	Hwang (2004) and Lee and Anderson (2013)

8.5 Conclusion

Based on the various eco-restoration techniques suggested for improving the health of urban water bodies and the case studies mentioned in that regard, the following conclusions are drawn:

- Eco-restoration can prove to be an effective management technique for improving the condition of urban water bodies. Several restoration techniques have been invented in the last few decades which are now being regularly implemented to improve the condition of water bodies especially in urban areas in many countries.
- To effectively implement these techniques in India, we need to gain knowledge about existing eco-restoration techniques being implemented around the globe and plan for socially, economically and ecologically sustainable development measures to maintain equilibrium between economic development and ecosystem.
- It is important to read about case studies from other countries while applying these techniques in India and plan an efficient and cost-efficient conservation and restoration network to minimize the negative effects of population growth.

We must continue to work towards our goal of a sustainable future and should learn from other countries since only by integrating all aspects of detail we can move forward to achieve our goal of sustainability.

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Chapter 9
Microplastics: Environmental Issues and Their Management

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Abstract Plastics are synthetic polymers designed as light weight, inexpensive as well as sturdy material. The application of plastic can be seen in almost all industrialized products. Applicability as well as rate of waste generation is increasing simultaneously. 380 million tonnes (MT) of plastic waste (PW) have been documented in the year 2015 instead of only 2MT in 1950. Central Pollution Control board had estimated 6.6 lack tonnes of PW generation in India in the year 2017–18. The capital of India, Delhi, alone contributes 690 tonnes per day. Nearly half of this remains uncollected. This uncollected PW get consumed by animal or burnt openly or clogs drainage and river system. This leads to starvation and many other adverse health impacts in animals, production of toxic gases or pollution of abiotic components and many more. Majority of this plastic waste is single used one. US National Oceanic and Atmospheric Administration (NOAA) has classified plastics in four categories based on their size: mega plastics (>1 m); macro plastics (<1 m), mesoplastics (<2.5 cm); and microplastics (<5 mm). On the basis of morphology, microplastics (MPs) are classified as "primary and secondary". "Primary" MPs also known as microbeads are one which have been manufactured (<5 mm) for their intended use in medicines and personal care products whereas "secondary" MPs are the result of weathering of primary larger size plastics. Microplastics are difficult to biodegrade and cannot be removed by conventional treatment methods. This results in accumulation of microplastics in water bodies. Accumulation of MPsin tissues can be found at almost all the trophic levels. No legal framework is in place for restrictive use of microplastics in India. This study will provide an overview of the current level of scientific work and knowledge on microplastic pollution in INDIA and will help to suggest the preventive measures for effective management of plastic waste.

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9.1 Introduction

Worldwide sharp growth has been observed in fabrication of plastic from two million tonnes (MT) to 380 MT from 1950 to 2015. Degradation process of plastic requires almost 50 decades; thus, their presence can be seen everywhere on earth crust in some or the other form. Recently Central Pollution Control Board (CPCB) evaluated Indian plastic waste (PW) generation as 660,788 tonnes (2017–18). This is only the half of total plastic waste production as still in many areas data related to this is not available. A study by CPCB on 60 major Indian cities evaluates around 4059 tonnes of PW generation per day in this peninsula. Indian capital Delhi alone is responsible for generation of 690 tonnes per day making this city topmost producer of PW (2017). Uncontrolled open dumping leads to 40% of this to remain uncollected. This uncollected PW get consumed by animal or burnt openly or clogs drainage and river system leading to Starvation or other adverse health impact in animals, production of toxic gases or pollution of abiotic components and many more. Unfortunately, a considerable amount of PW is single used. Federation of Indian Chambers of Commerce and Industry estimates growth of plastic processing to 22 MT per year by 2020 from 13.4 MT per year in 2015, nearly half of which will be single used.

Plastics are versatile material of synthetic long-chain polymers with low cost, lightweight, durable and recalcitrant properties. US National Oceanic and Atmospheric Administration (NOAA) classifies plastics on the basis of particle size into mega plastics with size more than 1 m, macro plastics with less than 1 m, meso-plastics less than 2.5 cm and microplastics less than 5 mm in size. Among all these categories micro plastics (MP) are considered as the most threatening one due to their tiny size and hence gaining importance in scientific world. On the basis of morphology, MPs are classified as “primary” and “secondary”. Primary MP also known as microbeads are one which have been manufactured (<5 mm) for their intended use in medicines and personal care products whereas secondary MPs are the result of weathering of primary larger sized plastics.

Plastics are synthesised to be durable. With time they only get fragmented to smaller and smaller pieces. Conventional treatment processes are not capable to restrict them, especially micro and nano size particles. Wastewater containing plastic particles less than 5 mm contaminates the receiving waterbody. Accumulation of these particles in different aquatic environment is thus a matter of concern. Studies report the presence of such particles in different trophic levels, such as zooplankton, marine lugworm, mussel, oyster, fish, sea turtles, dolphins, whales, and seabirds. Recent research found trace of MPs in human placenta. MPs as well as the additives used in plastic manufacturing can be bio accumulative and bio transitive. Many of these chemicals are known to be carcinogenic. Here this study will provide an overview of the current level of scientific work and knowledge on microplastic pollution in INDIA and will help to suggest the preventive measures for effective management of plastic waste.

9.2 Review of Literature

Being one of the most requisite commodities of today's life, the demand as well as production of plastic is observing a sharp growth from 230 million metric tonnes (Mt) in 2005 to 322 Mt in 2015. The rapid consumption of plastic goods especially single use one has become a matter of concern for waste management. Around 6300 Mt of plastic waste has been generated globally by 2015. Discharge of plastic waste in different water bodies leads to pollution of both water column as well as sediments (Zalasiewicz et al. 2016).

9.2.1 Sources of Microplastics

Nowadays almost everything comes in plastic packing, many of which may be multi layered. Online shipping in urban areas has increased this demand even more. Situation is such that, finding eco-friendly non plastic packing is challenging. Identified transmission pathways for terrestrial sources of micro plastics (MPs) comprises wastewater from daily use products like toothpaste, sun cream, shower gels, face wash, detergents etc. Cosmetic products majorly contain poly ethaline (PE). MPs are also considered as abrasive in domestic products. Paint flecks off the utensils can also be the source of MP (Anderson et al. 2017). Various industrial operations like air blasting are one of the well-known sources. Inadequate waste management practices, landfill leachates, flitting, loss of products from industrial and agricultural activities, wastewater treatment plant (WWTP) effluents, rainfall runoff are among the major contributors of terrestrial PW whereas accidental leakage from marine activities, commercial fishing etc. are among the major contributors of marine PW to the aquatic ecosystem. Marine sources contribute only 20% of plastic garbage whereas 80% of it is originated from terrestrial source (Andrady 2011).

Considerable number of studies have been conducted on special and temporal distribution of MPs in marine environment and their impact to the ecosystem. Though these studies have been majorly conducted in developed countries, still it gives a brief knowledge about overall problem associated to marine MP pollution. Studies on freshwater ecosystems are only one fifth of that of marine pollution. Though the work in the freshwater plastic pollution is limited yet it is comparable to marine contamination levels and the distribution is highly heterogeneous (Blettler et al. 2018). Plastic litter not only damages the aesthetic beauty of waterbodies but also known to causes loss of biodiversity and are capable of bioaccumulation and bio transmission to higher trophic levels.

9.2.2 Prevalence of Microplastics in Different Environment

The distribution of MPs shows clear geographical variations. Major natural forces like wind current and geographic circulation, turbulence and pelagic factors causes large scale distribution of PWs in dynamic riverine systems. Transmissibility of MPs also gets regulated by inherent properties like density, shape and size. These MPs of dynamic ecosystem gets transmitted and hence accumulated in marine environment. Natural weathering factors and long water residence time eminently affect quantity of microplastics in isolated waterbody like lakes (Free et al. 2014). Once plastic litter gets into an isolated environment, it gets accumulated and gets fragmented with time (Klein et al. 2018). Evidence of MPs have been seen all over the earth's crust including tropical areas (Nor and Obbard 2014); as well as "polar waters of Antarctica and Arctic" (Bergmann et al. 2015). MPs can be found in all parts of waterbody like surface water, water column, benthic zone of water bodies and beaches. Studies reported surface water concentration of MPs from 10^{-5} to 10^5 pieces/m^3 and 40 to 400 pieces/L in sediments (Desforges et al. 2014; Nor and Obbard 2014). Waterbodies close to densely populated areas report higher level of pollution (Eriksen et al. 2014).

Studies related to plastic pollution have been conducted mostly on surface water and beach sediments. As per the reports more than 100 different species have been entangled in various type of plastic waste ranging from plastic bags, bottles, packaging straps to fishing lines in oceans. Most common species include pinnipeds, sharks, grey seals, turtles, and seabirds (NOAA 2014). Similar type of plastic waste can often be seen in freshwater systems and soils including agricultural fields (Piehl et al. 2018), cities and industrialized areas (Fuller and Gautam 2016), and also in rather remote areas (Scheurer and Bigalke 2018). Once deposited at the soil surface via a variety of input routes, several pathways, including biological activity, contribute to the incorporation of microplastic particles into the soil (Huerta-Lwanga et al. 2017). The decomposition rate of microplastics in soil is currently unknown, and the assumption is that this material is persistent, and will thus accumulate.

Microscopic analysis of intestine reveals presence of MPs in different tropic level. Once MP is ingested, they may be bio-accumulated or excreted or may reach to body fluid as well as to tissues through assimilation. Microplastic particles of Polyvinyl chloride (PVC) and polystyrene (PS) of size 150 μm were found in the lymph and circulatory system of rodents and humans (Hussain and Jaitley 2001). More recently, particles were proved to interact with mammalian cells in the intestinal system (Carr et al. 2012). A new term "Plasticenta" has been introduced after a group of researchers found evidence of MPs in human placentas. Pigment identification reveals the source to be paints, adhesives, plasters, nail paints, beauty aids and toiletries (Ragusa et al. 2021).

Once these tiny particles have been ingested, they cause damage through various mode of action. Generally tiny plastic particles are ingested by aquatic animals or sea birds by mistaking them as food and hence get immured. Many chemicals and additives used in plastic manufacturing may prove to be toxic to biota and can interfere with endocrine systems. Pathogenic microbes also grow on plastic trash.

9.2.3 Degradation of Microplastics

Plastic gained popularity against other conventional material like glass or metal due to being durable, economic, low cost and lightweight. The durability property only leading to obnoxious present of it in almost all part of earth crust.

The rate at which plastics will degrade or exhibit tenacity in aqueous environment depends on various parameters like polymer type, manufacturing process, intended use, size, shape density etc. Physical factors like ambient temperature, solar radiation, oxidation or hydrolysis and microbes like *Bacillus cereus, Micrococcus sp., or Corynebacterium* are capable of degrading it but the process is very slow. Solar radiation makes plastic brittle, enhances weathering process and is known for yellowing of it. Wind and water current spread low density plastics across the environment. Degradation and weathering expose toxic chemical additives used during manufacturing process. These chemicals are capable of bio accumulation in aquatic animals (Teuten et al. 2009). Microplastics act as medium for accumulation of persistent organic pollutants (POPs). Consumption of POP containing microplastics by aquatic animals is a matter of concern (Lusher et al. 2017). Even at low concentration this POPs along with chemical additives pose threat to young animals as well as human beings (ATSDR 2015; GESAMP 2016).

Recently a species of bacterium have been found to be capable of degrading and assimilating polyethylene terephthalate (Yoshida et al. 2016). However, the biodegradation process gets adversely affected by lack of solar ultraviolet (UV)-radiation, decrease in temperature as well as availability of oxygen in the benthic zone. Less than ten percent (1–7%) weight reduction in a month has been observed for PE due to microbial degradation in deep sea condition (Harshvardhan and Jha 2013). Hence the category of polymers claimed as biodegradable cannot be converted to its simplest form efficiently.

9.2.4 Environmental Effects of Microplastics

Signs of plastic can be seen almost everywhere on the earth crust. Salt processed from sea water contains much more microplastics as compared to the same derived from lake water (Liua et al. 2018). Just like water even in soil crust plastic abundance is significant. Natural soil conditioner like sewage sludge or organic manure also contains microplastics. Plastic mulching or plastic contaminated fertilizer serves as source of plastic to soil and even to edible terrestrial plants (Nizzetto et al. 2016). Though there is undeniable chance of bioaccumulation of microplastics by higher plants, very limited research has taken place related to this field (Liua et al.

2018; Li et al. 2019a, b). Plastic impacts interaction of moisture with soil (evaporation, percolation) and hence can cause more pronounced drought effecting crop growth and production.

Just like marine animals, freshwater creature has also been reported to ingest tiny plastic particles by mistaking it as food. Intestinal presence of indigestible foreign particles causes starvation (digestive tract blockage and stomach lining damage), altering metabolic function, disrupting feeding and reduced and delayed reproductive ability, resulting into a lifespan reduction. On the other hand, injuries, stress, contaminant bioaccumulation of toxins (endocrine disrupting chemicals (EDCs), (POPs), pesticides), tumour formation, immune response malfunctioning makes the situation worse (Sanchez et al. 2014). The consumption of this aquatic contaminated organisms causes spread of MPs and toxins to higher organisms.

Reproduction process was affected in oysters due to two-month exposer to PS microplastics. Reduced number of female gametocyte production with decreased diameter and even lesser sperm velocity were reported (Sussarellu et al. 2016). Fish mainly ingests microplastics via predation activities. A negative correlation was observed on plastic ingestion and food consumption as well as fitness of the fish (Lusher et al. 2014). Bioaccumulation of PS in fish intestine and translocation of the same through blood have been observed in Fish (Chen et al. 2006). Through fish biotransformation takes place in higher tropic level species like seabirds, seals and sea lions. Ingested accumulated plastic causes reduced apatite hence loss of fitness in seabirds (Ryan 1987).

It is anticipated that chemicals used during manufacturing process of plastics (plasticizers, colorants, flame retardants, antimicrobials) get bio accumulated also in human. Presence of bisphenol A, poly-brominated diphenyl ethers, tetra-bromo-bisphenol A and phthalates have been documented in human body. Many of them are known for their endocrine disrupting properties (Talsness et al. 2009). A new term “Plasticenta” have been introduced after a group of researchers found evidence of MPs in human placentas. Out of the collected samples in 75% cases the MP (pigmented) particles were observed. Out of total 12 MP particles only 3 have been identified as polypropylene. Pigment identification reveals the source to be paints, adhesives, plasters, nail paints, beauty aids and toiletries. These foreign particles are known for causing immunoreactions once they reach the host tissues (Ragusa et al. 2021).

9.3 Indian Context of Microplastic Pollution

Study on microplastic pollution in different aquatic environment in India is scares. As per the current knowledge, some researches have taken place along the waste coast of India including a lake from Kerala. International studies have found microplastics in tap water and bottled water samples from various metropolitan cities in India. Illegal migration is a problem faced since the time of independence leading to informal settlement across major cities of India. Locations like river floodplains are most targeted illegal settlement zones. Open dumping of solid waste is one of the ill practices in major developing countries. Plastics get introduced to waterbodies from uncontrolled open dumping. Global model analysis of plastic pollution in different aquatic environment reveals that on one hand many big rivers (top twenty) of world are polluted by anthropogenic debris like plastics and on the other hand they are banking major inland fisheries. Major Indian Rivers including Ganga have been listed among these plastic polluted rivers (Lebreton et al. 2016). A National Institute of Oceanographic study (running) has found microplastics absorbed in fish tissues. Among various polymers of plastics Polyethylene (PE) and Polypropylene (PP) have been found widespread application in India. To meet the increasing demand, it be imported (PE from "major gulf countries, Korea, USA, Singapore, Thailand, Germany, Spain and Malaysia") or the excess raw material may be exported (PP to "China, Egypt, UAE, Turkey, Vietnam and Indonesia") (FICCI 2014). The import or export is carried out through sea routs. The following table represents the progress in scientific study on MPs in different Indian waterbodies. Figure 9.1 shows that very few research have taken place so far in India. This research works mainly focuses marine plastic pollution along some part of west and east coast. Work on plastic pollution in freshwater is a major gap. From the fig it can be observed clearly that whatever understanding we have developed about plastic pollution in this part of continent is along the coastline. Though the research is limited but then also it clearly signifies good abundance of plastic particle in all collected sample. Sensitive ecosystem like coral reefs is under threat. Bioaccumulation as well as toxic impact can be seen in in commercial shrimps or fishes which can easily translocate to higher tropic level. It is thus pressing priority to analyse the microplastic pollution in all aquatic environments and also to understand their impact on biota of this peninsular (Table 9.1).

9.4 Management of Plastics

After stone age and metal age the current era can be represented as plastic age due to its presence in almost all over the earth crust. Increasing population, industrialization, urbanization, on one hand and versatile application, durability on other hand led to increase in plastic usage many fold resulting in mammoth plastic waste accumulation. Majority of this are single used plastic. With the increase in online shopping trend the generation of plastic waste in the form of packing material has also increased. Contradict to other solid waste plastic is light as well as quite durable resulting increase in volume of solid waste. Being light in weight it gets transmitted easily. Like India many developing nations are struggling with increasing rate of solid waste generation due to growing rate of urban expansion, economic upturn and rise in community living standards. Low, middle-income countries on the other hand facing challenges to deal with this mammoth waste (majorly plastic) due to lack of financial support (United Nations Human Settlements Programme 2016) and the World Bank (Hoornweg and Bhada-Tata 2012).

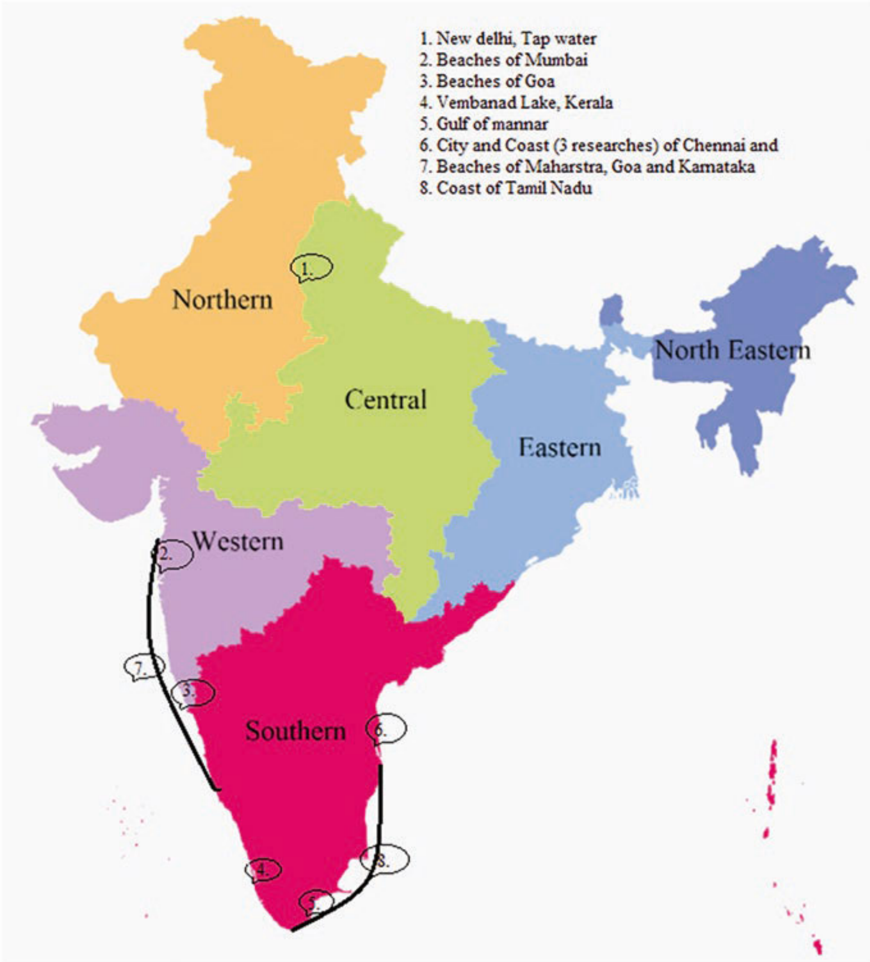

Fig. 9.1 Plastic pollution status in India

Terrestrial activity contributes 80% of the plastics available in sea (Jambeck et al. 2015). The land based plastic litters get transported to oceans by the means of riverine system. Natural phenomena like wind, tide waves, flood, tsunami etc. also contribute to this transmission in largescale (Veerasingam et al. 2016) resulting in increasing accumulation of plastic waste in landfill and natural environment. The conventional wastewater treatment process fail to restrain MPs due to their inert nature and very small size (<5 mm). When the treated effluent, rich in MPs, are discharged to large waterbodies they get contaminated with MPs and affect aquatic life gradually (Cheung and Fok 2016).

Major research has been taken place to evaluate special distribution as well as impact of MPs in marine environment. These researches have been conducted in

Table 9.1 Microplastic contamination reported in India

Location	Sample type	Predominant MPs	Source of Pollution	Concentration of pollutants	Remark	Environmental impact	References
Four beaches of Mumbai	Sediments	Not identified	Land-based sources mainly during recreational, religious and fishing	Mean abundance of 7.49 g and 68.83 items per square meter	Aksa, is isolated from the urban area, and found to have less contaminated compared to others.	High risk of ingestion by marine organisms	Jayasiri et al. (2013)
Six beaches of Goa	Sediments	PE and PP	Southwest monsoon carries MPPs to Goa beaches	Not determined	Southwest monsoon have been identified as main driving natural force	Not determined	Veerasingam et al. (2016)
Along the Chennai coast	Sediments	PE and PP	Rivers like "Cooum and Adyar" during flood. Northeast monsoon brings plastic particles through sea.	Not determined	The abundance of MPPs in November found to be three times higher than those found in March.	Not determined	Veerasingam et al. (2016)
Ten sites on Vembanad Lake	Sediments	Low density PE as dominant	Land-based sources	Nearly 100–500 particles per m2 with mean abundance of 252.80 ± 25.76 particles m_2.	Improper solid waste management leads to disposal hence accumulation of plastics waste in lake.	Extensive distribution of MPs in the lake, fish and clams cultivated in this polluted water considered as one of the major sources of protein by the locals	Sruthy and Ramasamy (2017)

(continued)

Table 9.1 (continued)

Location	Sample type	Predominant MPs	Source of Pollution	Concentration of pollutants	Remark	Environmental impact	References
New Delhi	Tap water, totally 17 samples	Not identified	Land-based sources	The range of plastic particles within all tap water samples was 0 to 57, with an overall mean of 4.34 plastic particles per liter of water. Out of total 17 samples 82% found to have contaminated by MPs.	Global study conducted on tap water in five countries including India. Totally 159 samples analysed, 83% of the tested sample contain plastic particles.	Prescribed quantity of liquid: 3 lit for adult male and 2.2 lit for adult female (National Academy of Medicine) resulting up to an annual consumption of MPs over 3000 to 4000.	Kosuth et al. (2017) "Orb media"
Coast of Chennai and Tinnakkara Island	Sediment	Not identified	Marin sources	Not determined	Chennai Cost has MPPs of longer residence time and may come from comparatively far away sources where as Tinnakkara Island has MPPs of shorter residence time and may come from nearby sources	Not determined	Mugilarasan et al. (2017)
Twenty locations along the coastal areas Rameswaram Island, Gulf of Mannar	Sediments	Dominant polymer PP followed by PE, PS, nylon, and PVC.	Tourist activities and fishing practices	Not determined	Max. microplastics population found during rainy season	Coral bleaching and tissue necrosis	Vidyasakar et al. (2018)

Location	Sample type	Predominant MPs	Source of Pollution	Concentration of pollutants	Remark	Environmental impact	References
Five coastal areas in Tamil Nadu	High and low-tide sediments.	PE, PP, nylon, PS and polyester	Land based activities like recreation, religious and fishing.	MPs abundance ranges between "439 ± 172 to 119 ± 72 (HT) and 179 ± 68 to 33 ± 30 (LT)" items kg − 1 of sediments.	MPs degradation makes them more suitable for toxic pollutants absorption.	Not determined	Sathish et al. (2019)
In and around Chennai city	Water from sea, underground, lake surface, can water (domestic) and branded drinking water.	Polyethylene terephthalate and polyamide.	Land-based sources (due to lack of proper waste management system).	Not determined	Heavy metals found to be adhered to MPs	MPs as environmental pollutants affecting surface water and groundwater.	Monnisha Ganesan et al. (2019)
Ten Study beaches of Maharashtra, Karnataka and Goa	Sediments	Microplastics >macroplastics >pellets. PE followed by PP,	Seasonal tourism-related activities as well as port and industrial activities,	"MPs (nearly 75 to 350) followed by macroplastics (nearly 50 to 200) and then pallets (nearly 45 to 250)".	On the basis of colour max abundance of "white-coloured plastics followed by pale-yellow, dark-brown, green, blue, transparent and red" were found	Lab experiment of PE microbeads exposer (72 h) showed toxic impact on shrimp	Maharana (2019)

PP (polypropylene), *PE* (polyethylene), *PS* (polystyrene), *PVC* (polyvinyl chloride) developed countries. It has been already well reported that major source of marine MPs pollution comes from inland plastic pollution through natural forces. Special distribution and impact of MPs pollution in freshwater ecosystem is gaining interest recently, hence the data related to the same is very limited. Inland fisheries of India have been ranked second in world after china. A detailed knowledge on impact of MP pollution in different aquatic environment of India is highly required.

Asia continent is one of the major plastic producers as well as consumer. Among various Asian countries India (14.17 Mt) stand 2nd after China (44.79 Mt). The per capita consumption of plastic in India (12 kg/capita/year) is only “1/10of US” and even less than “1/3 of China” but the amount of total consumption is accountable due to high population (Indian Council for Research on International Economic Relations 2018). Recent study shows that a considerable quantity (50–60%) of this consumed plastic get converted to waste (Ministry of Environment, Forests, Government of India 2015). On an average municipal solid waste comprises 10% plastic waste. This plastic waste generation shows an incising pattern in recent years. World Bank report provides a projected plastic waste generation rate to be doubled by 2025 in developing countries whereas this will show a decreasing pattern in developed countries (World Bank 2012). Industrialization and urbanisation not only responsible for generation of increases plastic waste but many developed countries also export their waste to developing or underdeveloped nations. This plastic waste is processed using cheap and low technology by having very little or no environmental control. India is among top 5 Asian countries importing plastic waste (167 kt in 2016) from developed countries like USA, Germany and many more. To handle this huge plastic waste in better way many Asian countries like China, Japan, India etc. has introduced regulatory norms. “In March 2019, India made two amendments to the Hazardous Waste” (Management and Transboundary Movement) “Rules, 2016, to impose a total ban on the import of plastic waste in all regions of India, including special economic zones and export-oriented areas” (Ministry of Environment, Forest and Climate Change 2018). A regulatory framework have been introduced in 2016 (Plastic Waste Management Rules) and have been amended in 2018. This framework laid vital role on informal sector and household for collection of segregated MSW resulting in collection of 50–80% of the generated plastic debris (Nandy et al. 2015).

9.5 Conclusion

From The Above discussion, it can be concluded that many regulatory steps have been taken to control generation as well as import of plastic waste and collection of the same. However, the following are the findings:

- The plastics finally find its way to landfills or many aquatic environments like lake, river and ponds where they get degraded and converted to micro plastics. The conventional treatment plants fail to trap these tiny particles. They get transported to oceans by rivers or wastewater treatment discharges. Some studies shows that more than 10 billion pieces of MPs per day get discharged through municipal WWTPs.

- Till date no legal restrictions have been posed on microbeads in India, although Bureau of Indian Standards (BIS) have notified microbeads as ‘not recognized as safe’ for cosmetic products.
- The knowledge on special and temporal distribution of plastic waste especially micro plastics in different aquatic environment in India is fragmented and limited. Information on source, transmission path, impact on biota is also very limited. Comprehensive study on this will help to draw a clear picture on problems related to plastic waste which in turn will assess in effective management of plastic waste.
- Recent technologies may guide the consumers to opt for plastic free products. Apps like “CodeCheck” for example simplify the identification of “hidden plastic” in our everyday lives.
- Model analysis on plastic waste emission shows that plastic pollution control is not only possible by proper waste management and legal restrictions but also innovative technologies need to be hand on hand to mitigate it. End of life plastic products need to be valued through circular economy by considering them resource material for construction sector. Fuel generation or energy production may also be considered as a viable option keeping the environmental impact in mind.
- Public awareness and acceptance of the ill effect of plastic waste will play an important role to eliminate the use of unnecessary plastics. Products need to be designed keeping recyclability in mind. Integrated plastic waste management need to be practiced for effective recovery of plastic waste.

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Chapter 10
Elucidating the Effect of Cement Dust on Selective Soil Parameters Around J&K Cements Limited, Khrew

Unsa Shabir and Nitish Kumar Sharma

Abstract The effect of cement dust has been a central role in orchestrating the soil characteristics and quality by changing the vital soil parameters. The aim of the present study was to elucidate the effect of cement dust on soil parameters- moisture content, pH, organic carbon and organic matter, electrical conductivity and exchangeable calcium and magnesium around Jammu and Kashmir Cements limited, Khrew. The present study analyzed the change in these soil parameters at the three sites under study indicating the adversity of cement dust pollution in effecting these parameters of soil. The results indicate that moisture content, pH, organic carbon and organic matter could be used as prime parameters that could be used to assess the quality of soil under the effect of cement dust.

Keywords Cement dust · Cement industry · JK cements limited- Khrew · Central pollution control board · Soil characteristics

10.1 Introduction

Cement industry has become a prime source of unbalancing the environment in one way or the other. Its pollutants not only affect the biological agents of the soil but also affect the physico-chemical properties of soil (Pareek and Pincha 2015). Cement industry has been listed as the 17th major environment polluting industry by Central pollution control board. The increased consumption of cement has led India to become the second largest manufacturer of cement following China, so far (Naqi and Jang 2019). Its processing produces dust and alkaline particulates as well

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as emission of gas like carbon dioxide, sulphur dioxide and nitrogen oxides (Farzadkia et al. 2016). The effect of cement dust on soil by various cement industries in Jammu and Kashmir has gained traction from the last 30 years. The most renowned cement plant in Kashmir under the brand name of Jammu and Kashmir cements Limited was set up in Khrew area of Kashmir with the daily production of 1200 tons of cement per day (Saunders and Magazine 2013).

As a result of increased demand of cement in the valley, more cement factories such as TCI, Dawar, Cemtac, Itifaq, Green valley were installed in Khrew area of Kashmir which produced the large amount of cement dust in the area. Large amount of cement dust are produced during the manufacturing step of cement, among which, bauxite (N2O3), clay, gypsum, limestone (CaCO3) and sandstone (SiO2) being the major raw materials used . The accumulation of dust pollutants on soil in particular deteriorates the quality of soil (Raja et al. 2015).

10.2 Materials Used along with Source

10.2.1 Permission

The study was approved by the competent authority of Chandigarh University, Gharaun, Punjab and SKUAST-K, J&K.

10.2.2 Study Area and Sites

The study area included three sites. Two sites (Site I and Site II) near JK Cements Ltd., Khrew area and one site (Site III) from Shalimar area of Srinagar. For comparative study, pollution free site (site III) at Shalimar area was taken as control site to remove any inconsistency.

Site-I was 1 km away from the JK cement plant, Site- II was in close proximity to the J&K Ltd. cement plant, While as, Site- III was in the Shalimar near Sher-e-Kashmir University of Agricultural And Sciences and Technology, Kashmir.

10.3 Methodology Followed for *Soil Analysis*

In the present investigation, surface soil samples up to a depth of 0–20 cm were obtained from three composite sites (site I, II and III), respectively, using soil corer and spread out on an aluminum tray. Prior to air drying, the un-decomposed residues such as root fragments, stones and coarse concretions were removed from the soil, after which, the soil samples were ground with mortar pestle and strained through a 2 mm sieve. The sieved soil was moved and preserved in airtight bags for further laboratory testing and analysis.

10.3.1 Soil Moisture Content

Water content of the soil is expressed as a ratio that can range from “completely dry” (zero) to the value of the porosity of the materials at saturation (Rowe 2018). It is critical for groundwater recharge, agriculture, and soil chemistry and plays an important role in determining soil quality. Moisture can come from a variety of sources, including adsorption on internal surfaces and capillary condensation in small pores. At low relative humidity, moisture is generally adsorbed water (Lunt et al. 2005). At higher relative humidity levels, liquid water, depending on pore size, becomes increasingly important. If the soil moisture content is optimal for plant growth, plants can readily absorb soil water and not have complete access to the water stored in the soil. Furthermore, a thin water film remains in the soil after a large amount of water has evaporated. The dissolution of salts by soil water forms the soil solution that marks the crucial step for delivering of nutrients to growing plants (Cobsy et al. 1984).

Therefore, the present study intended to find the soil moisture content in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, the percentage of moisture content of soil samples from a fresh composite was calculated on dry weight basis in the oven. 50 grams of composite soil samples were weighted using weighting bottles and transferred in autoclaved reagent bottle. The soil was dried in an oven at 105 C for 24 h until a uniform weight was achieved. Soil samples are weighed again after being cooled down using desiccators. Finally, percentage of moisture was calculated by subtracting the two weights. The following formula was used to calculate the percentage of moisture content:

$$\frac{(fresh\ soil\ weight)-(oven\ dried\ soil\ weight)}{weight\ of\ oven\ dried\ soil}\times 100$$

10.3.2 pH

Soil pH affects the amount of nutrients and chemicals soluble in soil water as well as amount of nutrients available to plants. In acidic environments, some nutrients are more readily available, while in alkaline environments, others are more readily available. Owing to the low pH, major part of nutrition of crops, their growth, and yield decline and these parameters increase when pH peaks to an optimum point (Seybold et al. 2018). Therefore, the present study intended to find the soil pH in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, the pH of the soil was determined using an electrometric method (McLean 1983). 10 gram of air dried soil was mixed with distilled water in 1: 2 ratio and mixed vigorously to make the soil suspension using stirrer at the regular intervals for 1 h. The soil pH was evaluated using a microprocessor based pH meter.

10.3.3 Soil Organic Carbon

According to Stockmann et al. (2015),the contribution of soil organic matter for retention of its nutrients and moisture, soil structure and turnover, its carbon sequestration and degradation of pollutants. Therefore, the present study intended to find the soil organic carbon in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, the soil organic carbon was measured using a titration method by Walkey and Black (1934). 0.50 g of soil sample which was air-dried was transferred in 500 ml flask which was conical. 10 ml 1N$K_2Cr_2O_7$, 20 ml H_2SO_4 was added to. The contents of the flask were swirled three to four times and set aside for half an hour. The flask was filled with 200 ml of distilled water and 1 ml diphenylamine indicator,10 ml orthophosphoric acid and 0.5 g sodium fluoride. Titration of the contents was done with 0.5 N (NH4)2Fe(SO4)2.6H2O. Change in color can be observed from blue to green. Similarly, blank was prepared which was made by distilled water. The formula given below was used was used to express the results:

$$\text{Percentage of Organic carbon} = N\frac{(B-C)}{weight\ of\ soil(g)}\times 0.003\times 100$$

Where,

N = Normality
B = Volume with blank
C = Volume with sample

10.3.4 Organic Matter

The ability to stock and supply basic nutrients (such as potassium, calcium, nitrogen, phosphorus and magnesium) and the retention of toxic elements is substantially increased in soil organic matter. It enables the soil to deal with its acidity changes and helps to decompose soil minerals faster (Lugato et al. 2021). Therefore, the present study intended to find the soil organic matter in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, the calculation for the percentage of organic matter was done as given below:

$$\text{Organic matter } \% = \text{estimated}\%\text{of organic carbon} \times 1.724$$

10.3.5 Electrical Conductivity

The electrical conductivity (EC) of the soil is used to calculate the amount of salts in it (salinity of soil). It's a vital method to estimate the health of the soil (Smith and Doran 1997). Therefore, the present study intended to find the soil electrical conductivity in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, soil electrical conductivity was assessed using a digital conductivity meter. Following a 20-min warm-up period, the digital conductivity meter was calibrated with 0.01 M KCl solution and rinsed with distilled water before adding the sample and setting the temperature and cell constants. The conductivity of the sample was measured in μ S/cm after it was dipped in the conductivity cell and connected to the meter.

10.3.6 Exchangeable Calcium and Magnesium

The cation exchange capacity is a measurement of the ability to hold positively charged ions (CEC). It is a soil that is critical to the soil structure's stability and availability. CEC's main ions in soils are the calcium (Ca^{2+}) and magnesium (Mg^{2+}) exchangeable cations and they are usually called the base cations (Khorshidi and Lu 2017). When soils become more acidic, these cations are replaced by H+, Al3+, and Mn2+, and common methods produce CEC values that are much higher than in the soil (field). Low CEC soils are more prone to cation deficiencies such as potassium (K+), magnesium (Mg2+), and other cations, while high CEC soils are less susceptible to cation leaching(Bache 1976).

Therefore, the present study intended to find the soil exchangeable calcium and magnesium in determining the effect of cement dust around the three specific study sites (Site I, II and III).

In the present study, 25 mL aliquot was mixed with 0.5 mL ammonium hydroxide buffer and 3–4 drops eriochrome Black –Tin an Erlenmeyer flask. After that, a titration against 0.01 N EDTA was carried out until a blue colour appeared as the end point. The following formulas were used to calculate the calcium and magnesium concentrations:

$$(\mathrm{Ca}+\mathrm{Mg})\,\mathrm{or\,Meq\,Ca\,/\,litre} = \frac{T \times Normality\ of\ EDTA \times 1000}{Aliquote(ml)\,taken}$$

Where T = volume of standard EDTA used in titration in millimeters.

$$(\mathrm{ca}+\mathrm{Mg})\,\mathrm{or\,Meq\,Ca\,per\,100\,g\,soil} = \frac{1000}{soil\ weight} \times \frac{100exact\ volume(ml)}{1000} \times MegCa\ or\ Ca + Mg\,/\,litre$$

Where volume of extract = 25 ml.

10.4 Statistical Analysis

All the statistical analyses of the collected data from the study and control sites were done using MS-excel 2007. The results were outlined as mean value.

10.5 Results

The findings on soil parameters -moisture content, pH, organic carbon and organic matter are described as:

Table 10.1 shows the depiction of moisture content of soil at different study sites. The analysis of the present study showed that the moisture content was highest at control site (site III) as compared to site II, the closest site from the cement factory.

Table 10.2 depicts the soil pH at different study sites. pH at the control site was acidic in nature as compared to sites, I and II which varied from neutral to alkaline nature.

Table 10.3 depicts the % of soil organic carbon at various sites of study. Soil organic carbon % was high at control site and low at site II, the closest vicinity from the factory site, respectively.

Table 10.4 depicts the organic matter % of soil at various sites of study. Organic matter of soil was high at control site and low at site II, the closest vicinity from the factory site, respectively.

Table 10.1 Representation of soil moisture content at three study sites

Sites	R1	R2	R3	Mean
Site 1	26.83	26.49%	25.5%	26.27%
Site 2	23.08%	21.09%	22.4%	22.19%
Site 3	30.6%	31.86%	30.05%	30.83%

Table 10.2 Representation of Soil pH at three study sites

Sites	R1	R2	R3	Mean
Site 1	6.95	7.01	6.89	6.95
Site 2	7.2	7.18	7.15	7.17
Site 3	6.1	6.09	6.07	6.08

Table 10.3 Representation of soil organic carbon % at three study sites

Sites	R1	R2	R3	Mean
Site 1	1.79	1.84	1.75	1.793
Site 2	1.42	1.51	1.43	1.453
Site 3	2.32	2.12	2.53	2.323

Table 10.4 Representation of soil organic matter % at three different study sites

Sites	R1	R2	R3	Mean
Site 1	3.085	3.172	3.017	3.091
Site 2	2.44	2.603	2.465	2.502
Site 3	3.99	3.654	4.361	4.001

Table 10.5 Representation of soil electrical conductivity at three study sites

Sites	R1	R2	R3	Mean
Site 1	0.553	0.534	0.562	0.549
Site 2	0.673	0.622	0.619	0.638
Site 3	0.234	0.213	0.241	0.229

The electrical conductivity dS/m of soil at various study sites is shown in Table 10.5. As we moved away from the cement factory, the current study's analysis revealed a decreasing trend. Site 2, which was close to the cement plant, had the highest value of soil electrical conductivity. At site 3, a control site, the lowest value has been found, indicating a large amount of cement dust on the top soil surrounding the cement factory.

Table 10.6 shows the exchangeable calcium and magnesium in the soil at different study locations. The value of exchangeable calcium decreases as we get further away from the cement factory. Site 2, which is located 1 km from the cement factory, has the highest calcium value. Its mean value (me/100gm) is 20.16. With a mean value of 13.35 (me/100gm), site 3, a control site in Kashmir's Shalimar region, had the lowest calcium value. According to the analysis, the value of calcium decreases as we move away from the cement factory site. However, the value of magnesium can be exchanged in the following table. At site 2, 1 km away from the cement factory, the highest value of magnesium was determined with a mean value of 5.42 (me/100gm), while on site 3, a control site within the Shalimar region with a mean value of 2.83 (me/100gm), the lowest value was found. The analysis shows that the value of magnesium continues to decrease as we move away from the cement factory.

Table 10.6 Representation of Soil exchangeable calcium and magnesium at different study sites

Sites	R1	R2	R3	Mean
Soil exchangeable calcium				
Site 1	19.41	19.23	19.12	19.25
Site 2	20.30	20.08	20.10	20.16
Site 3	13.5	13.27	13.30	13.35
Soil exchangeable magnesium				
Site 1	4.54	4.26	4.13	4.31
Site 2	5.50	5.34	5.42	5.42
Site 3	2.79	2.83	2.89	2.83

10.6 Discussion

In the present study, moisture content was highest at control site (site III) as compared to site II, the closest site from the cement factory which showed that soil quality with respect to moisture content is affected near the factory site. The results of the current study are in accord with the study conducted by Lamare and Singh (2020) reported the highest moisture content at control site and low moisture content around the cement factory, concluding that the emission of cement dust worsens the moisture content of the soil.

Soil pH at the control site was acidic in nature as compared to sites, I and II which varied from neutral to alkaline nature. Mandre et al. (1998) reported an elevation in pH in soil around the cement plant. Brady et al. (2010) showed the less pH i.e., slightly alkaline at the control site which was mainly due to the release of organic acid and decomposition of organic matter. From the above discussion it can be concluded that the acid neutralizing compounds present in cement dust elevates higher pH of the soil like gypsum and lime, therefore, affecting soil quality.

As Organic soil substances contribute to the retention of nutrients, soil structure, moisture retention and availability, pollutant degradation and the sequestration of carbon, therefore, in the present study, soil organic carbon % was high at control site and low at site II, the closest vicinity from the factory site. Similar results were reported by Lamare and Singh (2020) in which soil organic carbon percentage was lower in the vicinity and higher at the control site. Hence it can be concluded that change in the pH from high to low has worsened the quality of soil near the factory site.

Organic matter of soil was high at control site and low at site II, the closest vicinity from the factory site, respectively. The results of the study conducted are in contradiction with the study conducted by Asadu and Agada (2008) in which the soil organic matter was reported as low at control site as compared to the affected soil site showing the over enrichment of organic matter near the cement factory site. The results of the present are contradictory with the study conducted above. The present study showed the depletion in the soil organic matter in association with the low pH which might have contributed to the worsening of the soil quality near the factory site.

In this study, the conductivity of the soil at site II was the highest in comparison with the other two locations and on site III was low which means that the soil was more saline or the soil salinity near the factory site was high as compared to the other two sites. Moreover, the studies on electrical conductivity are very scarce. Lamare and Singh (2020), showed SEC levels closest to the factory site are higher than the control site and reported similar results. Hence, it can be concluded from the above discussion that increase in the electrical conductivity of the soil near the factory site worsens the soil quality, respectively.

The soil samples obtained during the period of the study showed more exchangeable calcium levels than the control site due to the accumulation of cement dust. The exchangeable calcium and exchangeable magnesium at contaminated sites have improved optimistically. Site II and site III showed higher exchangeable calcium content at the contaminated site and lower. In the soils around the cement factory, the highest calcium levels are attributed to the deposition of cement-containing calcium oxide. Similar patterns were found for exchangeable magnesium with a highest mean value at most contaminated site value of 5.42 (me/100gm) and the lowest mean value at control site 2.83 (me/100gm). In the contaminated sites as a result of cement factory emissions, higher levels of exchangeable magnesium were therefore found. Ibanga et al. (2008)found that exchangeable calcium and magnesium levels in surface soil near a cement factory were moderate to high. Hence, it can be concluded that change in the levels of exchangeable calcium and magnesium has been compromised near the factory sites.

10.7 Conclusion

In the light of the increasing number of cement factories in the Kashmir valley and their environmental effects, the present study entitled "Elucidating the effect of cement dust on selective soil parameters around J&K cements limited, Khrew". From the present study, it can be concluded that that these soil parameters explain the enormity of the cement dust pollution on soil moisture content, pH, electrical conductivity , exchangeable calcium magnesium and soil carbon and organic matter around J&K cements, Khrew. However, these parameters could also be used to evaluate soil quality by cement dust as indicative parameter.

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Chapter 11
Development of Correlation Between Ultrasonic Pulse Velocity and Rebound Hammer Test Results for Condition Assessment of Concrete Structures for Sustainable Infrastructure Development

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Abstract Condition Assessment of a structure is an important aspect for Sustainable Infrastructure Development to ensure its durability. Concrete structures around the world face a threat to their adequate structural and functional performance due to aging infrastructure, carbon dioxide penetration in the old infrastructure made of low-grade concrete. Increase in demolition and construction waste due to inadequate monitoring and maintenance of structures is another concern to environment if it is going directly to the landfill. Investigations on the concrete elements can be done using various non-destructive (NDT) and destructive (DT) methods. The Rebound Hammer (RH) and Ultrasonic Pulse Velocity (UPV) test NDT techniques are often used to assess concrete quality and service life. In the current study, experimental studies have been conducted to estimate the concrete compressive strength (CS) using the above test methods and a mathematical correlation has also been developed between their test results using linear regression analysis. Comparison has also been done on accuracy of correlation parameters using these two test results and that of the Combined Nondestructive Examination. i.e., the UPV Test and the RH Test.

Keywords Sustainable Infrastructure Development · Rebound hammer · Condition assessment · Ultrasonic pulse velocity

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11.1 Introduction

Concrete is used to construct various structures, such as high-rise building, bridges, water restrain structure etc., due to demolish of this structure the constructional waste are increase in environment and occupying the lands, these are the major concern around the world (Hong et al. 2015).

The amount of Carbon dioxide (CO_2) and humidity are increasing in atmosphere, due to the environmental pollution. These pollutants are penetrating in the concrete at later stage and form voids, cracks and other deterioration (Hamidian et al. 2012).

The durability of concrete plays an important role for the serviceability of Reinforced Concrete (RCC) structure. The service life of concrete can be improved by adding the superplasticizers based chemical admixture and supplementary cementing materials based mineral admixture. The Impermeability of concrete, abrasion resistance, and resistance to chloride ion transport, can also be improved.

There is a crucial issue to do the structural health monitoring without destruction the concrete structure. The UPV and RH test methods are the nondestructive test methods commonly used to evaluate the concrete quality. The accuracy of this NDT approach has been established in the past using a relationship between UPV and RH findings as well as their correlation with the destructive compressive test method as per IS method (Hamidian et al. 2012).

The current study comprises of experimental estimate of the concrete CS using the compressive test method and the NDT methods as discussed above. A mathematical correlation has also been developed between their test results using linear regression analysis. Comparison has also been done on accuracy of correlation parameters using these two test results and that of the Combined Nondestructive Examination. i.e., the UPV and the RH Test.

11.2 Material and Methodology

11.2.1 Cement (PPC)

Ultratech Portland Pozzolana Cement (PPC) Fly ash based conforming to IS 1489: 2015 (Part1) were used in concrete. The physical characteristics of the PPC are given in Table 11.1.

Table 11.1 PPC physical characteristics

Sl No.	Properties	Examination values	
1	Specific Gravity (SG)	3.15	
2	Normal Consistency (%)	33	
3	Initial Setting Time (Min)	65	
4	Final Setting time (Min)	340	
5	Compressive Strength (MPa)	72 h	29.7
		168 h	46.3
		672 h	55.8

Source: Author

11.2.2 Coarse Aggregate (CA)

The crushed stone aggregate was used conforming to IS 383: 2016, with a maximum size of 20 mm and 12.5 mm with SG of 2.74. The 20 mm and 12.5 mm size coarse aggregate was mixed with the ratio of 60% and 40% at the time of concrete cube casting.

11.2.3 Fine Aggregate (FA)

Natural sand from the Ghaggar River in Chandigarh, having a SG of 2.65, was used to confirm with IS 383: 2016 Zone II.

11.2.4 Water

The portable water used for mixing and curing the concrete sample is colourless, odourless, tasteless, and free of organic debris.

11.2.5 Mineral Admixture (MA)

ALCCOFINE 1203 is used as a mineral admixture as conform to IRC SP: 70, IS 456-2000, IS 12089-1987. ALCCOFINE 1203 is a product of slag-based mineral admixture with a high glass content and low calcium silicate concentration. Table 11.2 presents the physicochemical and molecular characteristics of ALCCOFINE 1203.

Table 11.2 Physicochemical characteristics of ALCCOFINE 1203

Molecular characteristics		Physical composition	
Ingredients	Configuration (Wt. %)	Properties	Outcomes
Iron oxide (Fe_2O_3)	1.20	Specific gravity	2.8
Sulphur trioxide (SO_3)	0.13	Average particle size	5
Silica (SiO_2)	35.3	Bulk Density (Kg/m^3)	640
Magnesia (MgO)	8.20		
Alumina (Al_2O_3)	21.4	Fineness (cm^2/gm)	12000
Calcium oxide (CaO)	32.2		

Source: UltraTech Cement

11.2.6 Chemical Admixture

Sika ViscoCrete-3110 is a concrete superplasticizer based on polycarboxylate of the third generation. It has a high level of impermeability, a high level of water reduction, and great flowability, leading to low placement and compressing effort.

11.3 Method

11.3.1 Mix Design

In the present experimental work, proportion for high performance concrete mix design of M50, M60 and M70 were carried out according to IS 10262: 2019 recommendations. The mix proportion are presented in Table 11.3.

Slump test, flow table test, and compaction factor test with the prescribed water/cement ratio can all be used to determine the workability of fresh concrete. The cubes are cast on the standard specimen of size 150 mm × 150 mm × 150 mm. After 24 h, the cube specimens are demolded as shown in Fig. 11.1. Demolded cube specimens are water cured for 28 days as shown in Fig. 11.2, before being assessed in terms of CS test as per IS 516 (Part 1/Sec 1): 2021, UPV as per IS 516 (Part 5/Sec 1): 2018 and RN as per IS 516 (Part 5/Sec 4): 2020.

11.4 Result & Discussion

Tables 11.4, 11.5 and 11.6 show the CS, RH, and UPV results of M50, M60 and M70 grade concrete after 7, 14, 21, and 28 days of curing.

The M50, M60 and M70 grade concrete results are correlated in M.S. Excel Software and the different linear regression graph are shown in below (Figs. 11.3, 11.4 and 11.5).

Table 11.3 Proportion of concrete mixes and ratio

Mix & compositions	PPC (Kg/m^3)	ALCCOFINE (Kg/m^3)	Water (Litter/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	Superplasticizer (litter/m^3)
Mix50	410	45.6	141	631	1255	6.84
Ratio	1	0.12	0.344	1.54	3.06	0.017
Mix60	423	47	141	623	1251	7.05
Ratio	1	0.11	0.33	1.47	2.96	0.0016
Mix70	448	49.8	131	614	1271	9.12
Ratio	1	0.11	0.2924	1.37	2.83	0.0204

Source: Author

Fig. 11.1 Demolded cube specimens. (Source Author)

Fig. 11.2 Concrete cubes in curing. (Source Author)

Table 11.4 Result of M50 Grade concrete

Days	Crushing strength (N/mm^2)	Rebound number (RN)	UPV (Km/s)
7	42.96	32.26	4.13
14	51.13	35.65	4.41
21	56.34	36.23	4.66
28	59.04	37.37	5.12

Source: Author

Table 11.5 Result of M60 Grade concrete

Days	Crushing strength (N/mm^2)	Rebound number (RN)	UPV (Km/s)
7	49.68	37.13	4.34
14	62.79	43.35	4.76
21	66.24	47.13	4.91
28	68.31	49.06	5.41

Source: Author

Table 11.6 Result of M70 Grade concrete

Days	Crushing strength (N/mm^2)	Rebound number (RN)	UPV (Km/s)
7	54.80	40.15	4.57
14	75.95	46.57	5.16
21	80.05	50.34	5.43
28	82.28	52.62	5.73

Source: Author

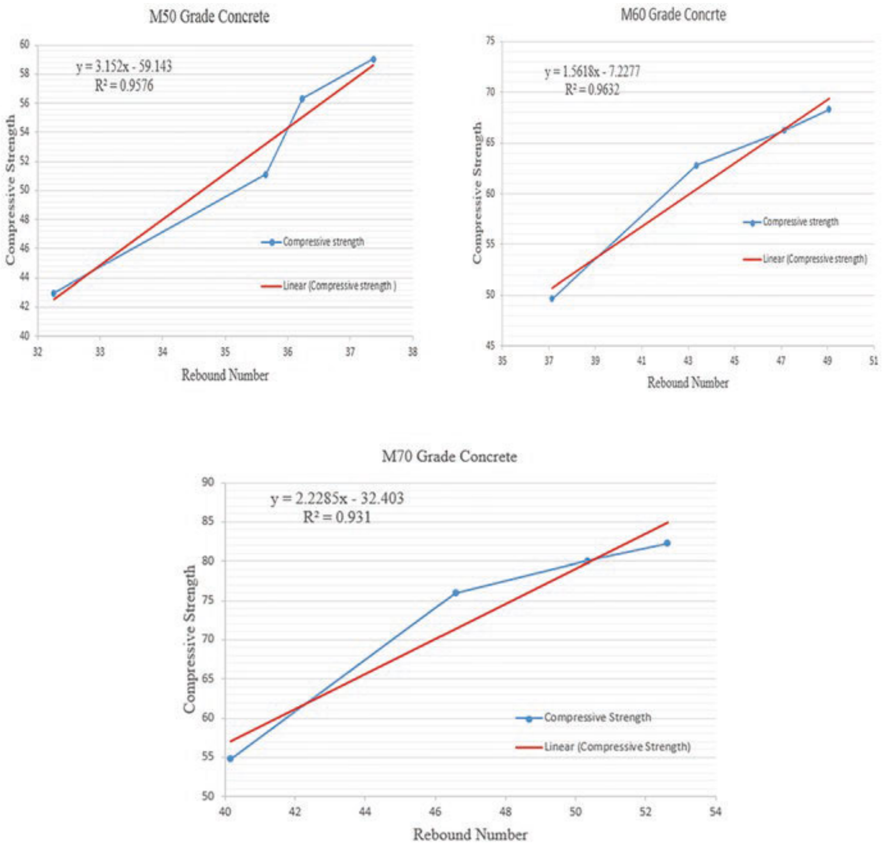

Fig. 11.3 Linear regression relation between CS and RN. (Source Author)

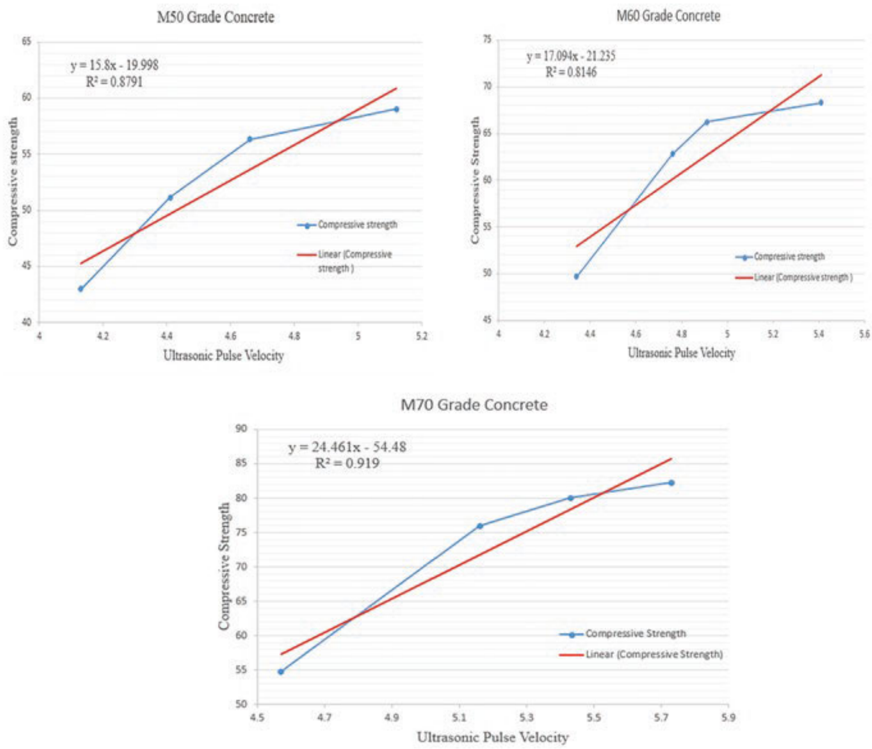

Fig. 11.4 Linear regression relation between CS and UPV. (Source Author)

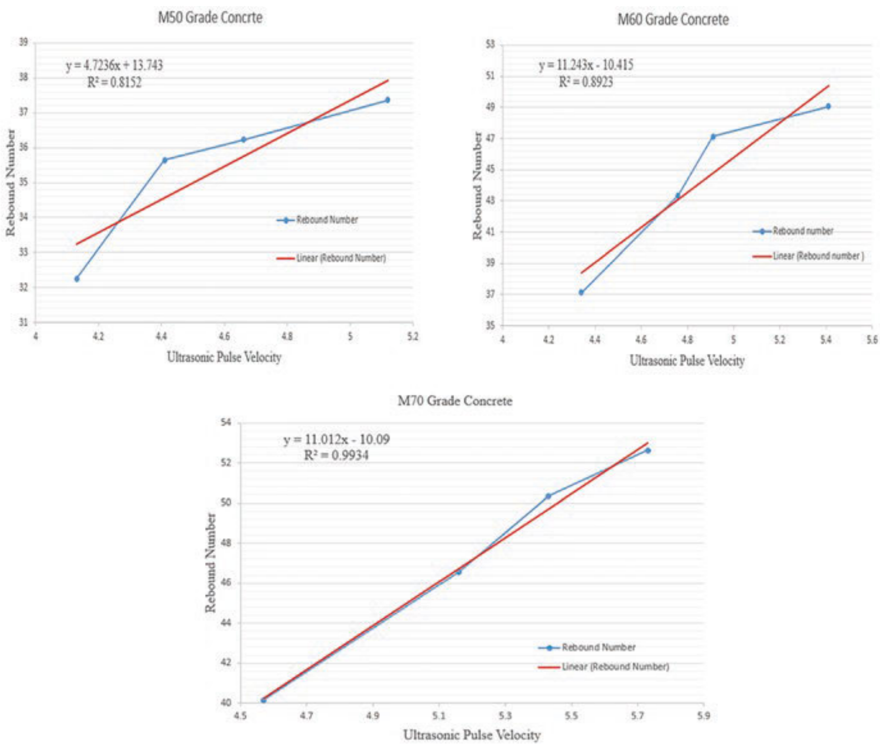

Fig. 11.5 Linear regression relation between RN and UPV. (Source Author)

Table 11.7 Linear correlation result from graph

Concrete grade	Graph	R- square value	Significance value	Linear equation
M50	CS Vs RN	0.958	0.0214	y = 3.152x − 59.143
	CS Vs UPV	0.879	0.0624	y = 15.8x − 19.998
	RN Vs UPV	0.815	0.0971	y = 4.7236x + 13.743
M60	CS Vs RN	0.963	0.0186	y = 1.5618x − 7.2277
	CS Vs UPV	0.815	0.0975	y = 17.094x − 21.235
	RN Vs UPV	0.892	0.0554	y = 11.243x − 10.415
M70	CS Vs RN	0.931	0.0351	y = 2.2285x − 32.403
	CS Vs UPV	0.919	0.0413	y = 24.461x − 54.48
	RN Vs UPV	0.993	0.0033	y = 11.012x − 10.09

Source: Author

The above figures are show the linear regression of M50, M60 and M70 grade concrete mix design. From the Table 11.7, the significance and R Square value of M50 and M60 grade concrete is showing an extremely strong correlation between the CS and RN. But in case of M70 grade concrete the RN and UPV is revealing an extremely strong correlation. The combined NDT test is providing better correlation in M70 grade concrete, but the RH is offering accurate CS in M50 and M60 grade concrete.

11.5 Conclusion

- The RH and UPV instrument are helpful in predicting CS for structural health monitoring.
- The RH and UP test results is providing 95% accuracy for calculating the CS of concrete.
- In M50 and M60 grade concrete, the CS test results have a stronger correlation with the RN.
- The linear regression analysis between CS and RNs presenting significance value of 0.021 and 0.018 for M50 and M60 grade concrete, respectively.
- The combined NDT test result is showing a significance value of 0.0033 for M70 grade concrete.

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Chapter 12
Alternative Fine Aggregates to Produce Sustainable Self Compacting Concrete: A Review

Mohammad Faisal Bazaz, Aditya Punia, and Sanjay K. Sharma

Abstract Self-compacting concrete (SCC), because of its magnificent fresh and hardened properties, is widely used around the world. Continuous increase in construction activities lead to enormous depletion of exhaustible resources and now the industry is on the verge of recognising the worth of such limited exhaustible resources. The disposal of some waste products into the land, on the other hand, leads to environmental imbalance. As a result of these factors, the approach to sustainable construction is becoming more prominent. As a result, researchers have performed experimental investigations into the feasibility of alternative fine aggregates (AFA) as a replacement for river sand in order to promote sustainable development and safeguard the environment. This paper provides a comprehensive overview of alternate sand's physical characteristics, as well as their impact on SCC's fresh and hardened properties. The use of AFA contributes significantly to the reduction of environmental pollution by lowering carbon dioxide emissions. SCC production costs are also reduced by using alternative fines. As a result, this paper seeks to give useful and important information on the subject, as well as a platform for new scholars to conduct future SCC research.

Keywords Alternative fines · Self-compacting concrete · Filling ability · Sustainable development · Manufactured sand

12.1 Introduction

Self-compacting concrete (SCC) has been termed "the most important development in concrete construction." Although, it was designed to address a growing shortage of skilled labour and deal with inefficient compaction, it has turned out to be profitable due to a variety of factors, including excellent segregation resistance and fluidity, increased durability, greater design freedom, faster construction, easier

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placement, less manpower, superior surface finish, and no need for specialised equipment. SCC was developed in Japan in 1986 for the first time, and its ability to self-consolidate and flow was partly attributable to the early development of superplasticizers (Okamura 1997; Okamura and Ouchi 2003).

Aggregates account for around 60–70% of the total volume in SCC. Self-compacting concrete's fresh and hardened qualities are mostly determined by the aggregates, therefore choosing right aggregates is crucial. The effects of fine aggregate texture and shapes are more significant as compared to that of coarse aggregate (Nanthagopalan and Santhanam 2011). One of the factors that can affect the flowability of SCC is poor aggregate gradation. This difficulty could be overcome by using inert and reactive fillers (Aijaz et al. 2014).

Over the last few decades, the rapid rise of construction has resulted in a massive spending on naturally occurring resources for concrete manufacturing (Bounedjema et al. 2017). As a result, the availability of these natural elements is becoming increasingly limited. The withdrawal of river sand, which accounts for around 35% of concrete volume, has major environmental repercussions, thus it is urgent to reduce its use and explore other possibilities (Mundra et al. 2016). Crushed Rock Sand (CRS), Recycled Fine Aggregates (RFA), and Industrial by-products are examples of alternative fine aggregates. These alternative fines can be employed as a full or partial substitute for river sand, resulting in two benefits: conservation of natural resources and mitigating environmental issues (Singh et al. 2018; Su et al. (2001).

12.2 Alternative Fine Aggregates

Crushed rock sand (CRS) is a feasible substitute to river sand and it also reduce waste disposal problem (Nanthagopalan and Santhanam 2011). Crushed rock sand is manufactured by crushing the quarried stone to a particle size less than 4.75 mm. Sridharan et al. (2006) observed that 20–25% of the entire production is left out as waste-quarry dust in each crusher unit in India. This waste problem may be overcome as it can be effectively used in concrete fabrication. The distinct roots from which CRS is manufactured are granite, limestone, sandstone, diorite, metamorphic siltstone, etc. Crushed rock sand is obtained by the sieving of crushed rock aggregates having different mineralogical configuration (Bonavetti and Irassar 1994). CRS is refined by crushing, screening, and shaping along with washing into ultimate products. The properties rely on parent rock fracture mode, composition, manufacturing process, location and nearby climatic condition. It also depends upon type of the crushing process like vertical shaft impact, impact crusher, etc. (Srivastava and Singh 2020).

Recycled fine aggregates, obtained from recycling of mineral scrap material, are produced mainly from C&D waste (Kou and Poon 2009a, b, c). Massive volume of construction and demolition (C&D) waste is generated every season and its disposition has turned into a serious environmental and social complication (Ji et al. 2013; Zhao et al. 2015). Reclaiming of this waste construction material is tempting as

Table 12.1 Physical properties of CRS

Author	Specific gravity	Fineness modulus	Water absorption (%)
Jadhav and Kulkarni (2013)	2.84	2.84	5.6
Nanthagopalan and Santhanam (2011)	2.65	–	1.0
Bouziani (2013)	2.7	2.14	5.71
Ding et al. (2016)	2.72	3.34	0.7
Bounedjema et al. (2017)	2.62	2.97	–
Wang et al. (2020)	2.61	3.33	–

Table 12.2 Physical properties of RFA

Author	Bulk density (kg/m^3)	Water absorption (%)	Fineness modulus	Specific gravity
Kirthika et al. (2020)	2690	10.61	2.83	2.51
Behera et al. (2019)	1260	11.5	2.56	2.1
Exteberria et al. (2013)	2010	13.1	–	–
Kou and Poon (2009a, b, c)	2300	11.86	–	–
Pan et al. (2017)	2640	4.35	2.8	–
Seung-Tae Lee (2009)	–	6.59	2.89	2.39
Stefanidou et al. (2014)	2450	8.0	4.97	–

compared to the use of exhaustible assets. The leading sources of RFA are bricks, concrete, bitumen, glass, etc. Recycled concrete fine aggregates are of poor calibre because of which they require some treatment to enhance their quality and escalate employment of the same (Kumar et al. 2019). As per the articles of researchers, RFA requires higher percentage of SP than river sand because of dust and old adhered mortar present in it (Singh et al. 2018).

Physical properties of several alternative fine aggregates play a key role in defining their behaviour and should be studied. Tables 12.1 and 12.2 show the physical parameters of crushed rock sand (CRS) and recycled fine aggregates (RFA).

12.3 Properties in Fresh State

12.3.1 Filling Ability

Filling ability which determines self-compacting ability of a concrete, depends mostly on particle shape and micro-roughness, but proportion of fines and clay lumps also makes significant effect. Crushed rock sand would possibly increase the water demand (Mahalakshmi and Khed 2020; Shen et al. 2018). A graphical representation showing the slump flow variation by different researchers is given in Fig. 12.1.

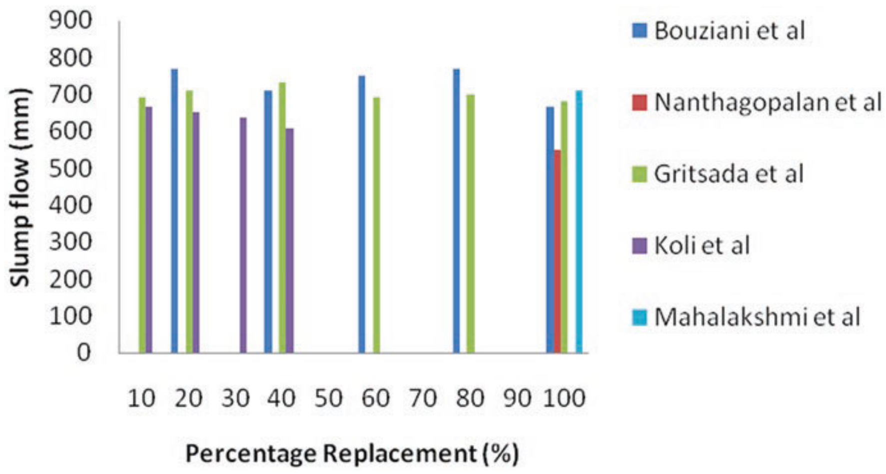

Fig. 12.1 Slump Flow variation of CRS

Tayeb Bouziani (2013) observed higher value of slump flow up to 80% CRS substitution possibly because of improved workability due to proper blending of particles with river sand. However, at complete replacement of natural sand, 11% reduction was reported which could be ascribed to the irregular shape of CRS particles and the excessive fines present in it. There was 13% increase in the slump flow at 60% substitution of crushed limestone sand while at 100% replacement of river sand, only 2.9% reduction was reported. The improvement in the slump value is attributable to the smooth texture and spherical shape of limestone particles (Sua-iam and Makul 2013). Utilisation of crushed rock sand up to 65% resulted in much higher slump flow of 845 mm which was counteracted by addition of certain percentage of limestone fines. This gives an idea that the incorporation of limestone fines has a positive effect on SCC which is mainly due to the increase in water demand of limestone fines (Benyamina et al. 2019). Similarly, Koli and Gundakalle (2016) developed SCC with different percentages of crushed rock sand and found that slump flow value declined as the replacement percentage of CRS is raised. This is so because of rough and angular shape of CRS and also due to the presence of more fines in the concrete that reduces flowability. Nanthagopalan and Santhanam (2011) reported that excess paste volume is required to achieve higher slump flow. Complete replacement of RS by CRS was beneficial for SCC as it contains higher proportion of fines, but it may result in increased water demand. Similar experimental investigations were reported where complete replacement of river sand by M-sand resulted in the slump flow of 708 mm (Mahalakshmi and Khed 2020). Also, incorporation of crushed rock sand by 25% along-with 30% fly ash as SCM lead to an increase in the slump flow by 20 mm (Güneyisi et al. 2012).

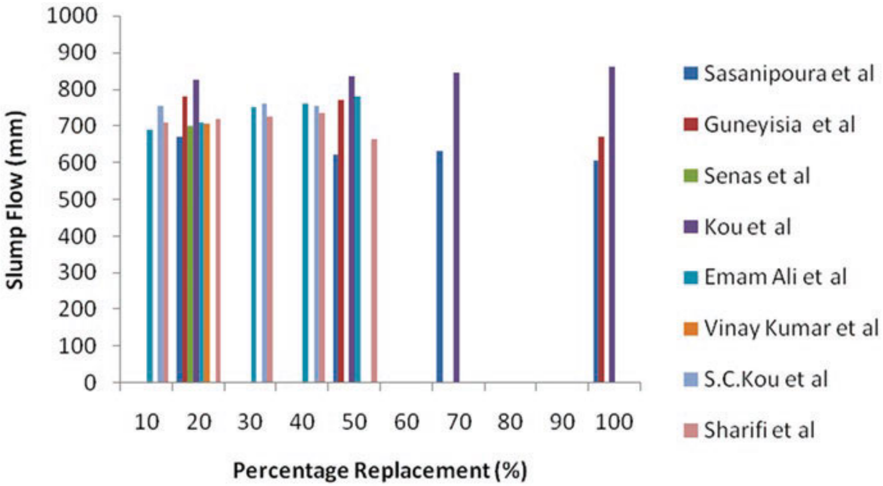

Fig. 12.2 Slump flow variation for RFA

Different types of recycled fines have different impact on the filling ability of SCC as shown in Fig. 12.2. It was observed that addition of recycled glass enhanced the filling ability while recycled concrete aggregates showed opposite effect. SCC made with recycled glass showed high flowability even at low dosage of super plasticizer. The continuous increase in the slump flow is due to finer particles of glass which contribute in filling most of the voids and also due to low water absorption of recycled glass particles (Emam and Al-tersawy 2012; Mahalakshmi and Khed 2020). Smooth surface of recycled glass aggregate was the factor found to be responsible for positive results (Güneyisi et al. 2016). Kou and Poon (2009a, b, c) developed SCC with 0%, 25%, 50%, 75% and 100% recycled aggregates and found the slump value increasing continuously up to 100% replacement. The higher water requirement of recycled aggregates increased the flow as some portion of water is available for increasing the flowability. Similar results were reported by Guneyisi et al. (2016) while varying proportions of RFA were utilised and the slump value increased continuously. With the increase in % of RFA, the slump flow remained more or less the same with reference to the control mix (Señas et al. 2016; Kou and Poon 2009a, b, c).

The slump flow of concrete decreased with the addition of recycled fine aggregate on account of uneven surface texture because of the old mortar adhered to the surface. There was 10% reduction in passing ability when natural sand was replaced from 25% to 100% (Sasanipour and Aslani 2020). The addition of recycled fine aggregates up to 20% in SCC showed slump value similar to reference SCC beyond which further increase in replacement of fine aggregates caused significant drop in slump value. It was noticed that SCC with 100% replacement failed to maintain the flowability characteristic after 45 min (Gesoglu et al. 2015). Slump flow time was also observed to reduce on account of addition of recycled fine aggregates

(Carro-lópez et al. 2015). Lopez et al. 2017 developed SCC with 0%, 20%, 50% and 100% recycled sand and found that the complete replacement of natural sand leads to segregation. Further, he reported that sample with 100% replacement by RFA loses it flowability after 90 min. Kumar et al. (2017) designed concrete with 20% recycled fine aggregates and reported that the inclusion of RFA decreases the filling ability slightly when compared to reference concrete.

12.3.2 Passing Ability

The major factors governing the passing ability of SCC are particle shape, powder content and water absorption of aggregate. The fine content in CRS leads to an increase in paste volume due to which the aggregates scatter systematically and thus concrete passes through the bars without clogging of the aggregates (Nanthagopalan and Santhanam 2011). Mahalakshmi and Khed 2020 reported an enhancement in the passing ability with the L-box ratio being 0.86. Similarly, Benyamina et al. (2019) found that the replacement of natural sand by crushed sand till 65% showed high L-Box values. The clayey particles present in fine aggregate increases the water demand and thus reduces the passing ability as indicated by the lower L Box value (Bouziani 2013; Sua-iam and Makul 2013; Shen et al. 2016; Shen et al. 2018). The incorporation of crushed sand up to 30% in the concrete mixture yielded satisfactory results beyond which passing ability decreases (Koli and Gundakalle 2016). Bouziani (2013) reported that the L Box ratio declined after 80% substitution of crushed rock sand due to the excess clay particles present in it. The angular shape and rough texture of crushed rock sand was found to be responsible for increasing the frictional resistance in paste volume and thus restrict the passing ability of concrete.

Incorporating recycled fine aggregates up to 100% in concrete keeps on enhancing the passing ability of SCC (Kumar et al. 2017; Koli and Gundakalle 2016). Kou and Poon (2009a, b, c) used recycled glass in SCC and found that the blocking ratios varied from 0.84 to 0.87 which means that the samples achieved adequate passing ability. Similar results were also reported by Sharifi et al. (2013) where the L-Box ratio was reported to decrease with the increase in proportion of recycled glass. The ratio went from 0.94 to 0.82 showing a decrease in passing ability despite satisfying EFNARC guidelines. The reason for low value is due to sharp particles of glass which makes it problematic to pass through the reinforcement bars (Mahalakshmi and Khed 2020). The L-Box ratio (H2/H1) decreased with the rise in the % amount of recycled fine aggregates. At 0% addition of RFA, the H2/H1 ratio was around 0.91 and at 20%, 50% and 100%, the ratio dropped down to 0.85, 0.90 and 0.78 respectively. Blockage at neck was observed when recycled fine aggregate percentage exceeded 50% (Kou and Poon 2009a, b, c).

12.4 Properties in Hardened State

12.4.1 Compressive Strength

Compressive strength is markedly affiliated to surface morphology of crushed rock sand particles (Shen et al. 2018). Powerful paste-fine aggregate interface and the inherent strength of CRS particles result in increased compressive strength (Donza et al. 2002). It was reported that an increase of around 12% occurred when the natural river sand was entirely replaced by crushed rock sand with the possible reason being the presence of greater quantity of fines and angular shape of CRS particles (Bouziani 2013). At complete replacement of RS by CRS, when SCC was designed for M-20 grade, the strength was found to be 23.56 MPa. Similarly, for M-40 grade and M-30 grade, compressive strength was reported as 46.25 MPa and 37.25 MPa respectively (Hameed et al. 2012). A rise in the value of compressive strength was seen with the addition of 65% crushed rock sand. The developed SCC had a compressive strength of 72 MPa at 28 days. However, addition of limestone fines as filler may lead to an increase in the early day's strength (Benyamina et al. 2019).

Compressive strength of SCC is affected by water cement ratio. At 100 percent substitution by CRS, the results determine that at lower water cement ratio, the strength was reported to be higher. At 0.7 w/c (without VMA), the compressive strength reported was 60 MPa and at 1.2 w/c (with VMA), the compressive strength was 25 MPa (Nanthagopalan and Santhanam 2011).

With 25% replacement of crushed rock sand, strength of around 58 MPa was reported. However, with the addition of 5% limestone filler and 30% fly ash in place of cement, the compressive strength was reported to increase up to 64 MPa (Güneyisi et al. 2012).

Compressive strength enhanced with 10% addition of limestone fine as natural sand replacement. The strength at 100% natural sand came out to be 65 MPa while at 10% LS, it came out to be 67.5 MPa showing an increase of 3.85%. However, the strength was observed to be decreasing with further addition of LS. The increase in strength is due to fine particles of limestone which act as fillers and helps in enhancing the microstructure while as further increase of limestone particles do not contribute to the filler effect and hence strength value decreases (Sua-iam and Makul 2013).

A continuous improvement in strength was reported with the addition of CRS up to 40%. Strength gain of around 6.51% was recorded at 30% CRS substitution after which a slight decrease in strength occurred at 40% CRS. The strength gain may be due to better interlocking of CRS particles within concrete matrix (Koli and Gundakalle 2016). SCC designed for 40 MPa gave a compressive strength of 44.50 MPa when river sand is completely replaced by M-sand. Figure 12.3 shows a graph which compares strength ratio for different CRS.

The elements that influence the strength of self-consolidating concrete are the type of aggregate employed, water cement ratio and dosage of silica fume (Gesoglu et al. 2015). The replacement of the natural fine aggregates with recycled fine

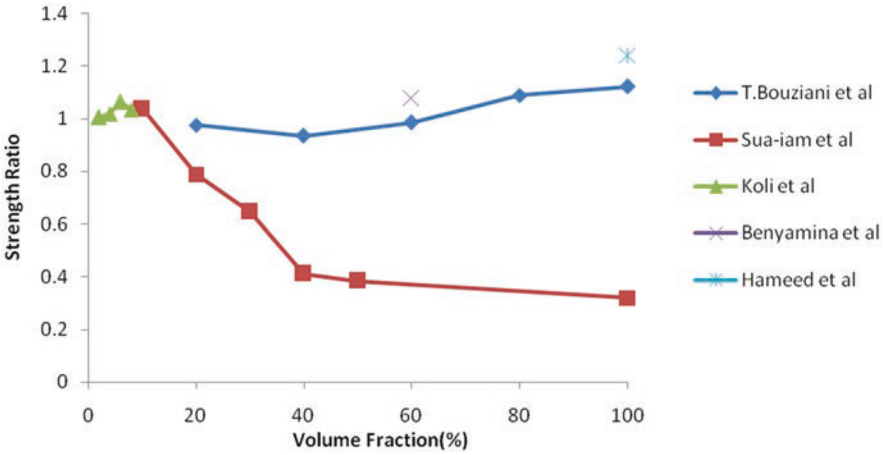

Fig. 12.3 Graphical representation of variation in compressive strength of CRS

aggregates shows a decline in compressive strength (Gesoglu et al. 2015; Sasanipour and Aslani 2020). It was observed by Sasanipour and Aslani (2020) that as the percentage of recycled fine aggregate increases, the strength drops significantly. Around 52% reduction in strength occurred due to substitution of 75% of recycled fine aggregates. The possible reason for inferior results is the old mortar adhered to the surface which reduces quality of ITZ. When the self-compacting concrete is formed with full substitution of fine aggregate by recycled aggregates, the strength was found to decrease by 15.8–26.9%. The lower strength demonstrated by recycled aggregates is because of low quality of ITZ between the recycled aggregates and cement matrix. Further, it was observed that low water binder ratio and silica fume compensates the drop in strength upto certain percentage (Gesoglu et al. 2015). The compressive strength decreased by 5% on account of additional use of 20% recycled fine aggregates (Señas et al. 2016). Kou and Poon (2009a, b, c) formed SCC with different portion of recycled fine aggregate and found that upto 50% addition of RFA, the strength does not seem to be affected. For 75 and 100% replacement ratio, strength was observed to decrease by 10%. Addition of fly ash proves to be beneficial as the reduction in strength is further decreased because of the pozzolanic reactivity. Compressive strength was found to be 5% higher for SCC with 20% recycled fine aggregate when compared with control mixture (Kumar et al. 2017). With the addition of recycled glass of varying percentage, the compressive strength was found to decrease by 6%, 10.4%, 12.7%, 17.5% and 23.5% at 10%, 20%, 30%, 40% and 50% substitution respectively (Emam and Al-tersawy 2012). Kou and Poon (2009a, b, c) added glass waste in SCC in the proportion 15%, 30% and 45%

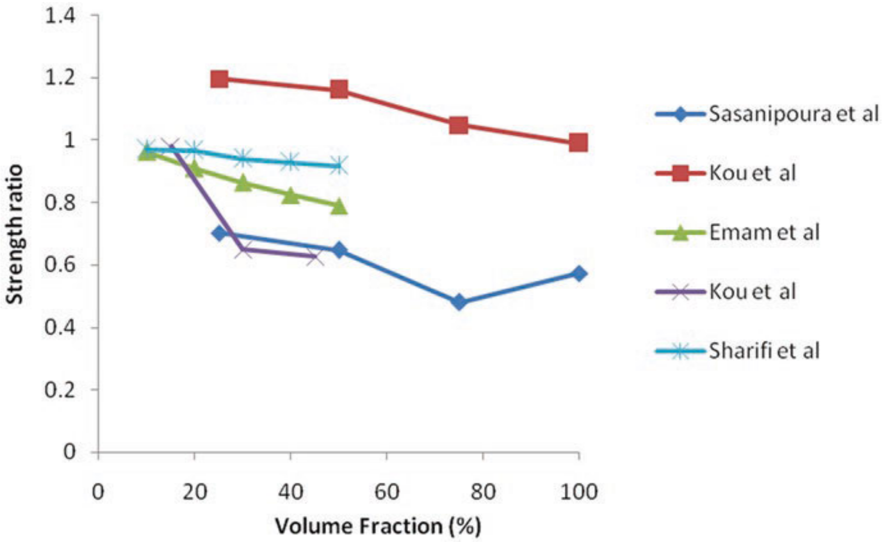

Fig. 12.4 Variation of Compressive strength with increasing percentage of RFA

and observed reduction of 1.5%, 4.2% and 8.5% respectively. The possible mechanism could be weak bonding between recycled glass waste and cement matrix (Emam and Al-tersawy 2012; Kou and Poon 2009a, b, c). On increasing the percentage of recycled waste glass, compressive strength declined due to weak adhesion (Mahalakshmi and Khed 2020). The variation of compressive strength with varying percentage of RFA is shown in Fig. 12.4.

12.4.2 Splitting Tensile Strength

Slight decrease in tensile strength was observed at 100% replacement of river sand. For M20 grade, the splitting tensile strength was found to be 2.85 MPa and for M30 and M40 grade, it was 3.15 MPa and 3.85 MPa respectively. Thesubstitution of river sand with 85% crushed rock sand and 15% MSP yielded better results (Hameed et al. 2012). 90 days splitting tensile strength of the SCC developed by 25% incorporation of crushed rock sand was reported to be approximately 4.0 MPa. Further, with the incorporation of 30% fly ash and 5% limestone filler, the strength increased by around 17.5%, i.e., 4.7 MPa (Güneyisi et al. 2012).

It was observed that the replacement of natural aggregates with recycled fines reduces the splitting tensile strength, but with lesser magnitude than compressive strength (Sasanipour and Aslani 2020). Concrete mixture with 100% recycled fine aggregates showed minimum strength when compared to other replacement ratios. The strength was found to decrease by 19.5% in comparison to normal concrete (Gesoglu et al. 2015). The tensile strength was found to decrease by 11% when recycled fine aggregates are added in SCC (Kou and Poon 2009a, b, c). Further, the samples with fly ash showed much higher strength than control mixture. Kumar et al. (2017) designed SCC with 20% FRA and reported 18% increase in tensile strength when compared to natural aggregate SCC. A decrease in the pattern of strength was noticed with the inclusion of recycled fine glass in SCC. The values decreased by 10.6%, 10.6%, 12.7%, 17% and 23.4% at 10%, 20%, 30%, 40% and 50% RFA substitution respectively. The splitting tensile strength was found to decrease by 11.5% due to the replacement of naturally available fine aggregates with glass waste. The reason could be increase of fineness modulus of fine aggregates that decreases the density and poor bonding among recycled glass fine and cement matrix (Emam and Al-tersawy 2012; Kou and Poon 2009a, b, c). With increasing percentage of recycled waste glass, the strength increased initially up to 20% replacement and then decreased. The possible decrease is due to reduction in density of SCC (Mahalakshmi and Khed 2020). The variation of splitting tensile strength with varying percentage of RFA is shown in Fig. 12.5.

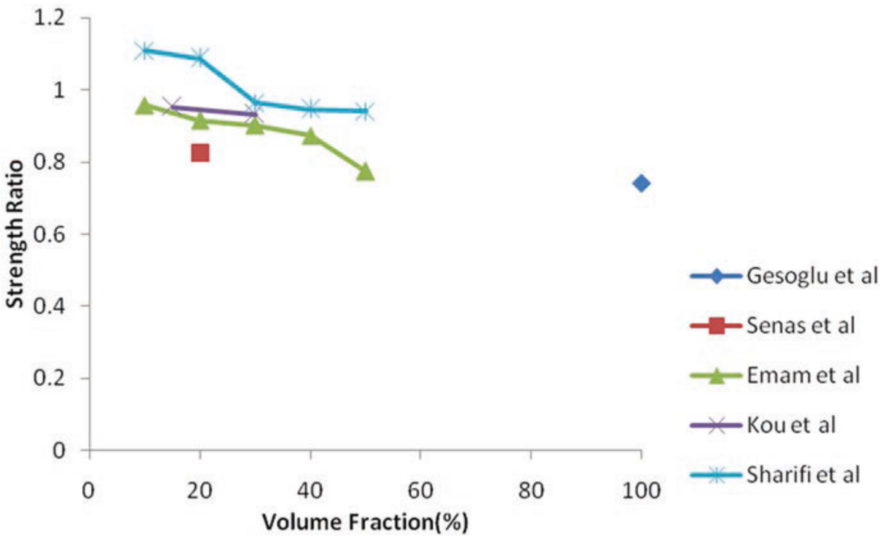

Fig. 12.5 Variation in splitting tensile strength with increasing percentage of RFA

12.4.3 *Flexural Strength*

With the substitution of crushed rock sand to 65%, 28 days flexural strength was found to be around 2.4 MPa. The addition of limestone filler decreased the flexural strength, but their incorporation led to an increase in the initial day's strength (Benyamina et al. 2019). Up to 30% substitution of CRS in SCC, the flexural strength was found to enhance by 8.60% after which a marginal decrease was noticed. The reason for increase in flexural strength may be because of the collaborative effect of improved interlocking and gradation of CRS particles (Koli and Gundakalle 2016).

Reduction in flexural strength was recorded by the inclusion of recycled aggregates. It was observed that strength decreases up to 20.3 to 27% with complete substitution of natural fine aggregates in SCC. The possible explanation for poor performance is the use of low quality of aggregates. It was further concluded that strength can be enhanced provided that recycled aggregates are taken from high strength concrete compared to reference mixture (Gesoglu et al. 2015). Addition of silica fume in self-compacting concrete improves the flexural strength of concrete (Emam and Al-tersawy 2012). Addition of recycled glass waste up to 10% resulted in marginal increase of flexural strength due to the fact that small volume of glass makes a better adhesion with glass and cement paste after which decrease in strength was reported. The decrease is because of high smoothness of glass which lowers the bond strength (Mahalakshmi and Khed 2020).

12.5 Discussion

Different alternative fines can be utilised as an alternative for river sand in sustainable and environmentally friendly construction. Waste materials from construction and demolition projects can be recovered and used as fine aggregate. This study assesses prior findings on the replacement of natural river sand with AFA, demonstrating that using these helps to maintain environmental balance while also increasing the qualities of SCC up to a certain substitution ratio.

12.5.1 *Current Challenges*

Although there are a variety of alternative fines that can be used effectively in SCC, there are a number of obstacles that prevent its widespread use. Studies reflect that at same replacement ratio, variation in engineering properties occur due to lack of command on composition and quality of alternative fines. Improper gradation and presence of impurities (particularly in CRS) leads to negative impacts at higher replacement levels of alternative fines. Removal of old adhered mortar from recycled fine aggregates is still a challenge as it needs to be cost effective. Because of a lack of government support and public awareness, there has been insufficient research in this sector.

12.5.2 Research Gaps

Following research gaps have been identified for further research based on the literature review:

- A thorough investigation into the use of alternate fines in SCC.
- Establishment of a common proportioning procedure for various fines.
- Cost-effective treatment process for recycled fine aggregates to lower the percentage of water absorption and remove old-adhered mortar.
- A study related to processes that control gradation and shape of CRS particles.
- Additional research into the durability qualities of alternate fines and their impact on SCC is required.

12.6 Conclusion

While there has been a lot of research into the use of AFA in conventional concrete, there are just a few examples of it being used in SCC. The following conclusions are reached as a result of the review work:

1. The physical characteristics of crushed rock sand are similar with natural river sand. Basalt and dolomite have high specific gravity which gives demonstrates the presence of coarser particles. Further, dolomite and limestone crushed sand contain excessive fines and result in higher water demand.
2. Specific gravity of recycled fine aggregate is less than that of normal fine aggregate on account of the presence of old-adhered mortar. RFA is porous and thus has high water absorbing potential. However, pre-treatment of RFA can decrease water absorption due to micro-packing effect.
3. CRS substitution in SCC shows an improvement in compressive strength due to angular shape and the presence of greater amount of fines. However, 100% inclusion of crushed rocks sand may not give overall better results.
4. RFA at lower percentage substitution is well-suited in SCC. Recycled glass waste, on the other hand, can be substituted up to 30% as it improves the fresh properties.
5. If the problem pertaining to excessive fines in CRS is dealt with properly, the overall performance may be boosted. Pre-treatment/processing of alternative fines also end up giving better results.

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Chapter 13
Structural Behavior of Reinforced Concrete Column Using Diamond Tie Configuration Under Elevated Temperatures for Sustainable Performance: A Review

Sudesh Kumar and Himmi Gupta

Abstract Every year fire causes thousands of deaths and loss of property across the world. Understanding of the thermal and mechanical properties concrete, structural steel, detailing and various fires protection materials at elevated temperatures is necessary to ensure adequate sustainable structural performance of structures. Columns are an important structural member of a structure and various reinforcement specifications, section geometry and cover standards are specified in design codes. Detailing of transverse reinforcement such as spacing of ties, ties configurations are also found to have considerable effect on performance of reinforced concrete columns under fire. The paper aims at summarizing the analytical, computational and experimental work undertaken in this field of study of improved fire resistance of reinforced concrete columns.

Keywords Fire resistance · Lateral ties · Columns · Analytical · Sustainable structural performance

13.1 Introduction

13.1.1 General

In India, there are a total of 2500 fire-related deaths per year. This fire will kill and destroy thousands of land. There have been fire accidents around the world which have resulted in extensive damage to buildings framed by reinforced cement

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concrete. The column is one of the most critical charging components, column failure leads to failure of the whole system. The growth in the usage of concrete in building construction means that the performance of artificial concrete frameworks needs to be studied. After prevention steps and burning, structures should be retrofitted in mind. Several buildings were destroyed because of improper fire policies and were not in a reparated state.

They found that the amount of spalling (the concrete sheet) for the RC column often rises with the rise in thermal gradient/temperature (temperature difference at one point of the column section). Then, a rise in the load extremes on the RC columns and a decrease in the transverse reinforcement distance was observed as well. This specifically shows that the fire tolerance of the RC column is measured by thermal gradients.

In addition, the body of the RC column segment was found to have perimeter fractures. These cracks are responsible for thermal gradient formation and for reducing the column constraints. The diamond configuration of the columns was also found to increase the harm sustained during the column fires by a thermal gradient fracture.

13.2 State of Development

Below you can find some important literature concerning and relating to the topic field:

Sofren Leo Suhaendi and Horiguchi (2004) In the investigation, the combination of polypropylene fibres was found to be an appropriate way to mitigate the process of When high-resistance concrete is heated, the runoff losses become more explosive. The findings of a study on the residual qualities of high strength fibre reinforced concrete are presented in this publication. Some criteria are based on the impact of fibre on the material's high solid residual characteristics. Fiber length, fibre volume ratio, and fibre content are only a few examples. The rest of the metrics, such as compressive strength, tensile strength at break, elastic modulus, and permeability modulus, can be viewed in the meanwhile. Polypropylene fibre relieving steel fibre costs less than reinforced heavy-duty concrete and has been demonstrated to perform better in terms of permeability and explosion, particularly permeability Hairdressing.

D. J. Naus (2005) this short study seeks to provide an examination of the effect of high heats on the analysis of RC elements. The study is primarily focused on the performance of steel and concrete elements used in the construction of contemporary millennium reactor ideas, wherein the material for fixed temperature was already subjected to an existing ASME regulation of more than 65 °C. Questions secondary to increased efficiency and hazards connected with toxic waste – disposal facilities due to poor design.

Sungwoo Shin et al. (2010) To assess the impact of the volumetric relationship of reverse reinforcement on column deformation, test hysterical action of ultra-high-strength, concrete tight columns. During simulation, the axial load ratios, transverse reinforcement configurations and transverse reinforcement volume ratios were replaced with half layers of actual structures by using eight 1/2 scale model of actual structure. Deformability of column was affected after simulation.

Martins and Rodrigues (2010) review the findings of an experimental and numerical study. The studied parameters: longitudinal strengthening ratio, thinning of columns and viscosity of the surrounding structure in the flaming column.

Wasim Khalik (2012) conducted material and system-level experiments, as well as computational experiments, on many high-performance concrete (HPC) combinations (including contribute to various and fibre combinations) to determine their physical properties at temperatures ranging from 20–800 °C.

Biolin U (2013), performs laboratory experiments at the member and systemic level in order to improve fire response evidence for FRP representatives of NSM. In order to determine the reliability, bonding and thermal expansion characteristics of NSM FRPs across a broad range of temperature, detailed studies have been conducted in the physical property classification. Fire resistance measurements were conducted on four NSM FRPs as part of the structural classification in order to enhance the stable T-beam.

Kodur Venkatesh et al. (2013) The form of both the resistances effect of reinforcing horizontal (RC) poles in tie arrangement is determined empirically using this method. The technique proposed is based on seismic enterprise architectures and quantifies the force acting on the connection by determining the appropriate tension related to stress, mechanical forces, and temperature expansion. In contrast to the resulting force used to estimate bond rupture the binding intensity is temp (time) related (at the tie-baton interface). The suggested tie-under model is incorporated into existing software in macroscopic finite element (FE) analysis, which detects the full action of reinforced concrete (RC) columns fire response. To show the suggested technology's practicality in assessing the positive impacts of the 135° tie arrangement, model estimations were added and the solution of a full-scale fire pressure testing on RC columns. In a case study using confirmed specimens, the impact of tie orientation on the fire resistance of reinforced concrete columns is evaluated. The numerical findings of this research indicate that HSC poles with a 135° bend have a longer lifetime than HSC poles with a 90° bend. To validate the suggested technique for determining the beneficial impact of the 135° tie design, model estimations were compared to findings from full-scale fire managed to rise in the RC beams. In a case study using confirmed specimens, the impact of tie alignments on the reinforced concrete of reinforced concrete is evaluated. Numerical simulations demonstrate unequivocally that HSC columns with a 135° bent tie are more resistant to fire than HSC columns with a 90° bent tie.

Pratik Bhatt et al. (2019) Using a computer model which is based on ABAQUS boundary conditions (FE) analysis, predict the reaction of steel fibre reinforced composites (SFRC) pillars to the combined impacts of wildfire and structure stress. Using sequential coupled thermal analysis methods, the fire reaction of a solid column is calculated. The FF model's varying physical modifications related to the air temp characteristics of SFRC and rebar reinforcements. To validate the model's accuracy in predicting the SFRC column's overall fire reaction, numerical sample predictions of air temp and axial stresses were compared to data acquired as during fire test. TNC1 is a non-ferrous fibre column whereas THC4 and THS10 are HSC columns constructed completely of plain concrete. The suggested eight (3D) computer model based on Finite Element (FE) is capable of detecting the fire reaction of SFRC columns in within areas listed despite requiring previous knowledge of the fire circumstances.

Shujaat Hussain Butch and Umesh Sharma (2019) three full-size prestressed steel columns with a height of 3.15 m each (each with two controlled and gem arrays) are overloaded with maximum backflow capacity into the service load. Furnaces were used to conduct the tests, which followed the ISO-834 flame thrower curves. When compared to a rectangular knot arrangement with cryostasis, a column made of diamonds offers a 150% improvement in fire resistance. Additionally, no significant differences in chewing quantity were seen for the gold pillars. Additionally, it suggests that the pressure gradient mitigates the effects of the bond's diamond structure being broken.

Shujaat Hussain Butch et al. (2019) Fire Current Codes has been corrected. The guidelines have been revised to incorporate evidence on the extent of rebar extension and load-bearing expansion on the steel reinforcement of reinforcement bars. This section discusses the distinction between longitudinal and transverse rebar design. This guideline specifies the kind of construction that should be utilised with the concrete grade. Column fire ratings are calculated for different structural configurations utilising data from experimental testing conducted on the whole column. Reducing column-based columns results in decreased column strength which may result in a fire in column modelling. The type of failure of a minimally exposed column, as assessed by the deformation produced in loaded columns during a fire, is equal to failure with time. As a result of comparing the safety classifications of different structural regimes to those of conventional building and safety equipment, new standards for RC columns were established for the various characteristics listed above. To evaluate the service life of RC columns, revised criteria were established. Fire resistance is determined by a variety of factors considered in the research.

Mostafa Abdel Megied Osman et al. (2020) evaluates the improvement of the behavior of reinforced concrete columns strengthen by steel fibers after exposing to fire. Ten R.C. columns with a circular cross-section of 200 mm in Dia. and 1250 mm in Height with varying ratios of steel fibers added in concrete mix (0.50%, 1.0% and 1.50%), were fabricated, then exposed to fire (Elevated Temperature), and different methods of fire resistance were loaded up to failure. Results show that the strengthening with steel fiber increased the load capacity and stiffness of R.C. columns compared to control specimens.

Ruben Serrano et al. (2016) Continuous development and enlargement of structural elements is slowed by direct contact to altitudes of up to 400° Celsius. By adding steel fibres or polypropylene fibres into concrete, his study seeks to address these issues. Because it enhances both strength and fire behavior and avoids cracking and explosive concrete breaking, compression crack test findings on cylindrical concrete specimens indicate that polypropylene or steel fibre reinforced concrete is a feasible alternative to conventional concrete.

Farid Fellah et al. (2011) focuses on empty steel columns with reinforced concrete linings, which are often utilized in high-rise building construction. In Europe and North America, many investigations on the steel reinforcement of these profiles have been performed. Design engineers, on the other hand, need more practical tools than coders. Because the trial findings are widely dispersed, developing such a method would be difficult. His study looks at three distinct methods, each of which is based on a different procedure. We compared the test results to the outcomes of the three techniques. Each talent is assessed for its potential, but it should either be utilized with care or avoided altogether. The Kodur principles are simple to use. They're based on experience, but they're backed up by numerous tests and calculated and stored analyses. The outcomes of the experiment are pretty close to the expectations. However, this approach is only applicable to compressive load and is ineffective at specific loading rates (usually high), and it produces comparable results over a broad range of reinforced concrete. Furthermore, since most of the computed values are based on tests with set end circumstances, they may be hazardous in certain instances when applied to columns with changeable termination requirements.

SAFIR is a nonlinear computer algorithm that simulates building behavior during a fire. As a consequence, it offers an abundance of data. Furthermore, the software can handle single poles as well as complicated structures like moment-resistant frames under a variety of loads and boundary conditions. Accidental burning may occur in the event of axial load.

Shujaat Buch and Sharma (2017) has conducted extensive research on the broad range of techniques used to measure the corrosion resistance of concrete walls (RC) columns throughout the globe. Because of the intricacy of failures caused by fire-induced breaking, design criteria for evaluating fire resistance for RC columns are neither particularly conventional nor very safe. The theoretical technique of evaluating fire resistance, according to their assessment, lowers cross section or extends the analytical judgement, but varies from actual findings. Through experimental findings and different analytical techniques, this study investigates the service life and comparative of RC columns. The results of fire resistance experiments are compared to identify deviations from the norm. The structural capacity of an RC column is determined by a number of factors. The analytical equations provided are broad estimates of physical protection that are either conventional or unobserved. The findings of the experiments indicate that determining fire ratings is very variable. Spalling is a limiting element in determining fire resistance, and it is primarily determined by permeability, load extremes, and the fire scenario. Inverse reinforcement has both a good and negative effect on RC column fire resistance. The complicated behaviour of spelling and temperature gradient-related stresses is not adequately predicted by theoretical techniques. The function of crosswise rebar spacing, spacing restrictions, and the impact of cracking on cross rebar spacing ratios and heat fluxes must all be investigated.

13.3 Conclusions

Existing research shows efforts to understand the thermal and mechanical properties of concrete, structural steel, detailing and various fires protection materials at elevated temperatures. These have helped in more sustainable and durable infrastructure. It has been found that the type of concrete, type of lateral reinforcement and its configuration affect the structural performance of reinforced concrete columns under elevated temperatures. Plain columns with high performance concrete show poor resistance to fire due to fire degeneration and accelerated intensity degradation. However, inclusion of fibres in various volume and shape configurations greatly enhances their fire resistance. The inclusion of steel fibres in the column of High strength concrete can contribute up to 4 h of fire resistance.

The fire tolerance performance of RCC columns with diamond tie configuration of lateral ties has been found to be almost 150% higher as compared to rectangular tie configuration. Also increase in percentage of lateral reinforcement increases the strength and ductility of columns. There is a greater fire resistance in high strength concrete columns with 135° bent links than the 90° bent pillars in this concrete. Increasing the longitudinal reinforcement ratio increases the fire resistance of RC Columns.

However, research has not been done on the fire tolerance of reinforced concrete columns with respect to change in the lateral reinforcement tie diameters. Experimental and numerical analyses comparison of reinforced concrete columns with different lateral reinforcement diameters can render a better understanding of their structural behaviour under elevated temperatures.

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Chapter 14
Reusable and Recyclable Industrial Waste in Geopolymer Concrete

Konduru Harini, S. Karthiyaini, and M. Shanmugasundaram

Abstract The industrial adoption is wide spread in present scenario because of this generation of waste increasing enormously. Reuse and recycling of it is very crucial to safeguard the environment. Through recycling of waste materials and the reduction in carbon emissions geopolymer concrete has the considerable capability to firmly come up with environmental sustainability in industrial sector as well as in construction sectors. Past two decades substantial amount of research has been performed to know the ability of geopolymer and to mitigate the use of ordinary Portland cement. However, geopolymer industry has to face number of challenges to adopt it in construction. Most amount of research was carried and also continuing for wide variety of waste as procures and as aggregates in geopolymer concrete. In this paper construction and demolition, energy production, metal industry, mining and enrichment of ore waste utilization in geopolymer concrete is discussed .Various properties of geopolymer concrete such as their rheology, fresh properties and hardened properties, their environmental susceptibility for aggressive conditions such as chloride and sulphate attack and also to various hazards salts because of which it losses in its strength are discussed. The main agenda of this paper is to review the research into various industrial waste-integrated Geopolymers and specify the difficulties to adopt it in industrial production with an observation to pointing the path for further research.

Keywords Geopolymer · Alkali activated concrete · Sustainable material · Reuse · Industrial waste

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14.1 Introduction

Globally cement demand and production increasing considerably and this industry is contributing nearly 5% of carbon dioxide emissions. Cement is also consuming lot of energy during its manufacturing process (Hasanbeigi et al. 2012). From a review of global cement industry trends as shown in Fig. 14.1 evolution of global cement demand from 1990 to 2018 increased tremendously. Asia is top among all the continents in the world and it mainly contribution is from china by consuming cement in extremely larger quantities compared to other countries. World average per capita is about 563 kg where as china is consuming 2950 kg. Over all china is consuming 2386 metric tons of cement and it was followed by India with second largest consuming country which is consuming 284 metric tons (Armstrong and Editor 2018).

Geopolymer main raw materials are industrial wastes this application reduces carbon dioxide emission, facilitates the recycling of waste and promote sustainable development in society. Fly ash geopolymer is a good replacement to OPC. If the fly ash is available in huge quantity then only it can be effective replacement to OPC. The Fig. 14.2 shows the process making of geopolymer concrete (Zhang et al. 2020).

Annual production of solid waste is nearly 960 million tons and this waste is generated during agricultural, municipal, mining, industrial and other processes. Agriculture source is generating 960 to 350 million tons, mining and industry sector is generating 290 million tons of inorganic waste and hazardous waste sources

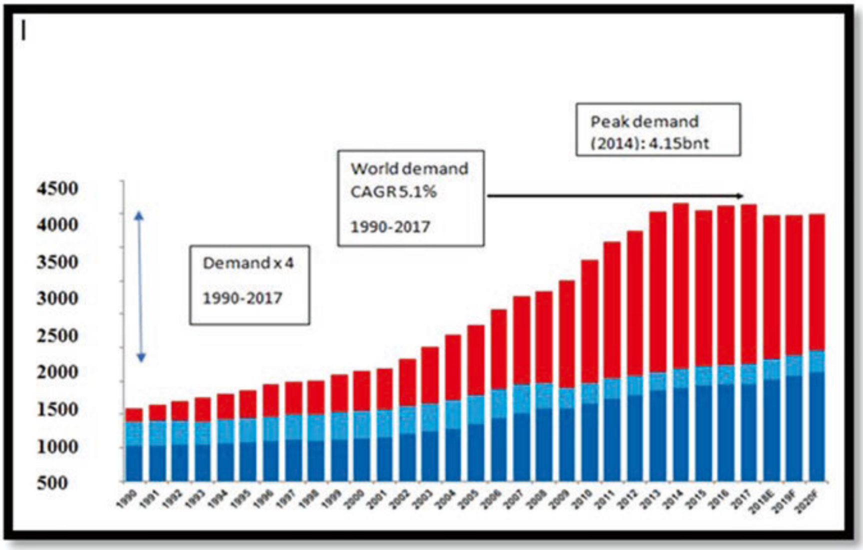

Fig. 14.1 Evolution of global cement demand, 1990–2018 F. (Armstrong and Editor 2018)

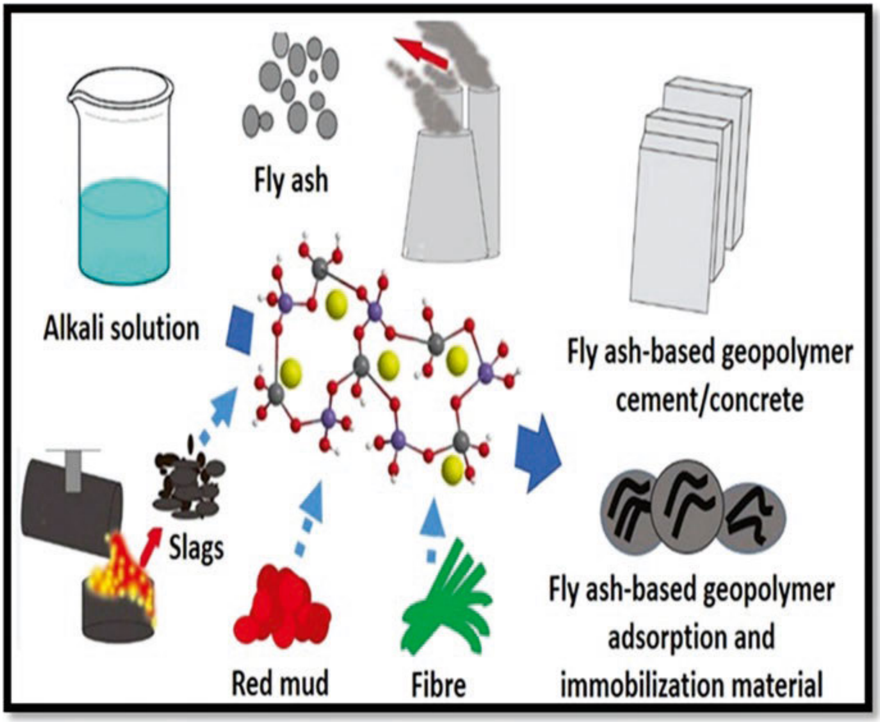

Fig. 14.2 Process of geopolymer concrete preparation. (Zhuang et al. 2016)

giving 4.5 million tons. As a result of mitigation we reuse and recycle Industrial waste in construction materials (Pappu et al. 2007).

Inorganic, non-combustible, heat resistant, 3D network of alumina-silicate materials that can be attain a shape quickly at low temperature these are the properties of geopolymer. Geopolymers nearly similar to zeolite minerals which is naturally available. Joseph Davidovits in 1978 coined these materials as Geopolymer (Davidovits 2013).

14.2 Construction and Demolition Industry Waste

The construction industry uses various types of materials, once the life span of materials expires, it can be reused partially in the new concrete which reduce the cost of the concrete. Some of Construction and demolition waste are concrete, bricks, ceramics, Glass, mineral wool, and reclaimed Asphalt. Among these wastes some can be used as coarse aggregate and other as cementitious materials. This process can be considered as economical and also environmental friendly method to reduce CO_2 emission and also demand for the production of cement and aggregate.

Large amount of land is utilized for dumping the construction waste, using reuse and recycling method the dumping of construction waste can be reduced. This kind of usage is adopted in normal Concrete also but it resulted in very poor quality of concrete with lower load bearing capacity when they were used as recycled aggregates. Adding some amount of cementitious material such as ground granulated blast furnace slag, fly ash metakaolin polymers relatively perform better than ordinary concrete. However chemical composition, physical properties of source materials, type of alkali activators and their concentrations, curing conditions play a key role in forming the geopolymer concrete. Silica and Alumina base construction and demolition waste can be successfully used in geopolymer applications. Sometimes construction and demolition waste might need some special treatment to use in geopolymer concrete that is special treatments like specific mix design, activation method and curing method. In Geopolymerization process NaOH concentration, Silicon dioxide to Aluminium oxide ratio, curing condition and amorphous content plays a predominant role and it also needs high skill training and industrial practices for better performance. A study has been conducted using ANOVA technique to confirm that it is even one factor difference can change the properties of the whole geopolymerization concrete and geopolymerization process so each and every parameter is independent and has a significant effect in the process of geopolymerization. In considering the polymerization process using construction and demolition waste there are some vital parameters and characteristics which were not sufficiently studied. Construction and demolition waste based geopolymerized concrete still need to be studied in the aspect of rheological characteristics such as initial and final setting time, shear stress, yield stress and viscosity and also durability related parameters such as resistance for electricity, diffusion of chloride, the process of carbonation, Freeze and thawing and the and alkali aggregate reaction are still need further research (Dadsetan et al. 2019).

14.2.1 Brick

Brick powder is taken as Precursor in the formation of geopolymer because of its low amorphous content this result was obtained by conducting materials characterization experiments. This brick waste may not be obtained only from production unit of brick but can also be collected from construction and demolition waste. This brick waste is not only used as a precursor, it can also be used as fine aggregate which is non-reactive and it can provide achievable approach in material design. It can also be utilized as brick powder which can absorb heavy metals and can be fixed in in geopolymer zeolite structure at temperature between 60 degrees and 80 degrees centigrade (Fořt et al. 2019).

Using recycled brick powder, high calcium Fly ash and alkaline Activator which consisted of Na_2SiO_3 and NaOH geopolymer binder is made. This mixture shows increase in the brick powder content, Na_2SiO_3/NaOH ratio and NaOH concentration decreased flow of fly ash based geopolymer motor. Brick powder has free dominant influence factor on flow property of the mixers. Followability of mix has linear decrement with increased in brick waste and for this mixes NaOH concentration of 6 M or below this is not sufficient to dissolve fly ash particles to form aluminosilicate and Calcium silicate compounds due to which it will form loose microstructure and reduction in compressive strength (Wong et al. 2020). Table 14.1 shows the properties of brick powder based geopolymer concrete.

14.2.2 Waste Glass

The importance of systematic and proper waste glass powder can be used as the precursor material in the production of sustainable geopolymer concrete. The use of waste glass powder can reduce uncontrolled depletion of the natural earth resources and to develop an eco-friendly solution. Water glass powder proportion can improve

Table 14.1 Properties of brick powder geopolymer concrete

Author	Property	Value	Remark
Fořt et al. (2019)	Reaction heat evolution	60 °C	Only one peak appeared immediately after mixing.
Fořt et al. (2019)	Curing temperature	60–80 °C	No crack formation. Very dense structure observed.
Fořt et al. (2019)	Weight loss	10.89% (20 °C) 12.18% (80 °C)	Because of both curing and silicate modulus of the alkaline activator.
Fořt et al. (2019)	Most compacted structure	Silica modulus = 0.8	Dense structure with high reaction rate
Vafaei et al. (2021)	Appearance change		Due to acid attack. Less effected at bottom due to coverage of block by container. Suggested to hang the specimens if possible
Vafaei et al. (2021)	Variation of mass	16% (HCl) 56.6% (H_2SO_4)	It also depends on time of exposure and HCl reported less values when compared to H_2SO_4
Vafaei et al. (2021)	Breakdown of geopolymer network	PH = 3	Dense geopolymer formation were breakdown in acid attack.
Wong et al. (2020)	Flow	–	Higher amount of brick powder reduces flow of geo polymer concrete.
Wong et al. (2020)	Compressive strength		Brick powder could be replaced up to 20% so that it will not affect the strength.
Wong et al. (2020)	Sorptivity		NaOH play key role but effect brick powder is very minimal on Sorptivity
Wong et al. (2020)	Water absorption		Brick powder effect was very minimal

the workability characteristics. The most important properties are less specific area, less water absorption capacity, texture being smooth and water glass powder filling ability, which will also reduce the alkaline liquid required quantity which is used for lubricating the surfaces of the particles. When considering about compressive strength, addition of 20–30% of waste glass powder is optimum to get good results and further adding effect its strength due to its brittleness, less reactivity and high amount of alkalis formation. For split tensile strength 0–15% would be an optimum range. Beyond 15% there is significant decline due to brittleness and high silica content of glass powder. Waste glass powder contains excellent fresh, hardened and structural properties (Manikandan and Vasugi 2021).

Alkali deficit and excessive alkali condition hinder dissolution of waste glass to larger extent. Proper amount of waste glass can lower the sodium hydroxide quantity without considerable loss in compressive strength. This will imply in reducing the cost (Xiao et al. 2020).

River sand is an excellent resource to use as a fine aggregate but now a days due to economic and environmental restrictions sand cannot be utilised in larger extent. So waste glass is one such alternative which can be utilised as substitute to sand which also increase alkalinity of matrix. That help with greater degree in dissolution and reaction in the proximity of the aggregates. This mainly useful in later stages to reduce carbonation process by higher alkalinity consumption in gel formation stage. The amorphous form of glass take part in reaction eventually and develop a strong bond. In glass group geopolymer process may be delayed but finally formed geopolymer is denser and stronger (Hajimohammadi et al. 2018). Table 14.2 shows the properties of waste glass based geopolymer concrete.

14.2.3 Reclaimed Asphalt

Reclaimed asphalt is used in the paving industry as aggregate. But large quantity is still dumped in landfills and wasted without any use. This has many environmental implications. The effect of these land dumping will cause Leaching which will pollute the land and surface water resources. Hossiney et al. (2020) says it has promising managing technique like using geopolymer matrix for pavement blocks. Using reclaimed asphalt in fly ash geopolymer require extra effect to get good finishing surface and density is reduced compared to natural aggregate. This will have lower

Table 14.2 Properties of waste glass

Author	Property	Value	Remark
Luhar et al. (2019)	Slump	40% increase	
Luhar et al. (2019)	Slump flow	103.3% boosted	
Xiao et al. (2020)	Early strength	Less up to 14 days	Due to its slow reaction rate it acted as a filler material.

compressive strength and mass loss due to abrasion is also more. But the values are not less for Indian standard light traffic vales. Water absorption is in within limits. The water absorption was lesser when compared with normal aggregate mixes. If less absorption of water in mix will have asphalt presence and when it was heated it may lead to voids. Using the reclaimed asphalt reduces burden on quarries and also reduces landfills (Hossiney et al. 2020). Reclaimed asphalt is considered as an potential use of in geopolymer matrix for pavement base material (Hoy et al. 2017). Recycled asphalt has its potentiality in pavement construction.

14.2.4 Mineral Wool

Mineral wool in geopolymer concrete will increase the compressive strength and cause porosity. Mineral wool beyond 20% would decrease the compressive strength. The curing temperature 50 °C will fetches good compressive strength values. Further studies need to be done for extended curing duration in ambient temperature effect on mechanical strength. With small amount of impurities Mineral wool waste is suitable as geopolymer precursor. Mineral wool age is not taken into consideration. Mix of glass wool and stone wool has great resistant to freeze-thaw conditions. Further need for studies in mineral wool is for alkaline conditions, optimization of mix design and also to find optimum mineral wool (Yliniemi et al. 2019).

14.3 Energy Production Wastes

14.3.1 Fly Ash

Geopolymer concrete important ingredients are industrial wastes, use of industrial waste will decrease the carbon dioxide emission, facilitates the recycling of waste and promote sustainable development in society. Fly ash could be used mainly as replacement of OPC. This is also possible only when there is good supply chain for effective use. The reaction mechanism of fly ash geopolymer concrete involves breaking and re-joining of Si-O and Al-O bonds. This happens in the presence of alkaline activator, this end up with very hardened and durable geopolymer with excellent mechanical properties (Zhang et al. 2020).

Curing temperature will have effect in fly ash based geopolymer concrete, when they exposed to carbonation**.** Heat cured specimen shows a greater resistance than ambient cured specimen. Higher compressive strength mixes will have greater resistance to carbonation (Li and Li 2018).

On geopolymer specimen immersed in sulphuric acid has most adverse effects such as magnesium sulphate and sea water. Mass gain was absorbed in first 15 days in OPC and geopolymer specimens then on prolonged usage in same acid solution mass of specimen started losing and geopolymer concrete specimens registered with vey less amount of loss in mass. The investigations evidenced that good relationship between fracture energy and compressive strength and fracture energy and splitting tensile strength. Similar good relation observed for critical stress intensity factor versus compressive and splitting tensile strength test. This shows that it was an good replacement for OPC concrete (Kurtoğlu et al. 2018).

The polymerisation action can be increased by heat curing, as compressive strength can be raised at early age. Elastic modulus and poisons ratio of class f fly ash based geopolymer has obtained similar results to those of conventional concrete. Stress- strain expressions developed for ordinary Portland cement concrete can be applicable for geopolymer made using fly ash with reasonable accuracy (Albitar et al. 2015).

Addition of water content of 30 kg/m^3 would be optimal with slightly unfavourable effect on properties of geopolymer concrete. Increase in chemical admixture content improves 115% of workability but it slightly increase in water absorption and porosity which further imply on reduction of compressive strength, tensile strength and modulus of elasticity (Aliabdo et al. 2016).

Experiments were conducted on geopolymer based short column which were strengthened by wrapping the glass fibre as reinforced polymer. It was evidenced by experiments that geopolymer paste is forming strong bond. Deformations were recorded low and M30 grade has given much ultimate strength (Karthiyaini and Nagan 2014).

14.3.2 Bottom Ash

Incinerator bottom ash is used in this study for its geopolymerization along with aerating agent. The lower concentrations of alkaline solution effect polymerisation rate and it reduces but higher concentration form foaming in the stage of mixing. Optimising the alkaline solution is important. The molarity of 8 would be forming good geopolymer matrix. Mixing time and also liquid to solid ratio are significant factors to control physical and mechanical properties of the resulting aerated incinerator bottom ash geopolymer. Very good correlation between compressive strength and dry density is observed. Increase of porosity has linear negative relation with dry density. This geopolymer matrix efficiently immobilizes most of the toxic metals and heavy metal leaching is reduced in high rate (Chen et al. 2016).

The incineration bottom ash combined with metakaolin has shown good results for strength, when it used alone for geopolymerization process. The optimum liquid to binder ratio important for maximum compressive strength when matrix is made with equal amount of bottom ash and metakaolin and the ratio is 0.5. Ambient curing has fetched good compressive strength results compared to other type of curing (Logesh Kumar and Revathi 2016).

High fineness increases compressive strength and these are 5% less susceptible to sodium sulphate solution compared with OPC based system. At the age of

120 days samples registered 3.6% loss in weight. The better performance is mainly due to its cross-links aluminosilicate polymer structure which is stable (Sata et al. 2012).

14.4 Metal Industry Waste

14.4.1 Blast Furnace Slag

Blending of ground granulated blast furnace slag (GGBFS) with fly ash based geopolymer concrete, will makes it sustainable material which can be set at ambient temperature, with no addition of heat curing. At ambient curing the matrix obtained good compressive strength as well as tensile strength. With increase in GGBFS content the mechanical properties also increased. UPV measurements are an effective way in evaluating maturity of geopolymer concrete. The stabilisation of UPV was observed only after 7 days similar to that of OPC. The values of dynamic modulus of elasticity computed based on UPV measurements (Sitarz et al. 2020).

Initial and final setting time was decreased with increase in GGBFS. Increased concentration of sodium hydroxide solution increases compressive strength. Higher dosage of GGBFS in geopolymer paste form denser structure which leads to higher strength concrete (Saha and Rajasekaran 2017).

Lower particle size helps in reducing carbonation and also retarder which is containing potassium sodium tartrate can improve carbonation resistance. There is a greater influence of curing temperature on carbonation resistance. Room temperature cured samples show less resistance towards carbonation. The samples with greater strength shows more resistance to carbonation (Li and Li 2018).

For same compressive strength at 28 days GGBFS and Fly ash based concrete has given 15–28% less modulus of elasticity (Bellum et al. 2020).

14.4.2 Ferrochrome Slag

Ferrochrome based geopolymer concrete shows good fire resistance. Water absorption increased only after 700 °C only. The higher compressive strength vale was shown at 300 °C (Zulkifly et al. 2017; Karakoç et al. 2016).

With increase in time of exposure to $MgSO_4$ content compressive strength decreased. There is no appearance change even after exposing it to 24 weeks in magnesium sulphate and also change length was less with 0.1% when compared with OPC (Karakoç et al. 2016). As ratio of ferrochrome slag increases its sensitivity to salts and sulphates decreases. There is a formation of micro cracks in microstructure of the samples when samples are dipped in 5% $MgCl_2$ solution. Samples in NaCl and $MgCl_2$ solutions shrink and samples in $MgSO_4$ did not show any shrinkage instead they expanded (Özcan and Karakoç 2019).

14.4.3 Foundry Sand

The encouraging outcome of bottom ash-GGBFS- FS is geopolymer blocks attained satisfactory strength even at loss molarities, at ambient curing condition. Maximum compressive strength is obtained for sample with density 2400 kg/m^3. Foundry sand was replaced as an fine aggregate (Thaarrini and Ramasamy 2016). Addition of foundry sand to geopolymer mixes reduces, the workability due to porous surface on its texture and also clay type of fine material found on top of it. With higher replacement of FS the reactivity of procures drastically reduced (Bhardwaj and Kumar 2018).

14.4.4 Steel Slag

Instead of plain geopolymer concrete, steel slag based geopolymer concrete has increase in its strength properties. Sun light cured samples obtained good results than the ambient cured samples (Premalatha et al. 2018). If steel slag is applied or used as coarse aggregate it is showing good paste to aggregate bonding. Because of which compressive strength and surface resistivity increases considerably. These as aggregates incorporated samples registered lower amount of shrinkage. Steel slag aggregate unlikely to affect its volume stability up to 320 days (Khan et al. 2016). If steel slag is added to geopolymer matrix in powder form its optimum percentage would be 10%. Curing plays a great influencing role in mechanical strength. Moist curing is preferred than exposed curing and sealed curing. Effective use of slag is good source in geopolymer concrete (Bai et al. 2018). Based on compressive strength, apparent density and tensile properties and crack characterisation the optimum contents 21%. Prolonging curing time and increasing curing temperature were useful in strength development. With increase in strain, cracking also increased in number as well as width of each crack (Guo and Yang 2020). For breakwaters steel aggregate based Geopolymers are promising material due to its density and microstructure (Mahmood et al. 2020). These steel slag can also has promising feature for coating material (Abdel-Ghani et al. 2018).

14.5 Mining Waste

14.5.1 Kaolin

Kaolin is mineral which purest form of clay present in china clay. The geopolymerization reaction depends on initial Si/Al and reaction can be accelerated by increasing ratio from 1.4 to 2.49. With increase in ratio also changes amorphous structure to crystalline structure which imply in high strength and denser morphology. Mechanical energy increases with time progresses (Gao et al. 2020).

This also suffer from strength and weight loss to acid attack but values are low when compared to OPC and offers good resistance to acid attack due to kaolin .optimum percentage for replacing fly ash with kaolin would be 40% (Nnaemeka and Singh 2019).

Geopolymer with 30% replacing fly ash with metakaolin has fetched good mechanical strength and through life cycle analysis it was proven that this geopolymer reduces 61% of global warming effect compared to ordinary concrete. It also has positive results to aquatic terrestrial eco toxicity (Abbas et al. 2020). Wet burlap curing not suitable for curing the metakaolin based samples. With optimum temperature for curing lead high early strength. Sunlight can also use for curing in summer if temperature is above 35 °C. in cold weather Halogen curing with temperature range 50–55 °C is adopted (Al-Shether et al. 2016).

When 15% of kaolin is used in place of fly ash UPV values increased with age but at 7 days the values reduced for all the samples due to lower homogeneity and porosity. In rebound hammer all samples were proved as poor quality samples (Yahya et al. 2018).

14.5.2 Red Mud

Red mud is an industrial by-product, which will have negative effect if it is not managed in proper way. Geopolymer with red mud has more heat resistance and concluded as heat resistant material (Thang et al. 2018). Red mud –fly ash geopolymer is sound material to apply in various applications. Red mud addition provide better structural toughness and flexural strength compared to waste glass incorporation (Toniolo et al. 2017). The iron species evolved in those geopolymer matric is the key factor for structural and mechanical features (Kaya and Soyer-Uzun 2016). The concentration of As, Cu, Cr and Cd detached in leaching were recorded very low values (Zhang et al. 2016).

The matrix which containing red mud and fly ash offer good freeze and thaw property but comparatively less values for room cured samples (Zhao et al. 2019). As of now there is no particular mix design for geopolymer concrete and through genetic algorithm the prediction of thermal behaviour was analysed and evolved equation for that (Yeddula and Karthiyaini 2020). Red mud has low inherent reactivity and to overcome this blending Red Mud with other reactive materials like metakaolin, ground granulated blast furnace slag or fly ash. This can also be used in blends with multicomponent systems and hybrid binders (Hertel and Pontikes 2020).

14.6 Conclusion

Geopolymer concrete uses various types of by-products in its matrix for both protecting environment and also to mitigate the harsh chemicals spoiling the surface of earth by dumping them. Concluding each industrial waste

- Firstly considering Construction and demolition industry waste, Brick waste is used as partial replacement to supplementary cementitious material and has given good results in strength and susceptibility to adverse environments like different PH environments and also high temperature tolerance but has no role in Sorptivity. Water glass has shown its predominant role in high workability by increasing its slump values. Reclaimed asphalt mainly used as aggregate in paving industry but density is little compromised than normal aggregate. Mineral wool based matrix will fetch good compressive strength but leaving more porosity in concrete after hardening.
- Next discussed about energy production waste, among all wastes Fly Ash is predominantly used in Geopolymer matrix and research is prolonged even to the structural members, paving blocks and precast industry. Bottom ash is another energy production waste which can produce good strength mix but less density due to its aerated mix and it has more porous mixes.
- Metal industry waste, blast furnace slag can alter the setting time by varying its proportion. With high dosages density is improved and using it with lower particle size can reduce carbonation. In similar way other discussed slags also show susceptible properties for adverse environments. This industry waste also has its application for partial replacement of aggregated in geopolymer matrix.
- Lastly discussed about mining waste, kaolin can be replaced up to 40% for its good compressive strength and can show less effect than OPC in acid attack considerably. Life cycle assessment of kaolin based showed that it can reduce global warming effect. Red Mud based geopolymer is more heat resistance and has very large verity of applications. It provides good structural toughness and flexural strength. Iron species evolved in those geopolymer matric is the key factor for structural and mechanical features.

All over the world lot of research is going on with the influence of metal production waste and also mining waste in order to develop Sustainable concretes. These by-products can be treated and replaced them as both binder materials and aggregates. Another reason is these by-products are hazardous when we dump them in landfills. Along with conducting research adopting this technique in industrial scale need to be done to make hazardous by-product as sustainable materials. During the mix design formulation artificial intelligence and machine learning techniques can be utilised to avoid wastage of material as well as time.

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Chapter 15
Infrared Thermography Parameter Optimization for Damage Detection of Concrete Structures Using Finite Element Simulations

Ajay Gaonkar, Ganesh Hedge, and Madhuraj Naik

Abstract In this research paper, defect identification is carried out on a concrete block specimen. A finite element modelling software is used to simulate a 3D model of Concrete Block Specimen with different thickness of air void defect embedded at different location. The Concrete Block Specimen is heated using lock-in infrared thermography concept in the models to identify the location and other details about the defects. In lock-in infrared thermography, the model is heated repeatedly at regular intervals for required frequency and responses of the heating on the model is noted. The excitation power of 200-Watt, 500-Watt, 1000-Watt and 2000-Watt were used with 12 different heating periods, which were set from 5 to 60 min with 5 min interval. The duty cycle for each heating period was taken as 50%. Different data like thermal images, temperature difference on the defects, graphs of temperature v/s surface were found. Using a MATLAB program, area of the defects were calculated based on thermal images. An effort is made to find exact amount of heating and time required for a concrete structure to identify defects using simulation of Infrared Thermography in FEM. The area of defects estimated at 60 min for 55 min time period was close to the actual area of defects with minimum error.

Keywords Lock-in infrared thermography · Finite element model · Air void defects · Thermal images · MATLAB

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15.1 Introduction

Inspection and monitoring of structural conditions are a very important part of life-cycle management of engineering systems. All Civil structures including the critical infrastructure works like bridges, power plants, etc. deteriorate over time because of fatigue, environmental reasons, corrosion, impact of natural calamities and so on. Thus, there's a need to examine the health condition of the structures before any disaster takes place. Many researchers are performing different tests to develop new and advanced methods for damage detection without affecting the structure.

Infrared thermography is method of infrared energy detection emitted from object which is converted to temperature, and shown as a picture of temperature distribution. Use of infrared thermography (IRT) for the non-destructive testing (NDT) is termed as thermal non-destructive testing (TNDT). TNDT consists of thermal excitation of the object during the test and monitoring the temperature variation over the object surface during either heating or cooling phase. The existence of defects in the object interrupts heat flow causing localized changes in temperature distribution over the surface and this change are recorded using an infrared camera. Thermographic NDT techniques are gaining more attention as one of the effective NDT techniques as they're non-contact, remote sensing, time-saving and cost-saving techniques (Takahide et al. 2002).

Lock-in thermography is an active infrared thermography, during which a periodic energy waves (periodic excitation) in form of sinusoidal waves at a required modulation frequency is applied as an input to the surface (Thajeel 2014). The purpose of present study is to simulate a 3D model of Concrete Block Specimen using a finite element modelling software and to find the excitation energy and time required to detect all the defects present and also area of defects using a MATLAB program by applying lock-in infrared thermography on Concrete Block Specimen.

15.2 Development in Damage Detection Using Infrared Thermography (IRT)

Takahide et al. (2002) used a concrete block specimen with artificial delamination defects at different positions for experiments. To find the defects, lock-in infrared thermography was used under periodical heating based on the phase delay measurement. It was concluded that the size and location of the defects can be estimated using the change in area of contrast of the phase delay images and using the relationship between phase delay and excitation period defect depth can be estimated. Cannas et al. (2012) conducted experiment on a small concrete wall with artificial defects, temporarily heated up with two halogen lamps with a power of 500-Watt by placing them at a distance of 1.5 m. They also developed a same numerical model with Finite Element Method. This paper was constrained to find the defect position and temperature.

Fei et al. (2018) has built a 3D finite element model of Carbon/epoxy facings-aluminium honeycomb sandwich structure (C/E FAHS) material stimulated by sinusoidal excitation signal and in experiment lock-in thermography was used. The influence of structural parameters and the modulation parameters of carbon/epoxy facings were analysed. Results demonstrated that lock-in thermography was an efficient method of detecting debonding defects of C/E FAHS. Hiasa et al. (2018) explored favourable time window to perform IRT on a concrete slab with effect of debris on the surface of concrete using both experimental observations and numerical simulations. Same authors in 2017 (Hiasa et al. 2017) has conducted experiments on a concrete slab and used FEA simulations to determine temperature difference between sound and defect areas. Further, they concluded that defects at 1.27 and 2.54 cm depth can be detected using IRT.

Michal et al. (2019) has compared three non-destructive methods (Infrared thermography, Ultrasonic pulse echo and Ground-penetrating radar). These three methods were applied to a concrete bridge and also to a specimen in laboratory with artificial defects embedded to simulate cavities. The experiments performed on the concrete bridge shows, the partial capability of Ground-penetrating radar to detect cavities which are located just below the surface, while Ultrasonic pulse echo was failed to detect such types of defects completely. IRT was very much successful to locate cavities near to the surface but only under the convenient weather conditions. It was concluded that IRT was suitable bridge's diagnostics and quick method as it could scan the entire bridge without requiring direct access to the structure. Różański (2017) conducted experimental studies on laboratory cast reinforced concrete slab with four embedded damages. Various thermal excitation sources were used, and the slab sensitivity was investigated using different infrared cameras along with FEA simulations.

From the above cited papers, it was found that all authors have used different experimental procedure having different excitation time and magnitude. Optimization of the excitation time and magnitude should be must to save time and power. Also, detection of defect depends upon properties of the defects, material in which defect is there and how the testing is done. Defects of various sizes and depths with varying concrete parameters would require different amounts of excitation energy. Many authors have used FEM simulation to confirm infrared thermography experiments. Using FEM simulation, a mathematical formula can be developed to calculate exact amount of heat and time required for a concrete structure to identify all the defects. This will optimize the method and make it more methodological instead of the present practice of experimenting with different heating times and energy fluxes.

15.3 Methodology

15.3.1 Model Details

The FEM model was developed to simulate the lock-in infrared thermography. The concrete block specimen was of width of 1 m, height of 1 m and depth of 0.3 m. Square shaped air defects (100 mm × 100 mm) in different thicknesses were embedded in the specimen. Defects Location, depth 'd' and thickness 't' are shown in Fig. 15.1 below.

Lock-in infrared thermography were carried out for 12 different heating periods, which were set from 5 to 60 min with 5 min interval. The modulation frequency was in the range of 3.33 × 10–3 Hz to 2.78 × 10–4 Hz. The duty cycle for each heating period was taken as 50%. The graph of 200-Watt power with 5 minutes (min) heating period and duty cycle of 50% is shown in Graph 15.1. For heating the concrete block specimen magnitude of power 200-Watt, 500-Watt, 1000-Watt and 2000-Watt were used. For each excitation power, 12 FEM model were created with 12 heating periods mentioned above.

15.3.2 Model Properties

The concrete block specimen was modelled using FEM software and modelling was done in 3D having 1 m × 1 m × 0.3 m specimen size as shown in Fig. 15.2. The initial temperature of the concrete block specimen was taken as 293.15 K (Kelvin) and the material properties used in the FEM models is shown in Table 15.1.The meshing done was user-controlled mesh with maximum element size of 0.15 m and minimum element size of 0.028 m. The meshed model is shown in Fig. 15.3.

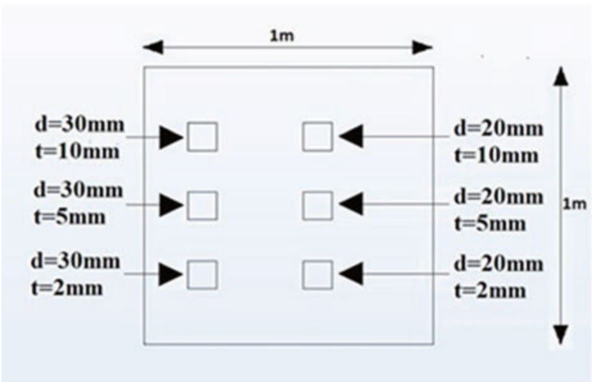
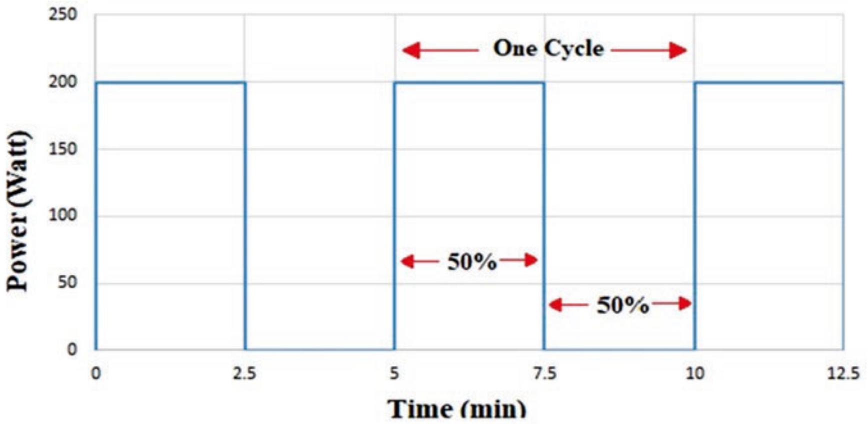


Fig. 15.1 Concrete block specimen with artificial delamination defects



Graph 15.1 Graph of 200-Watt power with 5 min heating period for 50% duty cycle

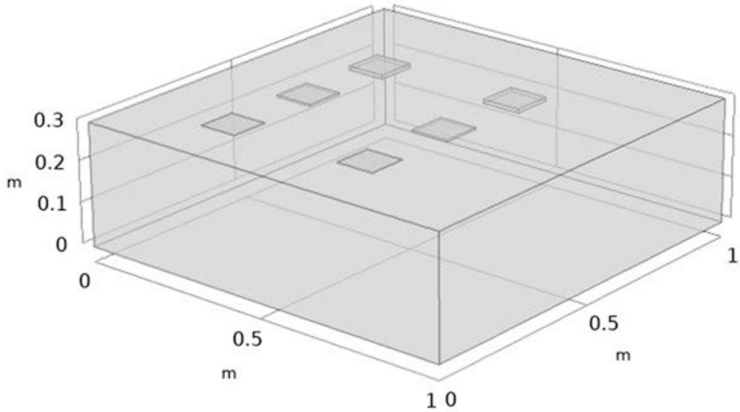


Fig. 15.2 3D model of concrete block specimen in FEM software

15.4 Data Analysis, Results and Discussions

Using FEM software, model of the Concrete block specimen 1 m × 1 m × 0.3 m with excitation power of 200-Watt, 500-Watt, 1000-Watt and 2000-Watt with varying heating period from 5 to 60 min with 5 min time interval having 50% duty cycle were analyzed and different results like thermal images of concrete block at different time intervals, temperature at different location on concrete block were obtained. Using this data, defects location, area of defects, difference between maximum and minimum temperature over defects were calculated and also a 3D graphs of temperature v/s surface were plotted.

Table 15.1 Material properties of the concrete used in model

Property	Variable	Value	Unit
Density	rho	2500 [kg/m^3]	kg/m^3
Thermal conductivity	k_iso ;kii = k_iso, kij = 0	1.8 [W/(m*K)]	W/(m·K)
Heat capacity at constant pressure	Cp	880 [J/(kg*K)]	J/(kg·K)
Coefficient of thermal expansion	alpha_iso ;alphaii = alpha_iso, alphaij = 0	10e-6 [1/K]	1/K
Young's modulus	E	25e9 [Pa]	Pa
Poisson's ratio	nu	0.2	1

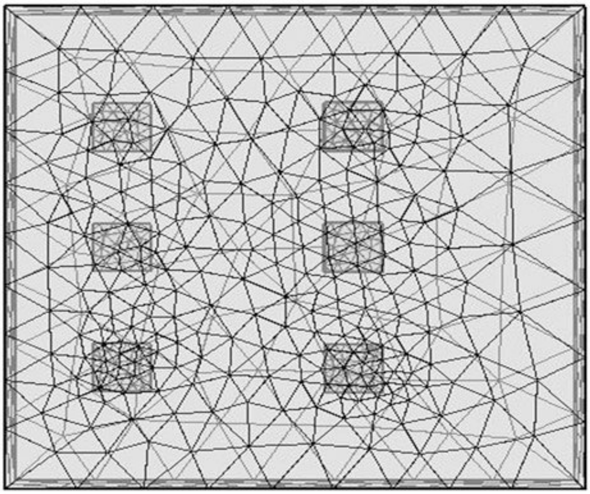


Fig. 15.3 Meshed model of concrete block specimen

15.4.1 Thermogram Images

Snapshot of typical concrete block images for 5 min heating period with 200-Watt heating power at different time is shown in Fig. 15.4.

Based on different thermal images obtained it can be seen that images of 10 min for all the heating period shows defects which were at 20 mm depth for all heating power and the 30 mm depth defects visibility was increasing as the time period was increased. The Fig. 15.5 of 5 min heating period and 60 min heating period with 500-Watt heating power at 60 min time, shows how the visibility of 30 mm depth defects was increased as heating period is increased.

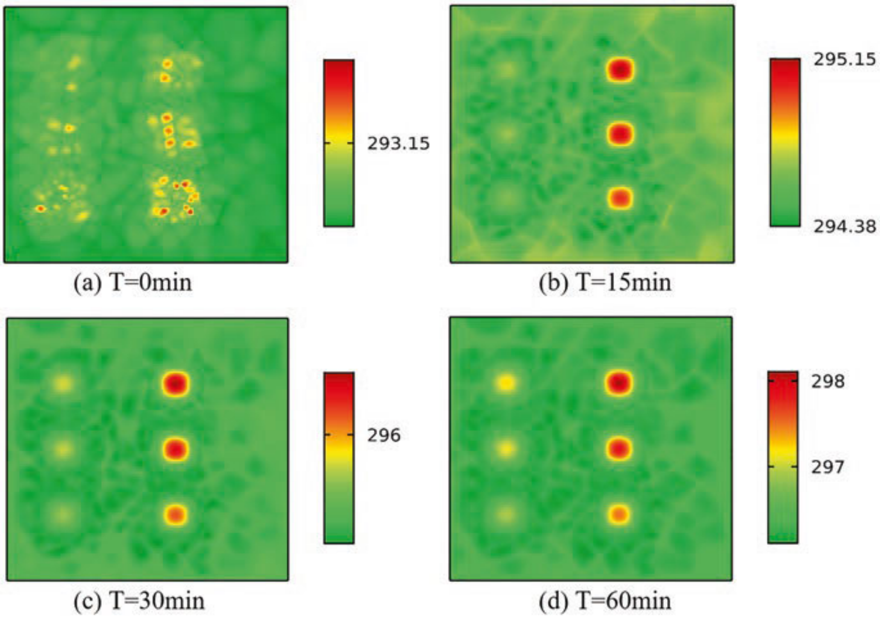


Fig. 15.4 Typical images of 5 min heating period with 200-Watt heating power

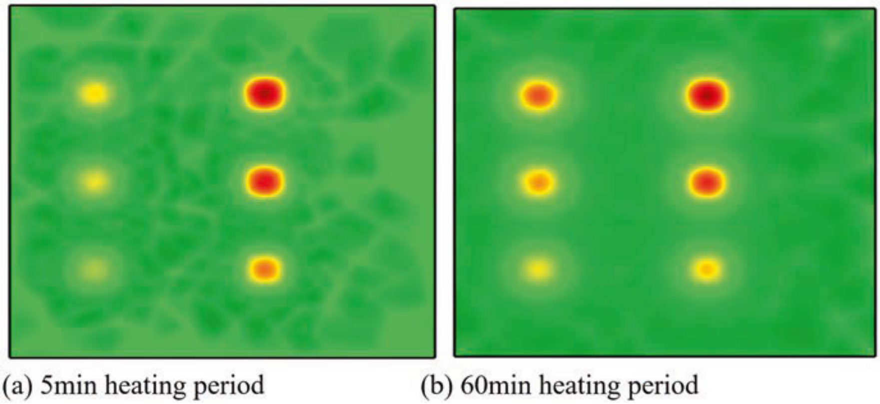


Fig. 15.5 Thermal images of 500-Watt heating power at 60 min time

15.4.2 Temperature Data

The maximum and minimum temperature over the defect area was measured for different excitation power and different heating period as mentioned in the methodology part. Using this data Temperature difference was calculated. For the 200-Watt heating power with the frequency of 3.33*10^−3 Hz and Time period of 300 seconds (sec), the typical temperature data is tabulated as shown in Table 15.2.

Similar table were tabulated as Table 15.2 with different time period (heating period). Using this tables, a temperature difference table for each excitation power was tabulated. From that it was observed that the temperature difference gradually increasing for initial time of 20 min for all heating period but as the time increases, the temperature difference increases faster in higher heating period than lower heating period up to 35 min and after that temperature difference starts deceasing for higher heating period. In case of lower heating period the temperature difference gradually keeps on increasing. The temperature difference is more for defects having higher thickness and depth.

15.4.3 Surface Temperature Graphs

Using the FEM software, the temperature data obtained on the surface of concrete block specimen was used to plot a 3D graphs of temperature v/s surface. The graphs of temperature v/s surface having 200 W excitation power with 5 min heating period with varying time is shown in below Graph 15.2.

The Graph of temperature v/s surface in Graph 15.2 shows peak temperature at the middle of defects. As the thickness of the defect is more, the peak of the temperature is high. The peak of temperature decreases as thickness and depth of the defect decreases.

15.4.4 Area of Defects

Evaluation of defect area from thermal image was done using a MATLAB program. These images were spatially calibrated with actual dimensions in the program and the area of the defect was calculated. For 200-Watt excitation energy, area of defect at 60 min is tabulated in Table 15.3.

Similar tables like Table 15.3 of area of defects were tabulated for other excitation energy of 500-Watt, 1000-Watt and 2000-Watt. Based on this tables, it was seen that there was slight change in area of defects by increasing excitation energy but there is increase in area of defects by increasing the time period. From similar table like Table 15.3, it was observed that for 55 min time period the area of defects estimated were close to the actual area of defects with minimum error.

Table 15.2 Typical temperature data for 200-Watt heating power with 300 s heating period

Details about defect (mm × mm × mm)	Depth of defect (mm)	Time (min)	T_{max} (K)	T_{min} (K)	T_{diff} (K)
100 × 100 × 10	20	5	293.87	293.75	0.12
100 × 100 × 5	20	5	293.87	293.75	0.12
100 × 100 × 2	20	5	293.86	293.75	0.11
100 × 100 × 10	30	5	293.76	293.72	0.04
100 × 100 × 5	30	5	293.77	293.73	0.04
100 × 100 × 2	30	5	293.77	293.73	0.04
100 × 100 × 10	20	10	294.57	294.20	0.37
100 × 100 × 5	20	10	294.55	294.19	0.36
100 × 100 × 2	20	10	294.50	294.19	0.31
100 × 100 × 10	30	10	294.24	294.14	0.10
100 × 100 × 5	30	10	294.26	294.15	0.11
100 × 100 × 2	30	10	294.24	294.14	0.10
100 × 100 × 10	20	15	295.15	294.54	0.61
100 × 100 × 5	20	15	295.11	294.53	0.58
100 × 100 × 2	20	15	295.01	294.53	0.48
100 × 100 × 10	30	15	294.66	294.47	0.19
100 × 100 × 5	30	15	294.68	294.47	0.21
100 × 100 × 2	30	15	294.64	294.46	0.18
101 × 100 × 10	20	20	295.68	294.86	0.82
101 × 100 × 5	20	20	295.61	294.84	0.77
101 × 100 × 2	20	20	295.47	294.83	0.64
101 × 100 × 10	30	20	295.07	294.78	0.29
101 × 100 × 5	30	20	295.08	294.76	0.32
101 × 100 × 2	30	20	295.02	294.75	0.27
101 × 100 × 10	20	25	296.12	295.13	0.99
101 × 100 × 5	20	25	296.03	295.10	0.93
101 × 100 × 2	20	25	295.83	295.08	0.75
101 × 100 × 10	30	25	295.43	295.04	0.39
101 × 100 × 5	30	25	295.42	295.02	0.40
101 × 100 × 2	30	25	295.34	295.00	0.34
101 × 100 × 10	20	30	296.52	295.39	1.13
101 × 100 × 5	20	30	296.40	295.35	1.05
101 × 100 × 2	20	30	296.16	295.33	0.83
101 × 100 × 10	30	30	295.76	295.29	0.47
101 × 100 × 5	30	30	295.74	295.27	0.47
101 × 100 × 2	30	30	295.64	295.24	0.40
101 × 100 × 10	20	35	296.86	295.62	1.24
101 × 100 × 5	20	35	296.72	295.58	1.14
101 × 100 × 2	20	35	296.45	295.54	0.91
101 × 100 × 10	30	35	296.06	295.52	0.54
101 × 100 × 5	30	35	296.03	295.49	0.54

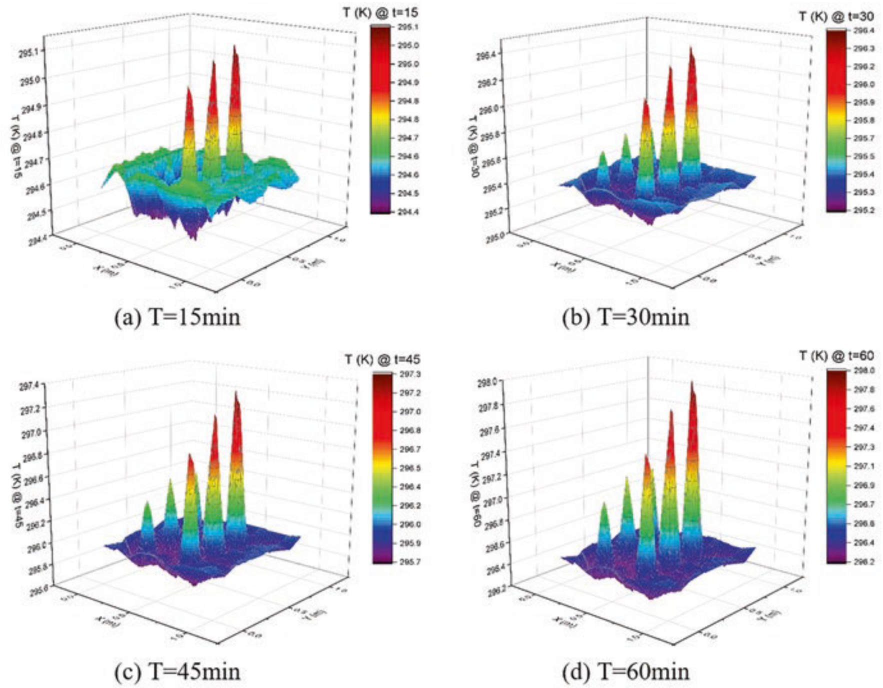
(continued)

Table 15.2 (continued)

Details about defect (mm × mm × mm)	Depth of defect (mm)	Time (min)	T_{max} (K)	T_{min} (K)	T_{diff} (K)
101 × 100 × 2	30	35	295.91	295.46	0.45
101 × 100 × 10	20	40	297.16	295.83	1.33
101 × 100 × 5	20	40	296.99	295.78	1.21
101 × 100 × 2	20	40	296.70	295.73	0.97
101 × 100 × 10	30	40	296.32	295.73	0.59
101 × 100 × 5	30	40	296.28	295.69	0.59
101 × 100 × 2	30	40	296.14	295.65	0.49
101 × 100 × 10	20	45	297.43	296.03	1.40
101 × 100 × 5	20	45	297.25	295.97	1.28
101 × 100 × 2	20	45	296.93	295.92	1.01
101 × 100 × 10	30	45	296.58	295.93	0.65
101 × 100 × 5	30	45	296.52	295.88	0.64
101 × 100 × 2	30	45	296.36	295.84	0.52
102 × 100 × 10	20	50	297.68	296.22	1.46
102 × 100 × 5	20	50	297.49	296.16	1.33
102 × 100 × 2	20	50	297.14	296.10	1.04
102 × 100 × 10	30	50	296.81	296.12	0.69
102 × 100 × 5	30	50	296.74	296.06	0.68
102 × 100 × 2	30	50	296.57	296.02	0.55
102 × 100 × 10	20	55	297.91	296.39	1.52
102 × 100 × 5	20	55	297.7	296.33	1.37
102 × 100 × 2	20	55	297.34	296.27	1.07
102 × 100 × 10	30	55	297.03	296.30	0.73
102 × 100 × 5	30	55	296.95	296.24	0.71
102 × 100 × 2	30	55	296.77	296.19	0.58
102 × 100 × 10	20	60	298.11	296.55	1.56
102 × 100 × 5	20	60	297.89	296.48	1.41
102 × 100 × 2	20	60	297.51	296.42	1.09
102 × 100 × 10	30	60	297.22	296.45	0.77
102 × 100 × 5	30	60	297.14	296.39	0.75
102 × 100 × 2	30	60	296.94	296.34	0.60

15.5 Conclusion

The civil structures over time get deteriorate and develop cracks, corrosion take place of bars, etc. Thus, there's a need to inspect the health condition of the structures before any disaster takes place. Many researchers are performing different tests to develop new and advanced methods for damage detection without affecting the structure. Thermographic NDT is one of the techniques. TNDT are gaining more attention as one of the effective NDT techniques as they're non-contact, remote sensing, time-saving and cost-saving techniques. Since there no fix data



Graph 15.2 Graphs of temperature v/s surface having 200-Watt excitation power with 5 min heating period with varying time

regarding the excitation power and heating period to be used therefore there is need to optimize the excitation power and heating period to get the proper details from the specimen.

The models of concrete block specimen were created in FEM software and lock-in infrared thermography was applied. From the thermal images of concrete block, it was observed that as the heating period is increased the visibility of the air void defects was increased. Thermal images have also shown the location of the air void defects which were at 20 mm depth from surface in 15 min of application of excitation energy and visibility of 30 mm depth defects was increased as time of application of excitation energy was increased for all heating period. Based on the temperature difference obtained on the defect, it shows that the defect located at less depth with more thickness the temperature difference was more and vice versa. The graphs of temperature v/s surface indicate peak temperature at the centre of the defect whose thickness is high and the peak changes as the depth of the defect changes.

The area of defect was found using MATLAB program. The area calculation tabulated show that the area of defect has minimal change as excitation energy was increased but changing the time period has a significant change in the area of defect. It was also observed that increasing excitation energy increases only defect surface

Table 15.3 Area of defect at 60 min having 200-Watt excitation energy

Thickness of defect (mm)	Depth of defect (mm)	Time period (min)	Actual area (cm^2)	Estimated area (cm^2)	Error (%)
10	20	5	100	88.4	−11.6
5	20	5	100	78.6	−21.4
2	20	5	100	56.8	−43.2
10	30	5	100	28.9	−71.1
5	30	5	100	12.9	−87.1
2	30	5	100	2.0	−98.0
10	20	10	100	90.8	−9.2
5	20	10	100	79.0	−21.0
2	20	10	100	58.9	−41.1
10	30	10	100	29.5	−70.5
5	30	10	100	13.0	−87.0
2	30	10	100	3.0	−97.0
10	20	15	100	90.5	−9.5
5	20	15	100	81.4	−18.6
2	20	15	100	60.1	−39.9
10	30	15	100	29.8	−70.2
5	30	15	100	13.3	−86.7
2	30	15	100	3.0	−97.0
10	20	20	100	90.2	−9.8
5	20	20	100	79.3	−20.7
2	20	20	100	54.8	−45.2
10	30	20	100	30.2	−69.8
5	30	20	100	14.3	−85.7
2	30	20	100	3.0	−97.0
10	20	25	100	103.6	3.6
5	20	25	100	86.4	−13.6
2	20	25	100	72.1	−27.9
10	30	25	100	48.7	−51.3
5	30	25	100	32.1	−67.9
2	30	25	100	5.6	−94.4
10	20	30	100	90.0	−10.0
5	20	30	100	81.4	−18.6
2	20	30	100	46.4	−53.6
10	30	30	100	31.8	−68.2
5	30	30	100	16.2	−83.8
2	30	30	100	4.1	−95.9
10	20	35	100	91.6	−8.4
5	20	35	100	82.3	−17.7
2	20	35	100	58.8	−41.2
10	30	35	100	30.3	−69.7
5	30	35	100	15.1	−84.9

(continued)

Table 15.3 (continued)

Thickness of defect (mm)	Depth of defect (mm)	Time period (min)	Actual area (cm^2)	Estimated area (cm^2)	Error (%)
2	30	35	100	3.1	−96.9
10	20	40	100	97.2	−2.8
5	20	40	100	82.9	−17.1
2	20	40	100	66.6	−33.4
10	30	40	100	31.6	−68.4
5	30	40	100	15.9	−84.1
2	30	40	100	3.9	−96.1
10	20	45	100	104.3	4.3
5	20	45	100	92.2	−7.8
2	20	45	100	75.5	−24.5
10	30	45	100	45.4	−54.6
5	30	45	100	25.9	−74.1
2	30	45	100	4.8	−95.2
10	20	50	100	109.8	9.8
5	20	50	100	94.6	−5.4
2	20	50	100	74.8	−25.2
10	30	50	100	69.3	−30.7
5	30	50	100	52.8	−47.2
2	30	50	100	10.1	−89.9
10	20	55	100	108.8	8.8
5	20	55	100	99.0	−1.0
2	20	55	100	92.6	−7.4
10	30	55	100	98.5	−1.5
5	30	55	100	97.1	−2.9
2	30	55	100	72.5	−27.5
10	20	60	100	90.0	−10.0
5	20	60	100	64.1	−35.9
2	20	60	100	40.9	−59.1
10	30	60	100	69.9	−30.1
5	30	60	100	53.7	−46.3
2	30	60	100	7.6	−92.4

temperature having the similar area as that of lower excitation energy. The area of defects estimated at 60 min for 55 min time period were close to the actual area of defects with minimum error. Based of FEM stimulation it is concluded that 55 min time period is better to find defects and defects area for 60 min duration.

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Chapter 16
Eco-Friendly Concrete Admixture from Black Liquor Generated in Pulp and Paper Industry

A. K. Dixit, Kumar Anupam, and M. K. Gupta

Abstract Black liquor, a lignin rich colloidal suspension, generated during pulping of lignocellulosic bio-resources in pulp and paper industry is often considered as a waste. Though a waste, it is a valuable resource for producing fuels, chemicals and several other value added products. Cement admixture is yet another value added product that can be developed from pulp and paper industry black liquor. Researchers around the world are concerned towards reducing the consumption of cement in construction due to the hazards of carbon emissions associated with it production process. Efforts are being made to develop admixtures which can reduce the quantity of cement clinker and at the same time preserve the quality of concrete. Use of admixtures in concrete is aimed towards resource conservation by reducing water requirement and energy consumption. In this series, black liquor has been found to be an effective admixture for concrete by researchers. Nevertheless, the performance of cement admixture depends on the physico-chemical properties of black liquor used. This paper aims to review the research carried out on utilization of black liquor as admixture in construction industry. It describes different types of admixture developed from black liquor such as set retarder admixture, viscosity modifying admixture etc. It discusses the effect of physico-chemical properties of different types of black liquor generated from variety of biomass based on different pulping processes. It reflects the performance of black liquor as admixture in terms of properties such workability, compaction, honeycombing, settling time, storage time, viscosity modification, shrinkage, compressive strength, tensile strength etc. Finally, this paper presents relevant conclusion drawn from different studies and advocates effective utilization of black liquor as admixture in construction industry.

Keywords Agro-waste · Lignin · Lignosulfonate · Pulp and paper · Waste management

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16.1 Introduction

Two major alkaline pulping processes to produce chemical pulps include Kraft (or sulphate) and soda. During chemical puling process, lignin is dissolved in cooking liquor and cellulose fibres are disassociated from lignin. The pulping process conducted in a pressurized digester at elevated temperatures. Typically, cooking liquor is made of Sodium Hydroxide (NaOH) or in Kraft process, Sodium Sulfide is also used. During the final pulping stages, significant amount of lignin condensation reactions take place resulting in a high molar mass lignin entity. Molar mass of lignin increases appreciably at the end of cooking, which results in a complex polymeric structure of lignin in comparison to cellulose, hemicelluloses and organic acids present in black liquor. This high molar mass lignin is difficult to biodegrade. In wood based mills where chemical recovery operations are successful, these lignin laden black liquor is combusted in boiler to recover energy. However, in majority of the small agro based mills, where chemical recovery is not feasible this lignin rich black liquor, till last decade, was discharged and caused several problem of pollution. As a consequence, the small agro based mills which once used to contribute nearly 30% of the total paper production in the country is now presently contributing merely 8.57%. In India where wood is deficient and the cost of recycled fibre import is exceeding; revival of agro based mills is very much anticipated. This revival is possible only when lignin rich black liquor produced in these mills can be managed through utilization in some value added applications. One such option is its use as concrete admixture.

A material other than water that is used as a component of concrete or mortar and is added to the batch immediately before or during mixing to modify one or more properties of Concrete is known as a concrete admixture. Depending on application, these can be accelerator additives, retarder additives, water reducing additives, air inlet additives, superplasticizer additives, and superplasticizer retarder additives. The use of these chemical additives in concrete is increasing rapidly in India. The number of industries producing additives has grown tremendously as awareness of the usefulness of these additives increases. There is no doubt that the use of admixtures has greatly influenced concrete pouring practice in India in recent years. Concrete is a range of graded aggregates (coarse and fine) that are connected together by a hardened cement paste. The concrete must be strong, free from excessive changes in volume and resistant to the ingress of water. The strength of the concrete results from the hydration of the cement by the water. The cement ingredients progressively crystallize to form a gel or paste that surrounds the graded aggregate and binds them together to create a conglomerate. In general, the strength and permeability of concrete are determined by its water and cement content. For high strength and low permeability, the ratio of cement to water should be low. Conversely, for ease of placing and compaction the easiest way of increasing workability is to increase the free water content. Nowadays chemical admixtures (plasticizers and water-reducing agents) are used for better strength and workability of cement.

On account of the fact that the admixture industry has emerged well with the time, use of lignin/lignosulfonate from agro based paper mills as concrete admixture can increase the profitability of agro based mills since these mills are struggling to survive. This will also help in resource conservation and at the same time will reduce import bill of the country. Hence, in order to understand the role of black liquor/lignin/lignosulfonate based admixture in cement this article is aimed to present an overview on utilization of black liquor as admixture in construction industry. The reminder of the article is sectionized as follows. Section two gives a brief account of black liquor, lignin and lignosulfonate. It describes the characteristics of black liquor obtained from pulping of different agro based raw materials, lignin and lignosulfonates. Section three presents an overview on different applications of black liquor and lignosulfonates as concrete admixture. In last, section four outlines relevant conclusion drawn from the study.

16.2 Black Liquor, Lignin and Lignosulphonate

16.2.1 Black Liquor

The spent pulping liquor, known as black liquor, is a complex mixture of organic and inorganic compounds with organic to inorganic ratio of 70:30. Table 16.1 shows the typical analysis of black liquors obtained from bagasse, wheat straw and rice straw. The black liquor consists of dissolved lignin as well as other carbohydrate polymers and has different combustion and transport properties compared to cooking liquor. The amount of lignin present in black liquor varies from 30% to 40% and has an extremely high cost value. Typical pulp mill operation contains a chemical recovery system to recover as many as chemicals as possible as well as to use the

Table 16.1 Characteristics of different black liquors

Parameter	Unit	Bagasse	Wheat straw	Rice straw
pH		12.5	12.3	11.2
Total solid	% w/w	13–16	13–16	16–18
Inorganics as NaOH	% w/w	33–35	34–36	35–36
Organics	% w/w	65–67	64–66	65–64
Chlorides as NaCl	% w/w	0.7–0.9	1.3–1.7	1.0–1.2
Silica as SiO_2% w/w	% w/w	1.0–1.5	2.5–3.0	0.05–0.1
Residual active alkali	g/l as Na_2O	5–7	5–7	5–6
Swelling value ratio	ml/g	13–15	9–13	20–25
Calorific value as GCV	cal/g	3100–3200	3050–3150	3000–3100
Carbon as C	% w/w	34–35	32–33	32–34
Hydrogen as H	% w/w	4.1	2.9	3.2
Nitrogen as N	% w/w	0.3	0.4	0.4
Sulphur as S	% w/w	0.5	0.5	2.0

Table 16.2 Viscosity levels of different black liquors

Raw material	Viscosity, mPa-s at 100° at total solids % w/w				
	45	50	55	60	65
Pine	9.1	18	40	160	215
Eucalyptus	2.3	83	380	490	640
Eta reeds	41	100	395	470	615
Bamboo	2	11	31	125	398
Wheat straw	40	89	299	450	1000
Bagasse	125	161	912	1100–1250	3100–3300
Rice straw	112	316			

lignin as energy source in recovery boiler to reduce the load on ETP plant. However, the efficiency of the chemical recovery system majorly depends on the raw material used, pulping method and the behaviour of the black liquor during evaporation and combustion. Since viscosity of agro-based liquor is higher compared to wood black liquor, agro-based black liquor is difficult to process. Table 16.2 shows the viscosity of black liquor obtained from different papermaking raw materials at different solids.

16.2.2 Lignin

Lignin is one of the natural polymers found in wood and accounts for around 30% of the weight. It is even the second most common organic substance in the world after cellulose. The chemical structure of lignin, like that of many other natural polymers, is very complex. As lignin is normally insoluble in non-polar and organic solvents, a frequent method used to separate cellulose from lignin is to treat wood chips with a chemical solution at high temperatures. Lignin is a complex colloidal molecule. During pulping part of the lignin gets dissolved and major portion is solubilized as large colloidal macro molecule. The nature of lignin in black liquor depends mainly on raw material; the pulping conditions employed like the cooking chemical charge, temp, time, steam pressure, etc. and the pulping process adopted viz. soda, sulphite or Kraft. Table 16.3 illustrates the physicochemical characteristics of the commercially available lignin isolated from agro residue black liquor. The chemical structure of lignin is shown in Fig. 16.1.

16.2.3 Lignosulfonate

By virtue of their exceptional properties, lignosulfonates are widely used, among others in animal feed, pesticides, surfactants, oil well additives, stabilizers in colloidal suspensions and as plasticizers in concrete additives. Lignosulfonates can be polymerized, hydrolyzed, halogenated, nitrated, oxidized, dehydrogenated or

Table 16.3 Characteristics of lignin from agro based black liquor

Parameters (On dry wt. basis)	Values	
	Crude lignin	Washed lignin
Moisture on as such basis%	78.9	80.0
Ash%	16.5	11.7
Lignin purity%	73.4	80.1
Silica%	8.0	8.2
Sodium%	1.03	0.4
Sulphates%	1.15	0.17
Chloride%	1.16	0.64
Elemental analysis	Carbon – 47.5% Hydrogen – 5.2% Nitrogen – 1.5% Sulphur – 3.1%	Carbon – 49.24% Hydrogen – 5.03% Nitrogen – 1.17% Sulphur – 3.485
Gross calorific value cal/gm	5535	6381

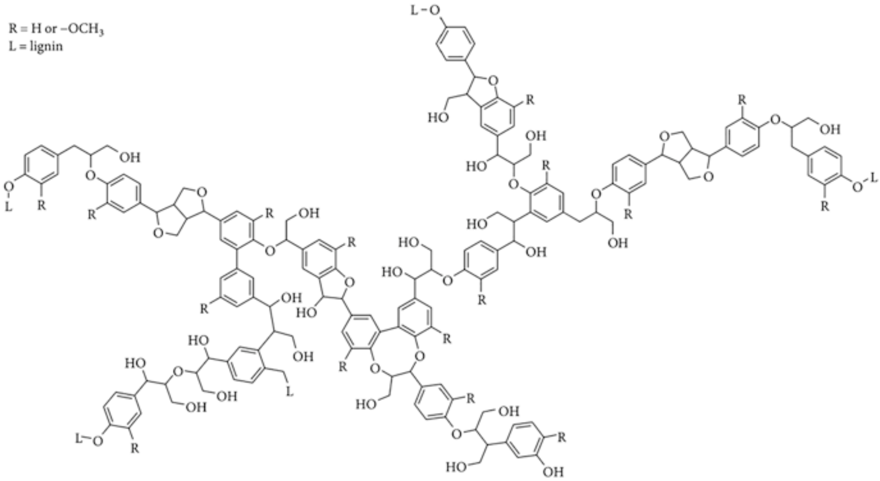

Fig. 16.1 Chemical structure of lignin (Lu et al. 2017)

desulfonated. They can enter into mixed dimeric reactions with other functional groups, for which they are excellent fillers. Polysaccharide groups can be oxidized, inverted, or removed by molecular separation processes. Depending on the specific application lignosulfonates can be available in a number of different bases such as sodium lignosulfonates, magnesium lignosulfonates, calcium lignosulfonates, and ammonium lignosulfonates. Figure 16.2 shows the appearance of different types of Lignosulfonate available in the market. The general properties of lignosulfonate include Sulfur amount 3.5–8.0 wt %, Sulfonated content [mmol g^{-1}] 0.5–10, Charge density [meq g^{-1}] 0.9, *M*W [g mol^{-1}] 1000–150,000 (Aro and Fatehi 2017). The market volume for lignosulfonates was $700 million in 2015 and is forecast to grow

Fig. 16.2 Appearance of Lignosulfonate available in the market (Source: https://www.greenagrochem.com)

by more than 3.5 GR by 2024, propelled by strong expansion in the construction segment. It is mainly employed as a water reducing chemical and gives cement the essential workability much at inflated temperatures. Conditions such as infrastructure expansion and population surge in the BRIC countries will stimulate the market for lignosulfonates in the residential and non-residential sectors. In addition, the low cost of the product causes them more appropriate for exploitation in those countries where the need for water reducing chemicals is substantially higher.

16.2.3.1 Sodium Lignosulfonates

Sodium lignosulfonate is obtained from the digestion liquid by purification, evaporation, chemical treatment and drying. Sodium lignosulfonate is a natural anionic surfactant made from a high molecular weight polymer, abundant in sulfo and carboxyl groups, and has superior water solubility, surfactance, and dispersibility. It

Table 16.4 Specification of Lignosulfonate available in the market

Name	Grade one	Grade two	Grade three
Product code	GAC-NaLS-1	GAC-NaLS-2	GAC-NaLS-3
Appearance	Brown powder	Brown powder	Brown powder
pH	7.0–9.5	9.0–13.0	4–7
Dry matters	95%	95%	95%
Water-insoluble	1.5% max	2% max	2% max
Water reducing capacity	8% min	5% min	8% min
Sulphate	2–5%	0	1–2%
Calcium and magnesium	0.5 max	0.5 max	5% around
Lignosulphonate	55% min	60% min	50% min
Reducing sugar	7% max	7% max	10% min
Moisture	7% max	7% max	7% max

Source: https://www.greenagrochem.com

can be utilized for several different industries. Sodium lignosulfonate (lignosulfonic acid, sodium salt) can be utilized in the food industry, as a defoamer for paper production and in adhesives for food contact. It has preservative characteristics and is employed as a constituent in animal feed. It is also implemented in construction, ceramics, mineral powder, chemical industry, textile industry (leather), metallurgy, petroleum industry, fire retardant materials, rubber vulcanization and organic polymerization. Typical applications of sodium lignosulfonates include dispersant for concrete additives; plastifying additive for bricks and ceramics; tanning agents; deflocculant; bonding agent for fibre boards; binding agent for moulding of pellets, carbon black, fertilizers, activated carbon, foundry moulds; and dust reduction agent during spraying for non-asphalted roads and dispersion in the agricultural domain. Table 16.4 displays the properties of typical Sodium Lignosulfonate manufactured from spent sulphite pulping liquor**.**

16.2.3.2 Calcium Lignosulfonates

Calcium lignosulfonate additive has been utilized in the food industry for several years and is used, e.g., as an emulsifier in animal feed, as a raw material in the making of vanillin, etc. Other typical applications of Calcium Lignosulfonates include Concrete, Plaster Board, Activated carbon, Carbon Black, Agglomeration, Chip Board, Ceramics, Resins PF, Soil stabilization, Tanning, Pigments, Pellet Binder, Corrugated Flute, Chemicals, Fertilizers and Dyestuff.

16.2.3.3 Magnesium Lignosulfonates

Typical applications of magnesium sulfonates include concrete, ceramics, paperboard, oil well drilling, ore flotation, fertilizers, wetting agent.

16.2.3.4 Ammonium Lignosulfonates

Typical applications of ammonium lignosulfonates involve for concrete additives; plastifying additive for bricks and ceramics; tanning agents; deflocculant; bonding agent for fibreboards; binding agent for moulding of pellets, carbon black, fertilizer, activated carbon, foundry moulds; dust reduction agent during spraying for non-asphalted roads and dispersion in the agricultural domain.

16.3 Black Liquor/Lignosulfonateas Cement Admixture

Lignosulfonate from alkaline sulphate pulping could be used as a source of retardant in concrete admixtures. Literature on evaluation of lignosulphonate indicated good possibility of utilizing these sodium based lignosulphonate as retardant in concrete admixture. Application of Lignosulfonate from black liquor has been utilized as concrete admixture since 1930s. By virtue of its special morphology, with particular functional groups like -SO_3^{2-}, -OH^-, and -O^-, lignosulfonates possess a considerable degree of reactivity and find a wide utilization in manufacturing water-reducing admixtures (Lou et al. 2013; Yu et al. 2013; Zhang et al. 2015). In order to maintain both workability and strength, water to cement ratio has to be optimized. When more water is added, workability of the cement is increased, but strength decreases (Nikhil and Jayasree 2018). Admixtures are specifically used for increasing the workability with minimum water cement ratio. However, admixtures should not decrease the strength of the cement.

The major benefit of water reducers is to diminish the water quantity by 5–10% to enhance the strength of the concrete by adequate to 25% for a provided fluidity (Yu et al. 2013). In general, the water reduction rate of typical plasticizers is less than 12%, however, it can be reduced over 12% by using superplasticisers. Commonly used admixtures or super plasticizers are lingo-sulphonates and hydrocarbolic acid salts. They are usually based on lignosulphonates, which are derived from wood pulping liquor (Nikhil and Jayasree 2018).

To obtain finished solid material as lignosulfonate, black liquor is treated by filtration, evaporation, sulphonation and drying in spray drier (El-Mekkawi et al. 2011). However, this process can be high-priced due to the cost of the sulfonation process, since the separation of the lignin from the black liquor is a very complicated operation. Bagasse pulp liquor, which is a by-product of the digestion process, may too be employed like a chemical mixture in building materials (Ananthkumar et al. 2018). The replenishment of 1% of water by black liquor from the digestion of bagasse enhances the freshness of the concrete and the substitution of 2% of water by black liquor improves the mechanical features of the concrete and functions as a setting retarder (Ananthkumar et al. 2018).

Lignosulfonates obtained from acidic pulping process can also be utilized like a workability boost for cement. Alkali lignin can be recovered form black liquor and after sulfonation may be employed like a cement admixture (El-Mekkawi et al.

2011). Sodium Lignosulfonate can be modified via combined oxidation-sulfomethylation to increase the fluidity of cement by 15% (Lu et al. 2017). Various dosage of black liquor generated by Rakta Pulp and Paper Mill form soda pulping process of rice straw with 10% total solids content was used as a cheaper cement admixture to enhance workability and impede setting of concrete (El-Mekkawi et al. 2011). The results showed that the when the black liquor is mixed directly with cement as admixture, it increased compressive strength of cement by 85% when 15% water was replaced by black liquor.

El-Mekkawi et al. (2011) explored different possibilities of using black liquor from rice straw pulping from different mills in Egypt to explore the possibility of using black liquor directly as cement admixtures. Black liquor from soda pulping of rice straw was examined at 10% total solids and added to the cement as admixtures in different proportion to evaluate its effect on strength and water reducing capacity. It was found that black rice straw liquor can be used as an inexpensive additive to enhance workability and delay the setting time of concrete. Black liquor made from rice straw improved the compressive strength of concrete by 85% with a 15% substitution of water by black liquor. Based on the results of the chemical analysis of the hardened concrete, it was also determined that the black liquor is safe for reinforced concrete, and it was determined that the admixture meets the pertinent Egyptian standards (El-Mekkawi et al. 2011).

Takahashi et al. (2014) explored a process of developing a water-reducing admixture in concrete from soda-AQ lignin in black liquor. The wheat straw lignin obtained from soda pulping black liquor was sulphonated and used as an additive for concrete, which demonstrated the reducing impact of water on concrete. Soda-AQ lignin precipitated from black liquor by lowering its pH from 10.5 to 2.0 using 20% sulphuric acid. The precipitated soda-AQ lignin was recovered by centrifugation. Soda-AQ lignin extracted below pH 8.5 was found to perform better as a water reducing admixture than extracted at pH 10.5. The assessment of Soda-AQ-Lignin also made it clear that Soda-AQ-Lignin with a relatively lower molecular weight and a higher content of phenolic hydroxyl groups might be more suitable like a water reducing admixture (Takahashi et al. 2014).

Zhang et al. (2015) examined how water-reducing rate, setting time and compressive strength of concrete get influenced with black liquor ratio in concrete. The black liquor graft polymerization process with sulfonated acetone-formaldehyde was investigated. The black liquor was acquired by sulfate cooking of wheat stalks having 69.3% lignin and 19.5% ash. To synthesize the BSAF (black liquor sulfonated acetone formaldehyde) copolymer, a solution of black liquor, hydrogen peroxide, and ferrous sulfate was heated to 60 °C with stirring. After the post-sedimentation time of 60 min, formaldehyde was added to initiate polymerization, which was carried out at 95 °C for 2 h. A BSAF copolymer was obtained with a solids content of 32% and a pH in the range 12–13. It was found that increasing BSAF gradually enhanced the water reduction rate of the concrete and significantly increased the setting time of the concrete. BSAF also improved the long-term compressive strength of concrete (Zhang et al. 2015).

Ananthkumar et al. (2018) investigated the use of bagasse black liquor as a cement admixture. Black liquor was added to the fresh concrete mix in various doses of 1–5% substitute of water by black liquor to investigate the effect on workability, compressive strength, flexibility, tensile strength and setting duration. It was found that the maximum processability was detected with a 2% substitute of water with black liquor. The utmost compressive strength was noted for a 1% substitution of water for black liquor. With a 2% substitution of water for black liquor, the maximum setting time was seen. The substitution of 2% water by black liquor boosts the mechanical characteristics of concrete and functions as a setting retarder. Experiments and results also showed that black liquor had a lower accomplishment with respect to lignosulfonate additives found in market for producing self-compacting concrete (Ananthkumar et al. 2018).

Yu et al. (2013) investigated a way to modify sodium lignosulfonate by combined oxidative sulfomethylation to make concrete superplasticizers. The black liquor was produced from the alkaline sulphite cooking of a raw material furnish having 80% reed and 20% wheat straw. The chemical characteristics of black liquor demonstrated pH: 8.16, Solids: 16.48%, Organics: 10.88%, Inorganics: 5.6%, Hemicellulose: 0.59% and Sodium Lignosulfonate: 12.69%.Sodium lignosulfonate superplasticizer was synthesized by mixing black liquor, PAA solution and $FeSO_4$ and heating the mixture to 60–100 °C with agitation of 800 rpm. After oxidation time of 0.5–3 h, formaldehyde and sodium sulphite were added and sulfomethylation reaction was conducted at 80–100 °C for reaction time of 1–4 h. Once the solution temperature became ambient it was processed in a spray drier. It was established that the fluidity and water reducing capability of sodium lignosulfonate improved significantly when the sodium lignosulfonate was prepared by oxidation at 80 °C for 2 h with 30% PAA and 0.5% $FeSO_4$ and sulfomethylation at 95 °C for 3 h with 20% formaldehyde and 30% Na_2SO_3 (Yu et al. 2013) .

Lou et al. (2013) used wheat straw kraft pulp black liquor and synthesized lignin-based superplasticizers applying H_2SO_4 acid precipitated lignin. Sulfonated graft lignin of medium molecular weight and content of sulfonic groups has been found to exhibit excellent dispersion in the cementite system. It was also noticed that the molecular weight of the sulfonated graft lignin intensified with the concentration of reactant and the dose of acetone and formaldehyde, while the opposite was noted with the rise in the dose of the sulfonating agent. The content of sulfonic acid groups of the sulfonated graft lignin boosted with the dose of the sulfonating agent. The sulfonated graft lignin produced had high water-reducing ability, low slump loss, and intense compressive strength. Higher molecular weight grafted sulfonated lignin had a higher dispersion performance (Lou et al. 2013).

Nikhil and Jayasree (2018) examined a possibility of using black liquor sludge as super plasticizer. The black liquor sludge that was used possessed the following properties – pH: 8, BOD: 16000 mg/l, Chlorides: 375 mg/l, Sulphides: 300 mg/l, Total solids: 9105 mg/l, TDS: 2115 mg/l and TSS: 6990 mg/l. Water was replaced by black liquor for 5%, 10%, 15% and 20% of water. It was established that the black liquor encourages concrete workability, enhances compaction and decreases honeycombing when 15% of water was replaced by black liquor. All the mechanical properties of the cement were found to be within acceptable limits and satisfied IS (Indian Standards) specifications. It was observed that black liquor sludge can be effectively used as admixture in concrete for increasing workability for both strength and high strength mixes. It could also be used for structural applications (Nikhil and Jayasree 2018).

Nadif et al. (2002) utilized soda black liquor to obtain sulphur-free lignin by virtue of acid precipitation. The performance of sulfur-free lignin was also compared to existing additives available in the market like naphthalene sulfonates and lignosulfonates. The nature of lignocellulosic source plant form which the lignin got extracted, and the pulping process that was adopted by the pulp mill mainly dictated the performance of the lignin. Many of the flax lignins have been found to behave superior to lignosulfonates, which implies that this sulfur-free material can also be used as a replacement for sulfur-comprising admixtures. It was also observed that hemp lignin admixture performed better in terms of flow of mortar compared to wheat straw lignin admixture and flax lignin admixture performed better than both the hemp lignin admixture and wheat straw admixture. With every lignin investigated, from flax, hemp and what straw, mortar flow improved and some sulfur-free lignins obtained from the acid precipitation digestion process of soda exceeded market requirements (Nadif et al. 2002).

Kamoun et al. (1999) mixed black liquor with minor quantities of sulfonated naphthalene-formaldehyde polymer to make a useful cement dispersant with long-lasting effects. The mixture was prepared using 87% active matter of sulfonated naphthalene and formaldehyde condensate in brown powder form mixed with residual black pulping liquor containing lignin, reducing sugars, organic salts, mineral salts and free soda. It was observed that the admixture prepared by mixing black liquor with sulfonated naphthalene formaldehyde polymer ensured high plasticity and durable action. It has also been observed that the qualities of cement mortar, particularly plasticity, can be monitored by altering the proportion of sulfonated naphthalene-formaldehyde polymer and black liquor. It was found that the degree of plasticity is determined mainly by the proportion of sulfonated naphthalene-formaldehyde polymer, but then again, its durability is determined by the proportion of black liquor (Kamoun et al. 1999).

Darweesh (2016) studied high molecular weight lignosulfonates acquired as a consequence of the acid sulfate wood pulp process. The main function of retarding water-reducing admixtures has been found to be to retard the setting duration of concrete, which has a detrimental impact on successive strength improvement, while allowing a subsequent reduction in the water-cement ratio. . To estimate the effect of adding cellulose black liquor to the cement, the black liquor was dispersed in the mixed water in a dose of 0–3% and then added to ordinary and limestone Portland cement. Black liquor was detected to drop the setting duration of both the ordinary and limestone Portland cement. The compressive strength of hardened cement pastes has been increased. It was also noted that the water consistency of both types of cement increased gradually with the concentration of black liquor i.e. up to 31.67% from 28% for ordinary Portland cement and up to 32.45% from 28.5% for limestone Portland cement (Darweesh 2016).

Dixit et al. (2009) prepared lignin based chemical admixtures to be used in OPC (ordinary Portland cement) and investigated its hydration behaviour. They performed experiments for 3 days, 7 days and 28 days respectively to evaluate the water consistency, setting duration and compressive strength of cement mortar prepared using this chemical admixture. The overall mechanism of the working of lignin as plasticizers during the hydration of OPC was presented. It was found that the initial and final settling time of OPC increased tremendously by mixing 1–2% lignin by weight of cement. By mixing 1% lignin the initial and final settling time increased by 120 and 115 minutes respectively and by mixing 2% lignin the initial and final settling time increased by 150 and 170 minutes, respectively. Also, the compressive strength of OPC mortar one part cement and three parts sand in the presence of 0.3% lignin on cement basis increased by 3.5, 0.8 and 1.4 MPa respectively after 3, 7, and 28 days.

16.4 Conclusion

Lignosulphonates obtained as waste by-products from pulp and paper mills was established to function suitably like retardant in mortar/concrete admixture by various researchers. The compressive strength of admixtures may be improved significantly with the use of pulp and paper mill based lignosulphonates. Employing the processes discussed above the waste lignosulphonates thus obtained as waste by product could probably be efficiently used as an industrial product meeting the standards or any other specification. Saleable by-product thus developed could improve the economics of the paper mills employing lignin removal process which may assist paper mills in obtaining zero liquid discharge.

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Chapter 17
Behavioural Study on Concrete with Organic Materials for CO_2 Absorption

K. Srinivasan and M. C. Sashikkumar

Abstract From the past two decades, the emission of carbon dioxide has been increased dramatically across the globe. Concrete is the widely used versatile construction material. Hence, this research work was conducted in order to control the emission of carbon dioxide with the help of this widely used material for a sustainable environment. An attempt has been made in the admixing of processed organic materials such as potato peel and seaweed in different proportions to the concrete mixture. Different proportion of mix were the addition of seaweed at 5% by weight of the cement, potato peel at 5% by weight of the cement, both potato peel and seaweed at 5% each by weight of the cement. Test methods such as carbonation and titration method were conducted to find the carbon dioxide absorption percentage; along with the conventional pressure sensitive test at 28 and 56 days. Combined addition of potato peels and seaweeds have improved the compressive strength, carbonation depth and amount of carbonation absorbed. When comparing the specimens with both potato peel and seaweed cured at 28 days and 56 days have showed in the ranges between 42.6 and 45.5 MPa; between 1.9 and 2.4 g; and between 1.9 and 2.6 mm, respectively.

Keywords Carbonation depth · Absorption of CO_2 · Potato peel · Seaweed · Amount of CO_2 absorbed

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17.1 Introduction

Across the globe, it is evident that the amount of CO_2 concentration in the atmosphere has increased to multi fold, including the contribution by the cement manufacturing industry (Carstensen and Rapf 2008). Though globalisation and industrialization were the primary reasons, significant contributions were through the adoption of various methods, processes, technologies, deforestation and societal ignorance by human kind. Ecological balance and environmental stability are the two essential aspects that the human kind to be taken cared. Global warming has occurred more than two decades due to the emission of greenhouse gases that has accounted for nearly 72% of the total emissions of both CO_2 and greenhouse gases. The major CO_2 gas is released from vehicles. Particularly, the emissions due to CO_2 have changed dramatically and have increased in the last five decades with the present increment of almost around 3% every year. The influence of the wants and needs of infrastructure development has made the human kind to utilize various natural resources that had depleted the sources. Among the widely used materials, concrete is the most used versatile material across the globe and presently, it is the need for a greener concrete (Tanaka and Stigson 2009). Due to its flexibility and simplicity in its manufacturing, the material was extensively used for infrastructure development both in the urban and rural areas.

However, concrete do have certain deficiencies over a period of its use. Most important deficiency is its durability aspects. Because concrete has two stages for its use viz. fresh and set concrete; and concrete (Neville 1995) is a heterogeneous material where it is susceptible to natural formation of porosity due to the addition of varied sizes of ingredients. The porosity, over the ages of concrete has a tendency to absorb/allow materials from environment due to its capillary action. It is drastically getting increased leading to serious effects like global warming. To control this, CO_2 absorbing concrete cubes was made by using the organic materials such as potato peels and seaweeds.

17.1.1 Potato Peels in Concrete

Though potatoes are rich in potassium, phosphorus, magnesium and nitrogen. Raw or cooked sources of potato peel, regardless of cooking methods, contains good sources of protein, fibre and ash content. However, after effectively utilized in the food industry, there were increased concern over the disposal of potato peels that it might contain potato blight, a type of fungus that causes problems in decomposition or environmental concern because of possible microbial spoilage. Valorisation of potato peels are in the construction industry, environmentally friendly light weight bricks, generation of biomass/biogas; other potential uses of potato peels are in abundant nutritive materials, apoptotic, antibacterial, low value animal feed, agricultural fertilizer, antioxidant, anti-inflammatory and chemo-preventive (Nandita and Rajini 2004). Presence of significant sources of Chlorpropham, used during the storage process of potatoes are also a great concern to be considered. It is to mention here that, there were no studies conducted on the significant utilization and/or inclusion of potato peels in the manufacturing of concrete. Hence, in the present study, to assess the potentials, an alternate way to utilize the waste sources were carried out.

17.1.2 Seaweeds in Concrete

Though the characteristics of seaweeds were that as a bio-degradability material but it provides heat insulation and heat capacity. Seaweeds (Brown 1998) are available as an abundant material across regions with higher humidity, where these could be obtained as a natural waste material. Seaweeds (Majid et al. 2019) have good sources as gel and thickening agent or resin characteristics that it could be used as binder material in the concrete composite. Seaweeds are used in the construction industry in order that it has improved the bond strength, improved strength and durability, and has potential to be utilised as an additive in the manufacturing of concrete. Hence, the CO_2 absorbing capacity was assessed in the present study, seaweeds were added both as individually and combined with potato peels.

17.2 Experimental Methods

17.2.1 Materials Used

In the present study, PPC 53 grade was used as binder material. Clean river sand was used as fine aggregate in accordance with IS: 383 and conforming to Zone – II with a specific gravity of 2.67. Broken granites was used as coarse aggregate with sizes range between 10 and 12 mm with the specific gravity of 2.88. Potable quality tap water was taken during the preparation of the mix. A water binder ratio of 0.39 was adopted with regard to the consistency of the binder material. Curing periods of 28 days and 56 days were adopted.

Potato peels were obtained as a waste material from food manufacturing industries. The sources of the skins of potatoes were potassium, further, it offers good adhesive and can be used as a binding material. Figure 17.1 shows the potato peels used in the present study. The peels were dried in a compact fluidized bed heater at 80 °C for a period of 3 h or until the peels were completely dried. Then the dried peels were ground finely into powdered and were used in the manufacturing process of concrete.

Seaweeds were obtained from commercial source and were used in the present investigation in order to fix the CO_2. Figure 17.2 shows seaweeds of the type Eucheuma Cottonii, that were used in the present study. The seaweed gels were

Fig. 17.1 Potato peels as obtained from the food manufacturing industries

Fig. 17.2 Seaweed as obtained from commercial source

dried in a compact fluidized bed heater at 80 °C for a period of 3 h or until the peels were completely dried. Then the dried peels were ground finely into powdered and were used in the manufacturing process of concrete.

17.2.2 Preparation of Specimens

Concrete mix grade of M_{40} in accordance with standard guidelines (IS 456 2007) and (IS 10262 2009) were adopted. Initially, binder materials and powdered peels and weeds were mixed thoroughly, and fine and coarse aggregates were added. The dry ingredients were mixed well. Then water was added as per the water cement ratio. Addition of peel powder, weed powder and combined peel and weeds powder in the mix were at 5% each by the weight of cement. Water reducing admixture of 0.3% by weight of cement was taken and added during the preparation of mix. Table 17.1 shows the details of specimens prepared for 28 days curing period and Table 17.2 shows the details of specimens prepared for 56 days curing period. Required number of cube specimens of size 150 × 150 × 150 mm were prepared as per the standard procedure. The specimens were then cured for the periods of 28 days and 56 days. After curing, the specimens were allowed to sun dried and kept ready for various tests. Figure 17.3 shows portion of specimens kept ready for tests.

Table 17.1 Details of preparation of specimens for 28 days

S. no.	% of addition	Specimens		
		Compressive strength test	Carbonation test	Titration method
1	Control	CS1 – CS3	CT1 – CT3	TM1 – TM3
2	5% of potato peels	CS4 – CS6	CT4 – CT6	TM4 – TM6
3	5% of seaweeds	CS7 – CS9	CT7 – CT9	TM7 – TM9
4	Combined 5% of potato peels & 5% of seaweeds	CS10 – CS12	CT10 – CT12	TM10 – TM12

Table 17.2 Details of preparation of specimens for 56 days

S. no.	% of addition	Specimens		
		Compressive strength test	Carbonation test	Titration method
1	Control	CS13 – CS15	CT13 – CT15	TM13 – TM15
2	5% of potato peels	CS16 – CS18	CT16 – CT18	TM16 – TM18
3	5% of seaweeds	CS19 – CS21	CT19 – CT21	TM19 – TM21
4	Combined 5% of potato peels & 5% of seaweeds	CS22 – CS24	CT22 – CT24	TM22 – TM24

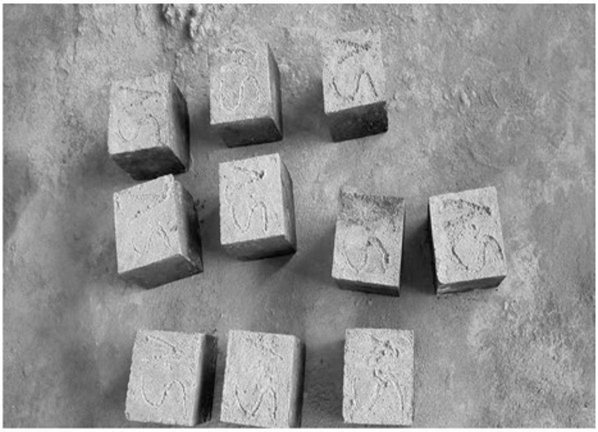

Fig. 17.3 Portion of specimens kept ready for tests

17.2.3 *Testing of Specimens*

17.2.3.1 Compressive Strength

Compressive strengths of the specimens were obtained using a standard compressive testing machine. Uniform loading was applied at a constant load rate until the failure of specimen and loading was stopped. Measurements were taken at the maximum failure load and tabulated. Compressive strength was calculated using the standard formula. Figure 17.4a, b shows the testing arrangements.

17.2.3.2 Titration Method (Deziel 2018)

Cured and dried concrete specimens were wiped off and placed in the laboratory CO_2 atmosphere. Laboratory CO_2 gas was produced using Sodium Carbonate and Sodium Chloride. A mix of 106 g of Sodium Carbonate and Sodium Chloride produces 44 g of CO_2. Hence, inside the chamber, a known quantity of the mix was placed. The initial amount of CO_2 gas was as 44 g and the final reading after passing it through the concrete cubes was noted. The difference in the g was noted as the amount of CO_2 absorbed by the specimen. The amount of CO_2 was calculated using the Titration method.

For this test, the concrete cubes were kept in air tight chamber in which CO_2 gas was produced by the mixture of sodium carbonate and hydrochloric acid. The mixture produces CO_2 gas, water and sodium chloride salt. The produced CO_2 gas was allowed to pass into the air tight chamber where the concrete cubes was placed for a period of 24 h. After 24 h, the remaining unabsorbed gas was collected into a balloon containing excess of Sodium Hydroxide solution through absorption and was converted into Sodium Carbonate for an equivalent amount. Presence of CO_2 in such a closed environment provides the necessary contact period with NaOH for complete absorption. The mixture containing excess of Sodium Carbonate and Sodium Hydroxide was treated with standard Hydrochloric Acid. The Titration 1 was carried out with the first colourless phenolphthalein indicator endpoint that the neutralization have caused the excess Sodium Hydroxide and was converted to Sodium Bicarbonate from Sodium Carbonate. Continuation to this, Titration 2 was carried out with the Methyl Orange indicator end point that has converted all the Sodium Bicarbonates in to water and CO_2. The difference in the millilitres between the first and second endpoints were used to calculate the CO_2 unabsorbed by the specimen. Figure 17.5a, b, c, d, e, f shows the testing arrangement. Amount of CO_2 was calculated using the formula.

$$\text{Amount of unabsorbed}\, CO_2 = \left(\text{Volume of titrant in litre} \times \text{Molarity of standard acid} \times \text{Molecular weight of}\, CO_2\right)$$

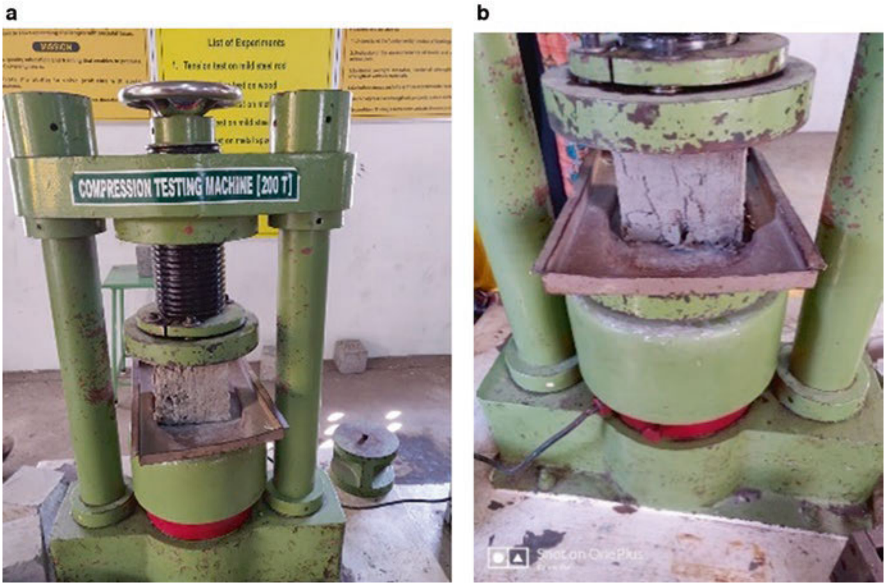

Fig. 17.4 (**a**) Compressive strength testing with specimens loading. (**b**) Compressive strength testing with failure of specimen

Form the initial and final absorption values, the CO_2 absorption capacity of the specimens were calculated.

17.2.3.3 Carbonation Depth

The carbonation depth (BS EN 14630 2006) test was conducted. Specimens were exposed in the CO_2 open environment for the periods of 28 days and 56 days. After the period of exposure, the specimens were split into two parts and observed. The phenolphthalein indicator was applied on the broken surfaces of the specimen and observed for change in the appearance of colour. Carbonation depth was measured and it is proportional to the square root of time. Figure 17.6a, b, c, d, shows the arrangement of testing for carbonation depth.

Fig. 17.5 (**a**) CO_2 gas produced. (**b**) CO_2 gas in airtight chamber. (**c**) Experimental setup. (**d**) HCl reacting with Na_2CO_3. (**e**) Titration Process. (**f**) Balloon containing excess NaOH

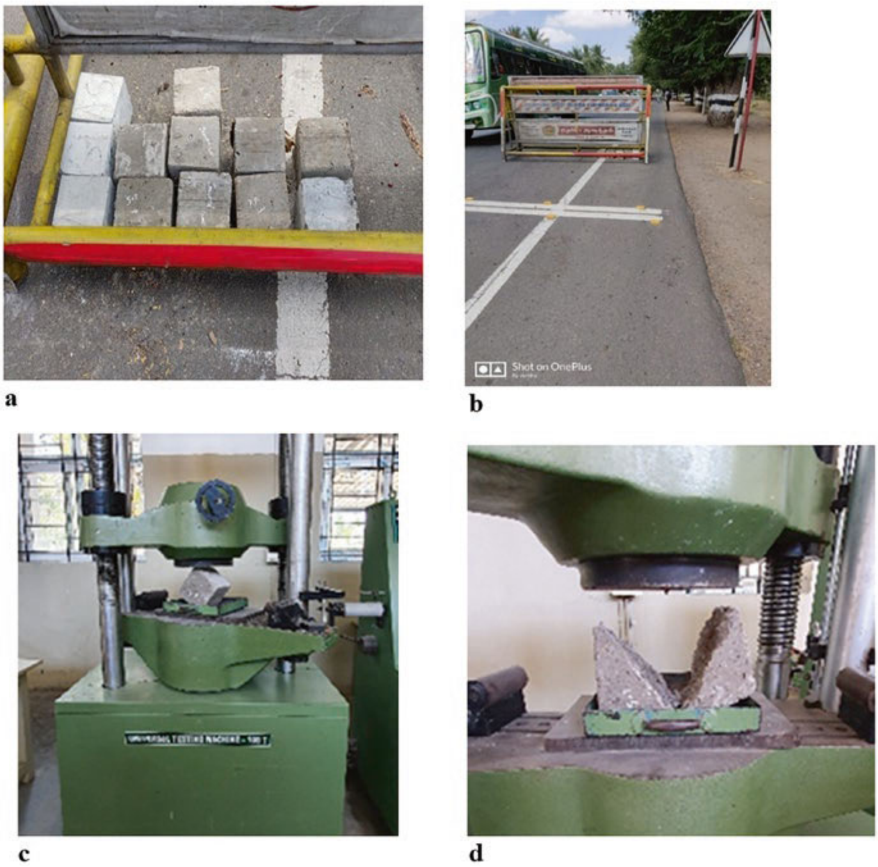

Fig. 17.6 (**a**) Specimens for CO_2 open atmosphere. (**b**) Specimens for CO_2 atmosphere. (**c**) Splitting of specimen. (**d**) Splitting of specimen

17.3 Results and Discussion

17.3.1 Compressive Strength

Figure 17.7 shows the compressive strength values at 28 days curing period. Specimens CS4 – CS6 with potato peel only showed lower compressive strength among other mixes. Similarly, specimens CS7 – CS9 with seaweed only showed lower compressive strength than control specimen but higher than specimens with potato peels only. While specimens CS10 – CS12 with both potato peel and seaweed showed higher compressive strength among other mixes. A percentage increase of 5.5% was observed. The increase in compressive strength in the combined addition might be due to the chemical reaction occurred between both the added potato peel and seaweed that would have provided the necessary pore filling characteristics.

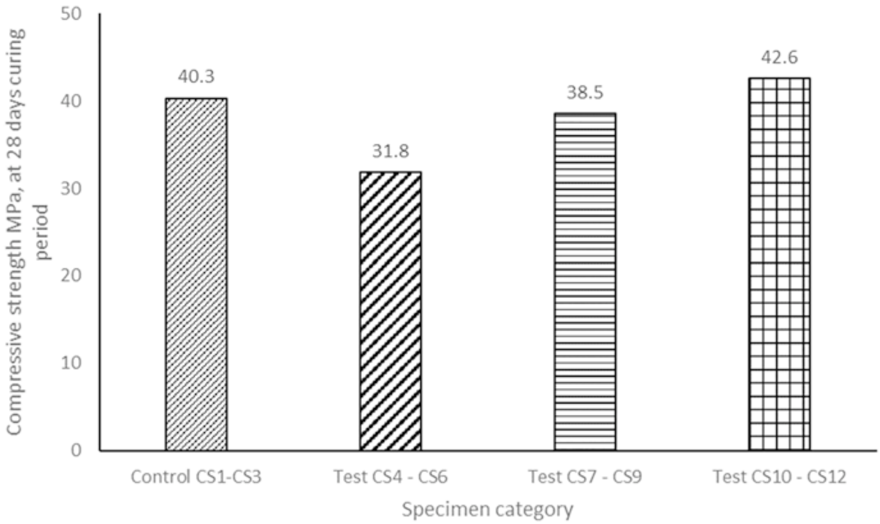

Fig. 17.7 Compressive strength at 28 days

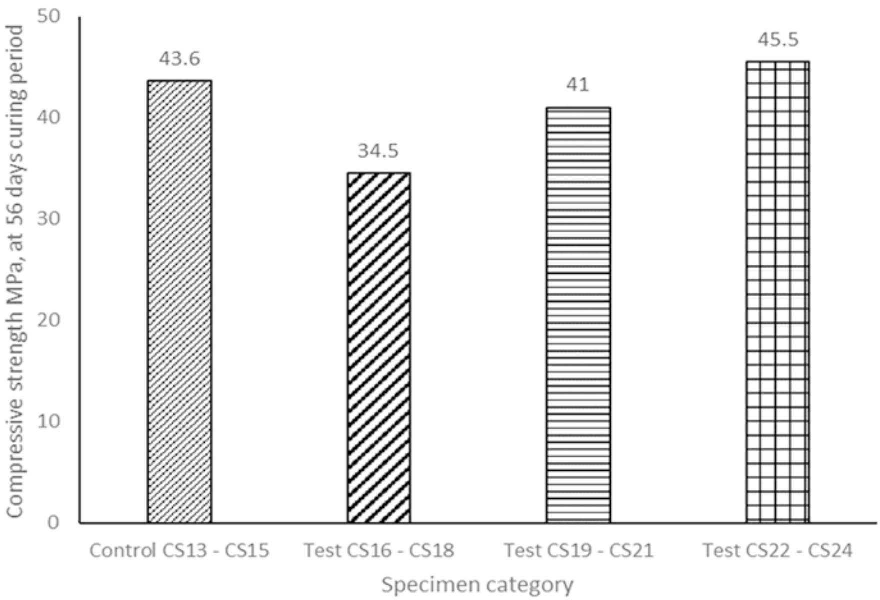

Fig. 17.8 Compressive strength at 56 days

Figure 17.8 shows the compressive strength values at 56 days curing period. Specimens CS16 – CS18 with potato peel only showed lower compressive strength among other mixes. Similarly, specimens CS19 – CS21 with seaweed only showed lower compressive strength than control specimen but higher than specimens with potato peels only. While specimens CS22 – CS24 with both potato peel and seaweed showed higher compressive strength among other mixes. A percentage increase of 4.0% was observed. The increase in compressive strength in the combined addition might be due to the chemical reaction occurred between both the added potato peel and seaweed that would have provided the necessary pore filling characteristics.

On the other hand, when comparing the specimens with both potato peel and seaweed cured at 28 days and 56 days have showed 42.6 MPa and 45.5 MPa, respectively, which was an increase of 6% that was effected due to the increased period of curing.

17.3.2 Titration Method

The amount of unabsorbed CO_2 was calculated using titration method for each type of concrete cubes casted and it was founded that CO_2 absorption capacity was varied for various cubes. From the initial and final absorption values, the absorption capacity of the specimens was calculated. Figures 17.9 and 17.10 shows the absorption capacity of the specimens at 28 days and 56 days, respectively.

From Fig. 17.9, it can be understood that the specimens added with potato peels and seaweeds have showed good absorption characteristics for CO_2. Further, the combined use of potato peels and seaweeds have showed better absorption characteristics than these were used individually. Control concrete also have showed little absorption of CO_2 that might be due to the inherent characteristics of concrete and

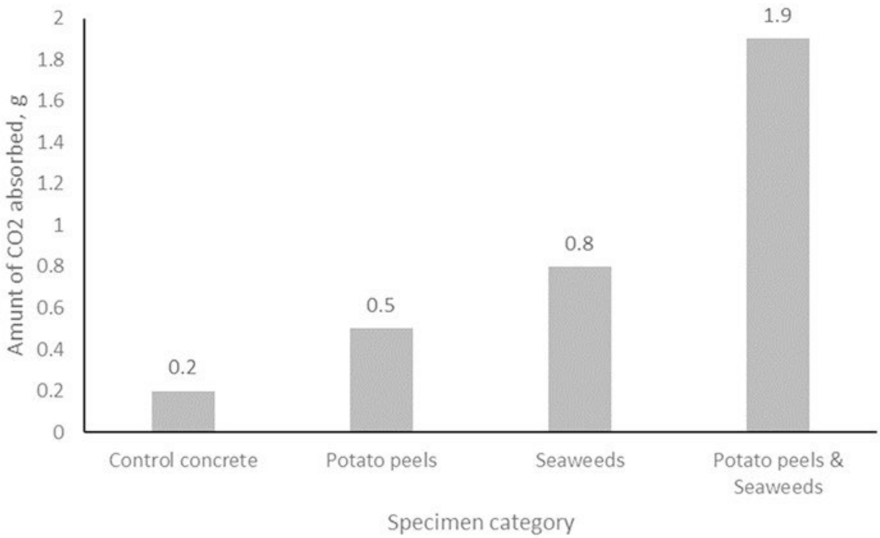

Fig. 17.9 Specimens at 28 days

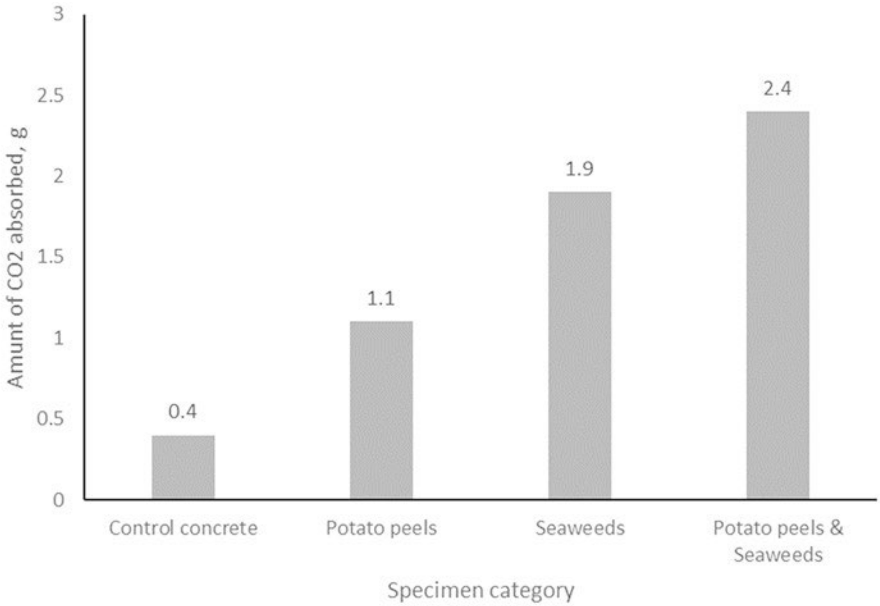

Fig. 17.10 Specimens at 56 days

its porosity. Specimens added with potato peels, seaweeds and combined with both have showed a percentage increase in the absorption were 60%, 75% and 100%, respectively, when compared with control specimens at 28 days. From Fig. 17.10, similarly, specimens added with potato peels, seaweeds and combined with both have showed a percentage increase in the absorption were 63%, 78% and 83%, respectively, when compared with control specimens at 56 days. Specimens with increased curing periods have proportionally increased the absorption characteristics of the specimens. Specimens with combined addition of potato peels and seaweeds have showed significant improvement. Hence it can be inferred that when the ages of concrete increases, then the absorption characteristics capacity can also be increased.

On the other hand, when comparing the specimens with both potato peel and seaweed cured at 28 days and 56 days have showed 1.9 g and 2.4 g, respectively, which was an increase of 20% that was effected due to the increased period of curing.

17.3.3 Carbonation Test Using Phenolphthalein Indicator

Figure 17.11a, b, c, d shows the representation of carbonation on the concrete cubes that were exposed to CO_2 open environment for period of 28 days and 56 days. It was evident that the control specimen did not showed any colour change and hence

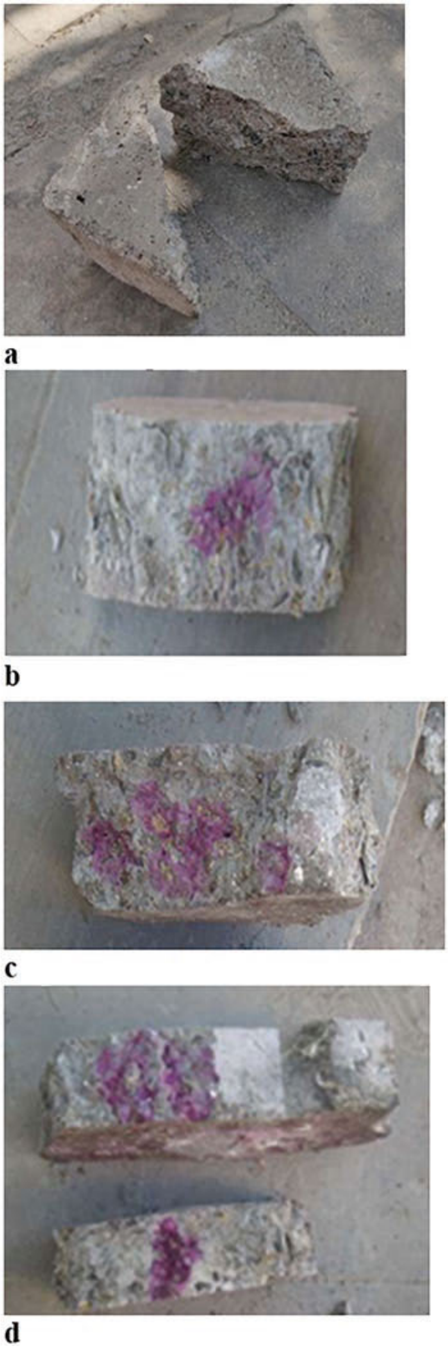

Fig. 17.11 (**a**) Control specimen at 56 days. (**b**) Specimen with potato peel at 56 days. (**c**) Specimen with seaweed at 56 days. (**d**) Specimen with Potato peels and Seaweeds at 56 days

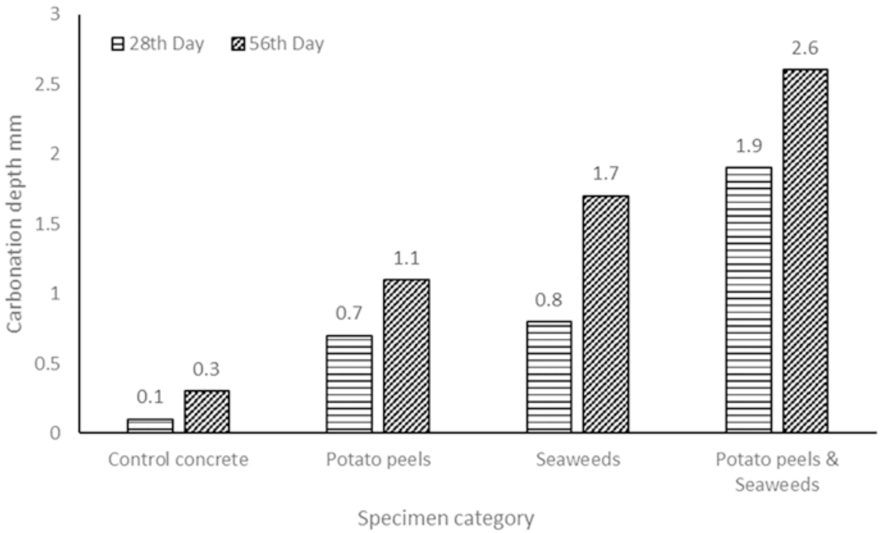

Fig. 17.12 Carbonation depth measurements of concrete cubes

no carbonation was occurred. However, the test specimens have showed the occurrence of carbonation on the top and bottom surface of the concrete cubes.

From Fig. 17.12, it can be understood that the specimens added with potato peels and seaweeds have showed good depth characteristics for CO_2. Further, the combined use of potato peels and seaweeds have showed better depth characteristics than these were used individually. Control concrete also have showed little depth of CO_2 that might be due to the inherent characteristics of concrete and its porosity. Specimens added with potato peels, seaweeds and combined with both have showed a percentage increase in the depth were 85%, 87% and 95%, respectively, when compared with control specimens at 28 days. Similarly, specimens added with potato peels, seaweeds and combined with both have showed a percentage increase in the depth were 73%, 82% and 88%, respectively, when compared with control specimens at 56 days.

On the other hand, when comparing the specimens with both potato peel and seaweed cured at 28 days and 56 days have showed 1.9 mm and 2.6 mm, respectively, which was an increase of 27% that was effected due to the increased period of curing.

Specimens with increased curing periods have proportionally increased the carbonation depth of the specimens. Specimens with combined addition of potato peels and seaweeds have showed significant improvement. Hence it can be inferred that when the ages of concrete increases, then the depth of carbonation capacity can also be increased.

17.4 Conclusion

From the above findings, the following conclusions were made (i) Combined addition of both potato peels and seaweeds have showed better performance than individual. It was inferred from this, there might be suitable chemical reaction occurred in the combined addition. (ii) It can be inferred that when the ages of concrete increases, then the depth of carbonation capacity can also be increased. When comparing the specimens with both potato peel and seaweed cured at 28 days and 56 days have showed in the ranges between 42.6 and 45.5 MPa; between 1.9 and 2.4 g; and between 1.9 and 2.6 mm, respectively, which was an increase of 6%, 20% and 27%, respectively that was effected due to the increased period of curing. However, this required a thorough microscopic study and examinations about the compounds formed. (iii) It was further concluded that combined addition of potato peels and seaweeds have improved the compressive strength, carbonation depth and amount of carbonation absorbed. (iv) Hence, the proposed findings can be utilised in the construction industry as pavement blocks, concrete blocks and kerb stones where most of CO_2 emissions occurred on the roads can be absorbed by the combined addition.

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Chapter 18
An Efficient Design and Development of IoT Based Real-Time Water Pollution Monitoring and Quality Management System

Hakam Singh and P. Sivaram

Abstract Water pollution is a significant cause of several diseases and requires intensive monitoring, procuring techniques to control contamination in water. Several techniques are implemented to stop water pollution, but somehow real-time monitoring achieves a significant impact among these. In this work, a real-time monitoring system based on Internet of Things (IoT) techniques is implanted to monitor, control, and take precautionary action through intimation to the authorities. The wireless sensor nodes are planted at different locations of water resources to check the water quality, significant impact among these. In this work, a real-time monitoring system based on Internet of Things (IoT) techniques is implanted to monitor, control, and take precautionary action through intimation to the authorities. The wireless sensor nodes are planted at different locations of water resources to check the water quality. The data obtained from sensor nodes are transmitted to a remote server, i.e., a cloud platform, and an analysis is carried out to check the water quality condition. The data samples collected from the different locations were analysed to identify the quality; the intimation is provided to the specific region controllers if water quality changes. The resultant information from the analysis can be used to take precautionary measures and identify the source of water pollution. The implementation of IoT makes it feasible to monitor and prevent water pollution in a real-time environment in a remote fashion.

Keyword Internet of Things · Wireless sensor nodes · Real-time environment · Cloud platform

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18.1 Introduction

Water is a vital element for living beings. However, numerous biological, physical, and chemical factors affect the water quality of rivers, ponds, streams, ground, and oceans. The contamination of aquatic resources causes many health problems and has become a problematic global issue. The man-made pollution of water resources globally is presently uncontrollable Fig. 18.1 (Veluda Water Filters 2021; Zaho et al. 2017; Sanjenbam Jugeshwor Singh 2019; Times of India 2019; Global Health 2020; Suraj Rajendran 2016; Jenn Savedge 2019) depicts the images of various water pollution sites. Several methods are implemented, and guidelines are set to solve the aquatic pollution problem. Traditional methods include a collection of samples from sites and testing in laboratories. These methods are ineffective and have issues like time and effort, barriers in data collection, and tough to monitor.

The emergence of the IoT in water management is a step toward real-time monitoring and flexibility, e.g., irrigation water management systems and automated water supply systems. IoT is an interconnection of intelligent communicable objects in a real-time environment. The objects are embedded within the electronic equipment and networked to sense and transmit data at the remote end for processing. Ideal IoT devices consist of Input/Output, storage, audio/video, and internet interfaces and comprise four layers named sensing, networking, data processing, and application layer. The sensor layer consists of sensing actuators that sense and transform the data over the network. The network layer regulates all networking functionalities like routing, network configuration. The data processing layer is

Fig. 18.1 Various water pollution sites

accountable for analytical analysis; many emerging techniques are functioning in this layer. The application layer is responsible for facilitating higher-level services to end-users, such as interface alerts. The emergence of the IoT in water management is a step toward real-time monitoring and flexibility, e.g., irrigation water management systems and automated water supply systems. IoT is an interconnection of intelligent communicable objects in a real-time environment. The objects are embedded within the electronic equipment and networked to sense and transmit data at the remote end for processing. Ideal IoT devices consist of Input/Output, storage, audio/video, and internet interfaces and comprise four layers named sensing, networking, data processing, and application layer. The sensor layer consists of sensing actuators that sense and transform the data over the network. The network layer regulates all networking functionalities like routing, network configuration. The data processing layer is accountable for analytical analysis; many emerging techniques are functioning in this layer. The application layer is responsible for facilitating higher-level services to end-users, such as interface alerts on suitable platform.

The emergence of the IoT in water management is a step toward real-time monitoring and flexibility, e.g., irrigation water management systems and automated water supply systems. IoT is an interconnection of intelligent communicable objects in a real-time environment. The objects are embedded within the electronic equipment and networked to sense and transmit data at the remote end for processing. Ideal IoT devices consist of Input/Output, storage, audio/video, and internet interfaces and comprise four layers named sensing, networking, data processing, and application layer. The sensor layer consists of sensing actuators that sense and transform the data over the network. The network layer regulates all networking functionalities like routing, network configuration. The data processing layer is accountable for analytical analysis; many emerging techniques are functioning in this layer. The application layer is responsible for facilitating higher-level services to end-users, such as interface alerts.

Figure 18.2 depicts the key features of the water quality management system for controlling water pollution (Chapman 1996). Several techniques enable the IoT networks (Doni et al. 2018; Ullo and Sinha 2020; Čolaković and Hadžialić 2018; Navarro-Hellín 2016; Rao and Sridhar 2018):

(a) Wireless sensor network configured by sensor nodes to collect, exchange and transmit data over the internet.
(b) Cloud computing services like storage, software applications over the internet. It makes a virtual computer using the same personalized experience worldwide.
(c) Big data analytics services like cleaning, pattern extraction, transformation, and visualization of a large volume of data.
(d) A communication protocol that allows devices to transfer data over networks.
(e) Microprocessor-based computer hardware system to carry out computation for real-time operations.

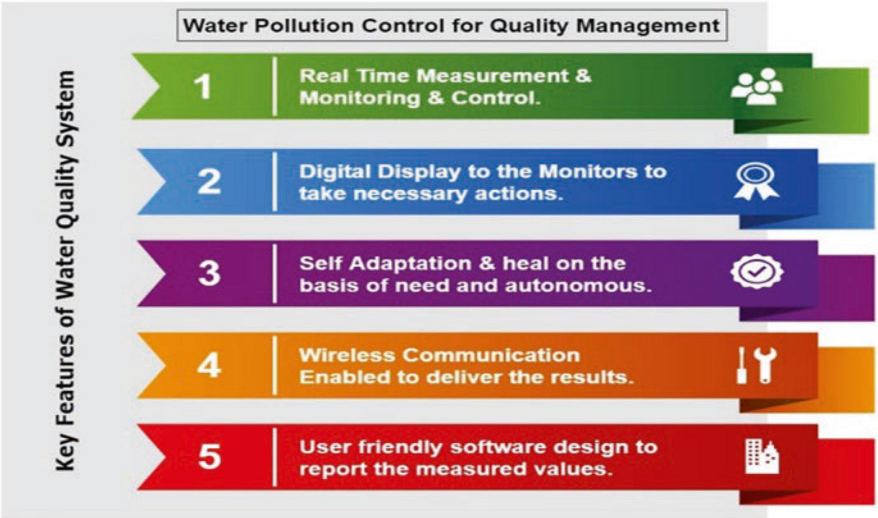

Fig. 18.2 Key features of water quality management system

18.1.1 Internet of Things in Water Pollution Monitoring

The robust operational environment of IoT encourages its enactment in water pollution monitoring. Sensor nodes are deployed in water sources (reservoirs) to collect and transmit real-time data to a remote server. The offered real-time data is processed and utilized to solve various water issues like quality, nonregularity, and contamination. The different sensors available to measure water quality such as, *pH Sensor:* The potential Hydrogen (pH) of a solution defines the acidic or basic nature, a significant indicator of water quality. Sensors used for determining pH are usually a single electrode, typically made of glass and quite delicate. The electrode is typically attached to an analyzer with an interface for data collection, calibration, and alerts. *Turbidity Sensors:* are used to measure turbidity, i.e., suspended solids in water. These are used for testing in rivers and streams and ponds. *Conductivity Sensors:* are used to obtain the total ionic concentration, i.e., the dissolved compounds in water. A standard conductivity sensor can be either an inline sensor directly inserted or a sensor in a housing, with a cable linked to a transmitter, which sends signals to a processing and/or recording device etc. IoTs remotely enable and reliably continuous water quality monitoring, consistent with precautionary activities. In available technologies, the IoT provides flexibility and ease of use components with strict integrity. Various research papers related to the proposed work were analyzed to identify the exact proposed systems and their operational capabilities. These have been detailed under the IoT-based Real-Time Water Pollution Monitoring and Quality Management System section. The paper also discusses the possibilities for extending the proposed work with various additional features.

18.2 Related Work

An automated water quality monitoring system was developed and implemented with active and passive sensors to collect data and Message Queue Telemetry Transport protocol to transmit between IoT devices (Budiarti et al. 2019). This is very much suitable for our proposed system. Another real-time system was proposed to measure river water quality; with this system, real-time data can be collected from the active site and analysed at a remote server (Chowdury et al. 2019). The system is highly flexible and helpful to stop the consumption and pollution of river water. Using IoT, a water parameter monitoring system has multiple sensor nodes integrated into a single platform to collect water parameters and communicate to remote servers (Krishna et al. 2020). An IoT system monitors the water level in storage tanks. The ultrasonic sensor checks the water level and transmits it on the cloud platform. This system helps the user to know the real-time status of stored water (Sivaiah et al. 2018). Another IoT-enabled water monitoring system uses an IoT device integrated with the water source to collect data and transmit it to the cloud. This system enables the user to monitor the water leakages and reduces water wastage (Mhaisen et al. 2018). A system using emerging techniques equipped with various water sensors and actuators to monitor and assist the fish farmer was proposed to address the effect of water pollution on fish farming (Nocheski and Naumoski 2018). Further, an IoT-based system was used to increase fish production and facilitate real-time monitoring (Tolentino et al. 2020). An underground water pipeline leakage-monitoring system was equipped with a pressure sensor to monitor the water pressure level and generate an alert message to the user on detecting any abnormality. Overall, this system reduced water wastage (Badawi 2019).

A systematic review was provided on applications of IoT on water monitoring systems, and various sensing devices were summarized and implemented in water quality monitoring systems (Radhakrishnan and Wu 2018). An IoT-based smart application was developed for gardening that automated the plants watering process and reduced the human efforts of checking the water level, switching water supply (Thamaraimanalan et al. 2018). A dispenser's water level monitoring system reduced the labor or supervision of the dispenser's monitoring. If the dispenser's water level becomes low, the system notifies to take necessary actions (Parashar et al. 2018). An IoT and machine learning was integrated to monitor the drinking water quality (Koditala and Pandey 2018). Niswar et al. have designed and implemented an IoT-based system to monitor water quality in soft-shell crab farming. This system provides awareness and suggests the acceptable water quality level for soft-shell crab farming (Niswar et al. 2018). Perelman and Ostfeld worked on the security aspect of water distribution sources. The stationary and non-stationary sensor nodes data is analyzed to implement security in water distribution sources (Perelman and Ostfeld 2013). Moparthi proposes a drinking water management system using the Arduino board and GSM techniques (Moparthi et al. 2018). Miry and Aramice worked on the water quality monitoring and analysis techniques. The system provides a quick turbidity analysis and informs the water quality to the user

(Miry and Aramice 2020). Doni et al. has done a systematic survey on air and water quality techniques and reveals that manual or laboratory methods are time-consuming and do not provide long-range results (Doni et al. 2018). Further, Ullo and Sinha have also done a review on smart environment monitoring systems and concluded that the involvement of emerging techniques strengthens the environment monitoring system (Ullo and Sinha 2020). Kodali et al. automated the greenhouse operation with the help of IoT, additionally, this system makes the market and buyer connection and reduced the efforts and times of farmers (Kodali et al. 2016). Kamienski et al. developed an IoT-based application in precision agriculture, that handles water resources as per their real-time environments (Kamienski et al. 2018). Zhao et al., have developed a Lora network-based system for smart irrigation (Zhao et al. 2017). This system allows the user to work from a remote location. An automatic water supplying system for plow-land is reported in the literature. This system is equipped with different actuators and sensing devices to make agriculture operations more flexible and easier (Imteaj et al. 2016). Devi et al. (2019) have designed an IoT, blockchain-based smart agriculture system. The blockchain architecture of this model involves several IoT sensors like smoke, PH control node, water moisture control, etc. The acquiesced data is processed on the cloud platform to control the agriculture field actions.

18.3 IoT Based Real-Time Water Pollution Monitoring and Quality Management System

The proposed system works in three phases: data acquisition, processing, and recommendation. In the data acquisition phase, the parametric values of water are obtained via sensor nodes and transmitted to a remote server. While in the processing phase, different optimization techniques are applied to bring out the result. The processing phase outputs are communicated to monitoring authorities in the recommendation phase, where the water quality management is done. A detailed description of the proposed system is depicted in Fig. 18.3.

1. **Data Acquisition Phase:** In this phase, basic parameters of the water are retrieved from the water sources and transmitted to a remote server or cloud platform. The initial task is the deployment of water sensors in the water source of interest. Due to predetermined operational sites and network coverage requirements, the deterministic sensor deployment method is suggested in this work. Afterwards, the sensor nodes get configured and start functioning, i.e., taking up water quality percept in real-time, the transformation of data, and transmission to a remote server. The transmitted data is a composite pack with fields such as Sensor Identity, Sample number, water quality parameters, location coordinates and time, e.g., W1pH, S1, ph-6, 31.5648 76.6409, 11:12 AM.
2. **Data Processing:** In this phase, an analytical process is carried out on a cloud platform. The acquiesced data, i.e., the data collected from the acquisition phase,

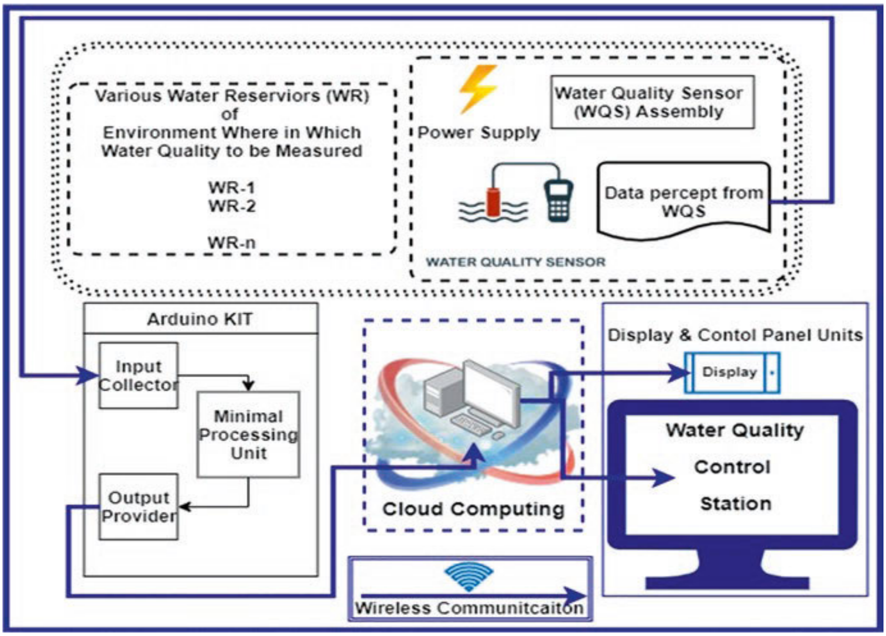

Fig. 18.3 The architecture of IoT-based real-time water pollution monitoring and quality management system

Table 18.1 Water quality standard value

Parameters	Acceptable limit	Permissible limit in the absence of alternate source
pH value	6.5–8.5	No-relaxation
Turbidity	1	5
Dissolved solids, mg/l	500	2000

is processed to identify abnormality and intensity of pollution. *Abnormality in water quality:* This can be identified using classification techniques. The values collected from sensors are compared with predefined or standard values in Table. 18.1. An approximation function is implemented to identify the upper and lower range of values. Suppose the resultant values are between the appropriation function. In that case, they are predicted as the quality of the water being at an acceptable level, else an alert message with the precautionary measure is sent to the monitoring authorities. This phase is named as recommendation phase for quality control.

Identify water pollution region: The location coordinates of the sensor nodes are used to identify the pollution region. The variation in water samples parameters is taken into consideration to identify the region, e.g., W1pH, S1, pH-6, 31.5648, 76.6409, 11:12 AM has a pH value of 9, while the W2pH, S1, pH-11, 32.5428, 79.6409, 11:20 AM has a pH value of 11. This means that the source is responsible for pH value variation between these two locations. The location coordinates are treated as vector entries to compute distance or to draw a location vector. The well-known Euclidean distance formula is used to draw a location vector among polluted sources. The vectored area is visualized as a polluted water region and considered for further water pollution prevention actions.

3. **Recommendation Phase:** This is the phase where the processed output data reaches the display/control unit for decision-making. The water quality management system is functioning so that human interaction is essential with the proposed system. Apart from the purpose of the corrective measures taken by the human to adjust the water quality, the generalized display panel-based reporting to the handheld devices is an additional feature added, where the user can have the details of the water quality values in the form of easy user interface like the water from so and so resources, is potable/usable or not.

Toy Example

1. **Data Acquisition Phase:** Water samples from different location (Tables 18.2, 18.3, 18.4, and 18.5).
2. **Data Processing:** Analysis is carried out on cloud platform or remote end (Table 18.6).

Table 18.2 Acquisition phase data location 1

Sensor identity	Sample number	Parameter-value	Location coordinates		Time
			Longitude	Latitude	
W1pH	S1	pH-6	31.5648	76.6409	11:12 AM
W1TD	S1	TD-1	31.5648	76.6409	11:12 AM
W1DS	S1	DS-1000	31.5648	76.6409	11:12 AM

Table 18.3 Acquisition phase data location 2

Sensor identity	Sample number	Parameter-value	Location coordinates		Time
			Longitude	Latitude	
W2pH	S2	pH-6.5	31.3444	76.3752	12:01 PM
W2TD	S2	TD-4.6	31.3444	76.3752	12:01 PM
W2DS	S2	DS-855	31.3444	76.3752	12:01 PM

Table 18.4 Acquisition phase data location 3

Sensor identity	Sample number	Parameter-value	Location coordinates		Time
			Longitude	Latitude	
W3pH	S3	pH -9	31.6138	76.2960	10:00 AM
W3TD	S3	TD-1	31.6138	76. 2960	10:00 AM
W3DS	S3	DS-1000	31.6138	76. 2960	10:00 AM

Table 18.5 Acquisition phase data location n

Sensor identity	Sample number	Parameter-value	Location coordinates		Time
			Longitude	Latitude	
WnpH	Sn	pH-8	31.1521	76.1023	11:12 AM
WnTD	Sn	TD-6	31. 1521	76. 1023	11:12 AM
WnDS	Sn	DS-800	31. 1521	76. 1023	11:12 AM

Table 18.6 Data processing

Locations	pH	TD	DS
L1 (31.5648, 76.6409)	6	1	1000
L2 (31.3444, 76.3752)	6.5	4.6	855
L3 (31.6138, 76. 2960)	9	1	1000
Ln (31.1521, 76.1023)	8	6	800

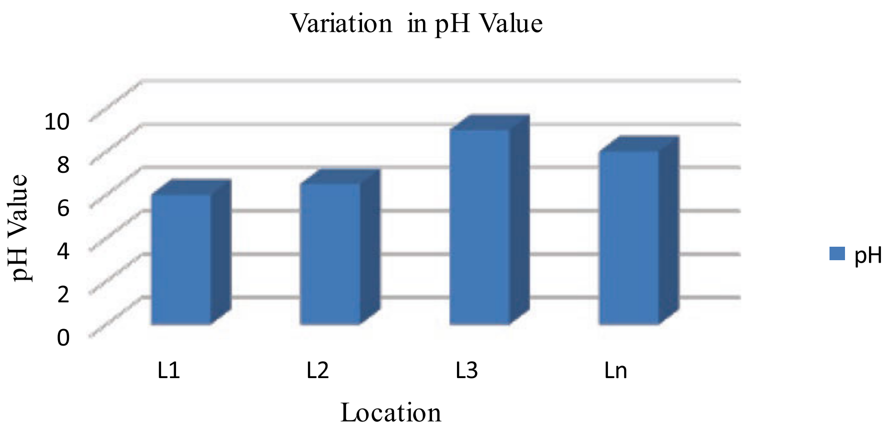

Fig. 18.4 Variation in pH value

3. **Recommendation Phase**

The processed output data reaches the display/control unit for the decision-making e.g., Ln has highest variation in turbidity (TD), and above the permissible level. In this case an alert message can be circulated/exhibited etc. Figures 18.4, 18.5, and 18.6.

18.4 Conclusion and Future Scope

An IoT-based water pollution monitoring system is proposed in this work that identifies the abnormalities and their source regions. The proposed system works in three phases, data acquisition, processing, and recommendation. In the data

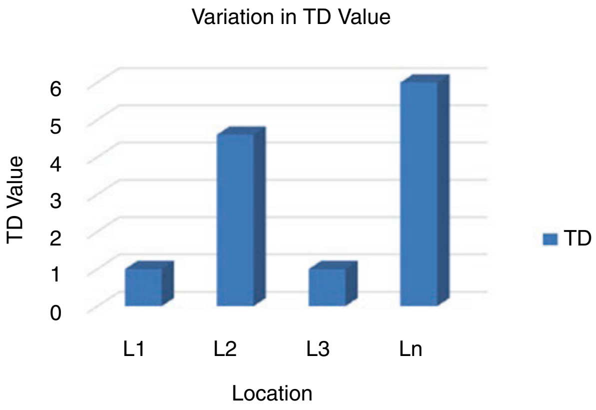

Fig. 18.5 Variation in TD value

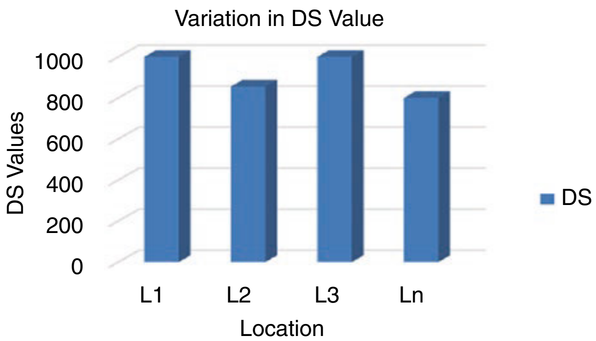

Fig. 18.6 Variation in DS value

acquisition phase, the fundamental parameter values are collected and transmitted to a cloud platform. On a cloud platform, analysis is carried out, and an appropriate response is made, such as an alert message in case of abnormality in water quality, region identification of pollution region. The adaptability of IoT, wireless sensors, data mining empowers the user to monitor and control resources from a remote location. IoT with accurate sensors and smart pieces of equipment are considered an essential component in smart farming. In future work, some other external parameters will be considered, and geographical analysis will be carried out to preserve the water quality.

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Chapter 19
Numerical Study of Composite Wrapped Reinforced Concrete Columns Subjected to Close-in Blast

Atul Pandey and Hari Krishan Sharma

Abstract A blast or an explosion has become a considerable form of threat to civilian infrastructures worldwide in recent-decades because of their highly dynamic, non-linear and destructive nature. As opposed to conventional loads, the response of RC members to a blast wave is highly erratic as it depends on a lot of factors such as type, shape, orientation and mass of explosive, standoff, ground reflection to mention a few. The damage of an RC member on application of blast pressure is also very severe as it is a combination of flexural and shear deformations, spalling and crushing of concrete etc. For RC columns however, when compared to beams or slabs the situation is more critical since its failure can often result in global structural collapse due to progressive failure. This research article provides a comparative analysis of the effectiveness of various composite wraps in protecting RC Columns against the detrimental effects of blast wave impingement by reduction of peak mid span displacement and subsequently the support rotation of column and reduction in deformation, energy and stresses of concrete and reinforcements. The analysis is performed using the CONWEP approach in LS-DYNA finite element package through which blast loading can be applied by specifying the mass and deflagration co-ordinate and then the CONWEP applies the blast load through a time-varying pressure which is very much similar to a real blast scenario.

Keywords Blast loading · RC column · FRP · Polyurea · Steel sheet · Strengthening

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19.1 Introduction

The events in which structures have suffered a collapse after being subjected to deliberate or accidental shock waves from explosions have become more frequent in recent times. Moreover, it has been established that the majority of deaths during such scenarios are not due to direct effect of blast wave but rather due to flying fragments and eventual collapse of the structure. Therefore, it has become imperative for the scientific community to research and implement different techniques to make existing and upcoming structures more resilient to blast loads in addition to conventional loads.

Some of the most current methods for blast protection of structural elements in existing structures have been the use of composites with high strength to weight ratios, sufficient ductility and stiffness of which fibre reinforced polymers (FRP's) are the most prominent particularly carbon FRP. But due to the high costs associated with its application as well as low failure strain and ductility, CFRP is not very reasonable, therefore the applicability of other FRP's such as aramid FRP, glass FRP and steel FRP along with strain hardening cementitious composites (SHCC), Elastomeric polymers such as polyurea, and metallic foams such as aluminium foam etc. are being explored (Goswami and Adhikary 2019).

Muszynski and Purcell (2003) subjected two simple single-story structures consisting of RC walls and columns externally reinforced with CFRP and GFRP to on-field far-range explosion and observed that the strengthened walls and columns showed only small flexural deformation and concrete spalling when compared to bare ones which collapsed catastrophically. They did not however compare the performance of the two FRP's. Mutalib and Hao (2010) used Pressure-Impulse diagrams to graphically represent the increase in blast resistance capacity of CFRP strengthened RC columns in terms of shear and flexural capacity enhancement. They compared the blast performance of three retrofitting modes i.e., CFRP strips, wraps and combination of both. Yan et al. (2020) performed experimental, analytical and numerical trials to obtain effect of variation of thickness of CFRP laminate and lamination modes (on blast face, on distal face, and both faces) on the mid-span displacement and extent of damage to the columns when subjected to close-in blast. Codina et al. (2016) experimentally compared the effect of using steel jackets and polyurethane bricks as external protection layer for RC columns on the degree of blast mitigation. Omran and Mollaei (2017) performed numerical simulations in ABAQUS to study the blast protection offered by different arrangements of steel jacket which included channel sections, angle sections and full wraps. Liu et al. (2020) established through numerical and on-field tests on circular RC piers that CFRP wrapping can also provide protection against contact blast by virtue of decrease in crushing and internal energy of concrete. Further they evaluated the degree of protection against contact blast with the number of CFRP layers. In addition to that the blast mitigation capabilities of a number of innovative materials have been tested for RC slabs such as (Wu et al. 2011) conducted field blast tests on aluminium foam protected RC slabs and compared parameters such as acceleration histories, peak and residual mid-span displacement, with NRC slab. Three different foam thicknesses having two different densities were mounted on the close-in blast facing side of the slab. Adhikary et al. (2018) experimented with the application of SHCC for blast retrofitting of RC slabs. They subjected one bare and four slabs retrofitted with 20 mm and 40 mm thick SHCC on only distal face and both (distal and blast face) respectively to a close-in explosion of 0.58 m/kg$^{1/3}$. Raman et al. (2012) suggested the use of polyurea spray for reduction in central deflection and energy dissipation of RC slabs. By employing load blast enhanced (LBE) or CONWEP method in LS-DYNA they applied blast pressure due to 2 kg TNT explosion suspended 1.6 m above one control and six polyurea retrofitted slab. The thickness of spray and application (only distal face, only blast face, and both distal and blast face) was varied. Kong et al. (2018) compared effectiveness of CFRP, GFRP and AFRP for strengthening of RC slabs against near-range explosion.

As can be deduced from the literature review there exists no studies in which a comparison of blast resistance of different composites for RC columns has been performed because most studies are standalone studies which concerns itself with a single retrofit material. The present research was therefore aimed at comparing the blast resistant capacities of the composites (FRP's, polyurea and steel sheet) externally bonded to bare RC columns in terms of lateral displacement control, Damage prevention, energy absorption and stress reduction capacities through numerical modelling in LS-DYNA.

19.2 FE Modelling of RC Column for Comparative Study

For the comparative study a total of 16 RC columns having an overall height of 3300 mm, square cross-section of 300 × 300 mm^2, 4–20 mm dia bars at a clear cover of 30 mm as the longitudinal reinforcement and 10 mm square hoops at 100 mm spacing as the transverse reinforcement with 150 mm length at both the top and bottom ends fixed to give a clear height of 3000 mm was modelled in LS-DYNA. The geometric and material properties for the control column was taken from a study conducted by (Dua et al. 2020) who also designed the columns arbitrarily without referencing any design codes. All the columns were subjected to a close-range free spherical air burst of 15 kg TNT charge from a distance of 1 m through LBE method. Column-1 was control column and was unretrofitted. Column-2 to Column-6 was fully wrapped with 0.5 mm thick layer of CFRP, GFRP, AFRP, polyurea and steel sheet respectively. Similarly, Column-7 to Column-11 and Column-12 to Column-16 was fully wrapped with 1 mm and 2 mm thick layer of the same composites respectively.

The concrete part was modelled with MAT072Rel3 by 10 mm solid hexahedral elements. Longitudinal and transverse reinforcements was simulated with MAT 024 by 10 mm beam elements. FRP laminate was represented with MAT 54/55 by the 10 mm 4-node Belytschko-Tsay shell element. The FRP wrap was provided in four layers through SECTION_SHELL keyword by inputting Beta angles 0°, −45°, 45°, and 90°. The fibres provided in 45° and −45° was to safeguard against diagonal shear cracks. The steel sheet and the polyurea was represented with MAT 024 by 10 mm 4-node Belytschko-Tsay shell element. Tables 19.1, 19.2, and 19.3 provides material model parameters for different parts. The CFRP properties were taken from (Liu et al. 2020), for AFRP and GFRP the properties were taken from (Kong et al. 2018). The properties and stress-strain behaviour at different strain rates for polyurea were taken from (Bahei-El-Din and Dvorak 2007) and properties of ASTM A240 grade 316 steel sheets were used for steel jacketing. The enhancement of concrete and steel strength due to high strain rate loading was incorporated into the respective material model through dynamic increase factor (DIF) versus strain rate curves. To obtain DIF of concrete in tension, the strain rate model given by (Malvar and Ross 1998) was incorporated, (CEB-FIP model 1990) was implemented for concrete DIF in compression and for DIF of steel, (Malvar L.J. model 1998) was utilized.

The blast load was applied by LBE keyword with values provided by Table 19.4. Summary of the comparative study models is shown in Table 19.5.

The tiebreak contact between FRP/steel sheet and concrete surface was provided through surface-to-surface automatic tiebreak contact (Tan et al. n.d.) with the epoxy adhesive properties taken from (Mutalib and Hao 2010) and for polyurea and concrete, surface-to-surface automatic tied offset contact was used (Raman et al. 2012). The simulation ran for 20 ms to acquire the peak mid-height deflection of column. Figure 19.1 shows the reinforcement details and the different parts of the retrofitted RC Column. Figure 19.2 shows the end restraint and charge position for Column-1.

19.3 FE Model Verification

Before proceeding with the comparative analysis, it was necessary to validate the modelling technique i.e., the mesh size, material models, strain rate model, method of including reinforcement, providing contact and blast load generation. This was done by modelling specimen based upon field tests carried by other researchers and matching the experimental results with the FEM results. If deviation was within permissible limits, the model was said to be validated.

Table 19.1 Concrete material model values for comparative study

Parameter	Value
Mass density (ρ) (kg/mm^3)	2.635e-06
Poisson's ratio (ν)	0.2
Unconfined compressive strength (σ_c) (GPa)	0.025
Maximum aggregate size (mm)	25

Table 19.2 Steel rebar, sheet and polyurea material model values for comparative study

Parameter	Value		
	Polyurea	Rebar	Steel sheet
Mass density (ρ) (kg/mm^3)	1.07e-6	7.85e-6	8e-6
Young's modulus (E) (GPa)	2.52	200	200
Poisson's ratio (ν)	0.46	0.3	0.3
Tangent modulus (E_t) (GPa)		1.6	1.6
Yield strength (σ_y) (GPa)	0.01	0.4	0.205

Table 19.3 FRP material model values for comparative study

Parameter	Value		
	GFRP	CFRP	AFRP
Mass density (ρ) (kg/mm^3)	1.8e-6	1.58e-6	1.44e-6
Longitudinal elastic modulus (E_a) (GPa)	30.9	138	60.7
Transverse elastic modulus (E_b) (GPa)	8.3	9.65	4.67
Normal elastic modulus (E_c) (GPa)		9.65	
Shear modulus (G_{ab})	2.8	5.24	2
Shear modulus (G_{bc})	2.8	2.24	1.586
Shear modulus (G_{ca})	2.8	5.24	1.586
Poisson's ratio (ν_{ba})	0.0866	0.021	0.028
Poisson's ratio (ν_{ca})		0.021	
Poisson's ratio (ν_{cb})		0.49	
Longitudinal compressive strength (X_c) (GPa)	0.48	1.44	0.312
Longitudinal tensile strength (X_t) (GPa)	0.983	2.28	1.42
Transverse compressive strength (Y_c) (GPa)	0.14	0.228	0.145
Transverse tensile strength (Y_t) (GPa)	0.04	0.057	0.036
In plane shear strength (S_c) (GPa)	0.07	0.071	0.053

Table 19.4 LBE keyword values for comparative study

Parameter	Value
Equivalent mass of TNT (W) (kg)	15
Charge centre coordinate (X,Y,Z)	(−1150,0,1650)
Type of blast source	Spherical air burst
Treatment of negative phase	By Friedlander equation

Table 19.5 Summary of comparative study models

Part	Type of element	No. of elements		No. of nodes	
		Control	Retrofitted	Control	Retrofitted
Concrete	Solid	297,000	297,000	318,091	318,091
Longitudinal rebar	Beam	1320	1320	1324	1324
Transverse rebar	Beam	2816	2816	2816	2816
Composite	Shell		36,000		36,122
	Total	301,136	337,136	322,231	358,353

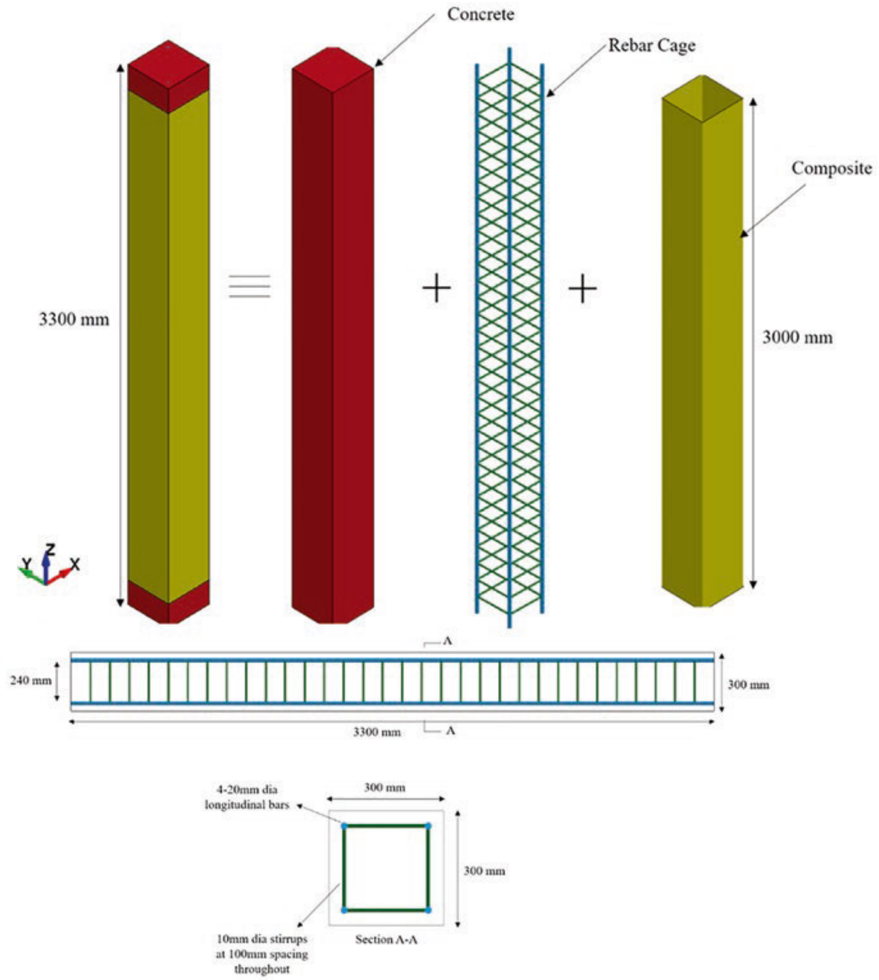

Fig. 19.1 Reinforcement details and components of comparative study model

For the purpose of validation, two test cases were selected from the field blasts carried out by (Yan et al. 2020) for numerical simulation namely F3-0 and F3-1 from the 12 cases. Both the columns were exposed to explosion due 1 kg TNT from a distance of 0.4 m (Z = 0.4 m/kg$^{1/3}$) in the experiment. F3-0 was unretrofitted and F3-1 was bonded with 2 mm thick CFRP laminate on its tensile/rear face. The modelling technique was the same as that used for comparative study models. Figure 19.3 illustrates the end restraints and charge position for the FE model of F3-1.

The maximum deflection of the control and rear face CFRP retrofitted model at the centre of span came out to be 144.566 mm and 101.212 mm respectively which was 16.7% and 19.2% higher than the corresponding experimental test cases respectively as shown in Fig. 19.4. The deviation can be explained by the fact that no axial

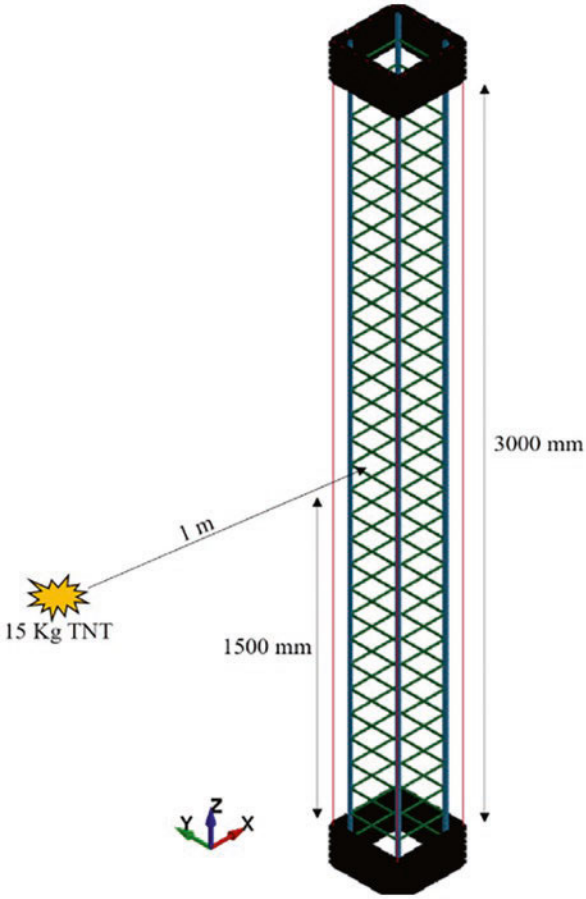

Fig. 19.2 End restraint and charge position for Column-1

preload was applied on the columns in the numerical model while on the other hand in the experimental study, the columns were in a pre-loaded state by virtue of pre-stressed bars. Still the deviation was within 20% and since our study was concerned with performing a comparative analysis to rate the blast resistant performance of various composites, the modelling technique could be safely employed.

19.4 Result and Discussion

The blast wave reaches the column at an arrival time (t_A) of about 0.25 ms and generates a peak positive reflected overpressure of 46 MPa at the mid-height of column where angle of incidence of blast wave is zero and thus the pressure intensity is maximum. Figure 19.5 gives the reflected blast pressure time history. It can be seen that after reaching the peak overpressure, it exponentially decays to zero within fraction of a millisecond. The negative phase is in the order of pascals and is therefore negligible in comparison to the positive phase of the blast loading.

Figure 19.6 describes the plastic strain damage contour profile of the unretrofitted column with the progression of blast loading. It varies from 0 to 2 which parallels the advancement across 3 pressure dependent failure surfaces i.e., initial yield, maximum failure and residual failure for the adopted concrete material model (Crawford et al. 2011). In the beginning of the loading history, small tensile cracks are formed at the mid-height of column which progressively expands in the longitudinal direction. The cracks also propagate toward the blast facing or compression face to crush the compression concrete. At 1 ms, direct shear cracks can be seen at the supports. Cracks due to diagonal shear begin to propagate from the ends from 5 ms into loading history. Finally, the erosion of highly strained concrete elements starts from 10 ms.

Figure 19.7 demonstrates the axial force contours in reinforcements of column-1 due to lateral blast pressure. From the figure it is evident that the stresses in the reinforcements rapidly rises up to around 5 ms after which it follows a downward trajectory. The maximum stress (axial) in the longitudinal bars was 409.114 Mpa at the middle of the blast facing rebar at 2.5 ms and in the transverse hoop it was 301.577 MPa which was also at the middle at 0.5 ms. Maximum axial stress for longitudinal and transverse rebar for Column-2 which was wrapped with 0.5 mm CFRP was 410.263 MPa and 432.901 MPa respectively and almost similar values were recorded for other retrofitted column as well. The increase in the stresses of the transverse hoops because of confinement by composite wraps can be explained by more erosion of concrete in case of control column which releases the stresses in the hoops. Thus, it can be safely assumed that stresses in reinforcements (especially tie reinforcements) increase on application of external wraps when subjected to non-contact blast.

19.4.1 Mid-Height Displacement

The maximum mid-height displacement (δ) is used to find out the rotation of supports which is defined by (UFC 3-340-02) as a function of peak mid-span deflection and clear span (*l*) and is given by Eq. 19.1.

$$\theta = \tan^{-1}\left(\frac{2\delta}{l}\right) \tag{19.1}$$

According to the standards, more the support rotation, more severe is the damage to columns. Figures 19.8, 19.9, and 19.10 gives the X-displacement time history of the centre-most node of the 16 columns having co-ordinates (0,0,1650) with thickness of laminate as 0.5 mm, 1 mm, and 2 mm respectively. Figure 19.11 describes

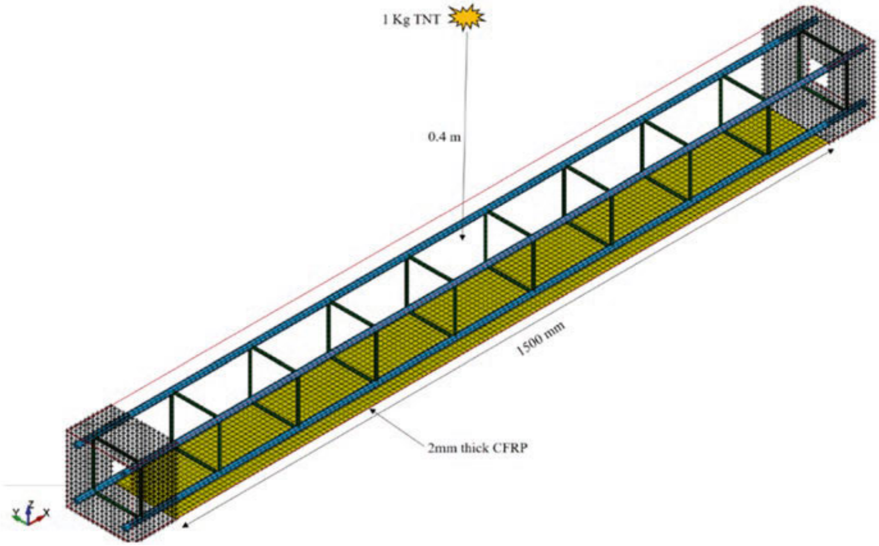

Fig. 19.3 End restraint and charge position of F3-1

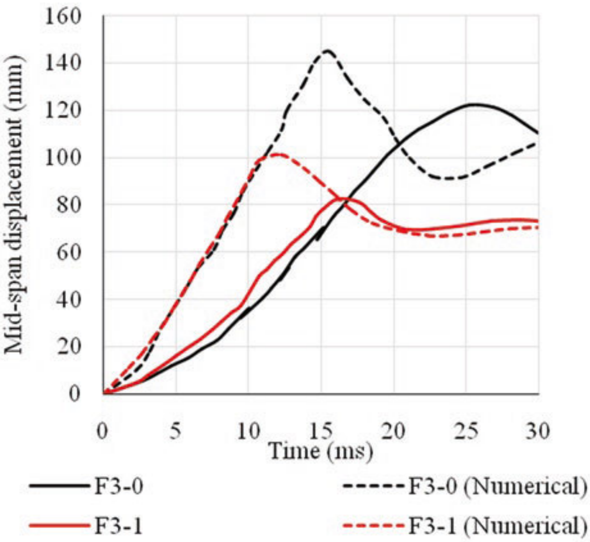

Fig. 19.4 Result comparison for verification model

the comparison of peak mid-height displacement with the thickness of each composite and Table 19.6 summarizes the peak displacement, support rotation and percentage reduction in maximum displacement for each retrofitted column compared to the control column.

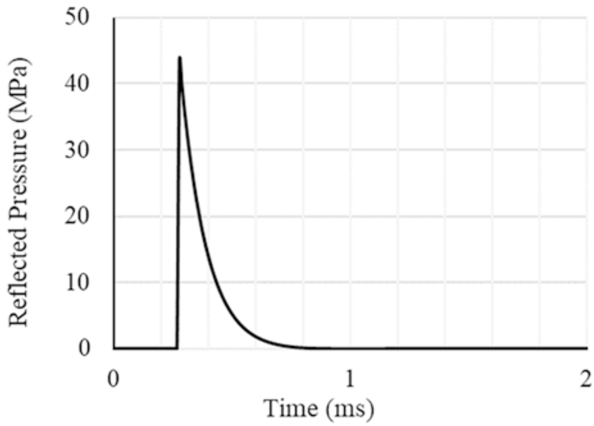

Fig. 19.5 Reflected blast pressure-time variation

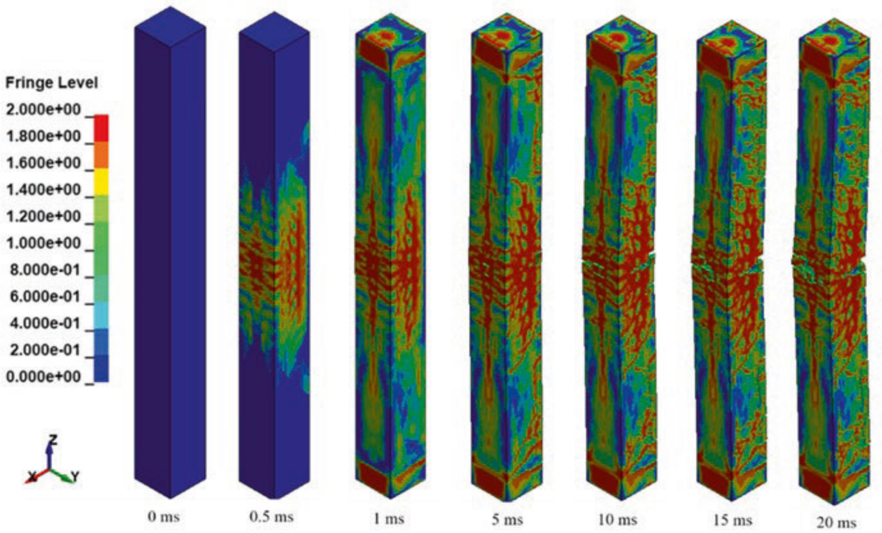

Fig. 19.6 Damage contours of column-1

From the figures and table, it can be stated that each retrofit measure managed to control the lateral displacement of column. The percentage reduction ranged from 20.05% for 1 mm thick polyurea coated column to 59.34% for 2 mm thick CFRP wrapped column.

Column-2, Column-7 and Column-12 which were retrofitted with 0.5 mm, 1 mm and 2 mm CFRP respectively reported a peak displacement of 29.367 mm, 24.708 mm and 18.566 mm respectively which corresponds to a percentage decrease of 35.69%, 45.89%, and 59.34%. The displacement control of CFRP increased with its thickness owing to increase in stiffness. The decrease in peak displacement with

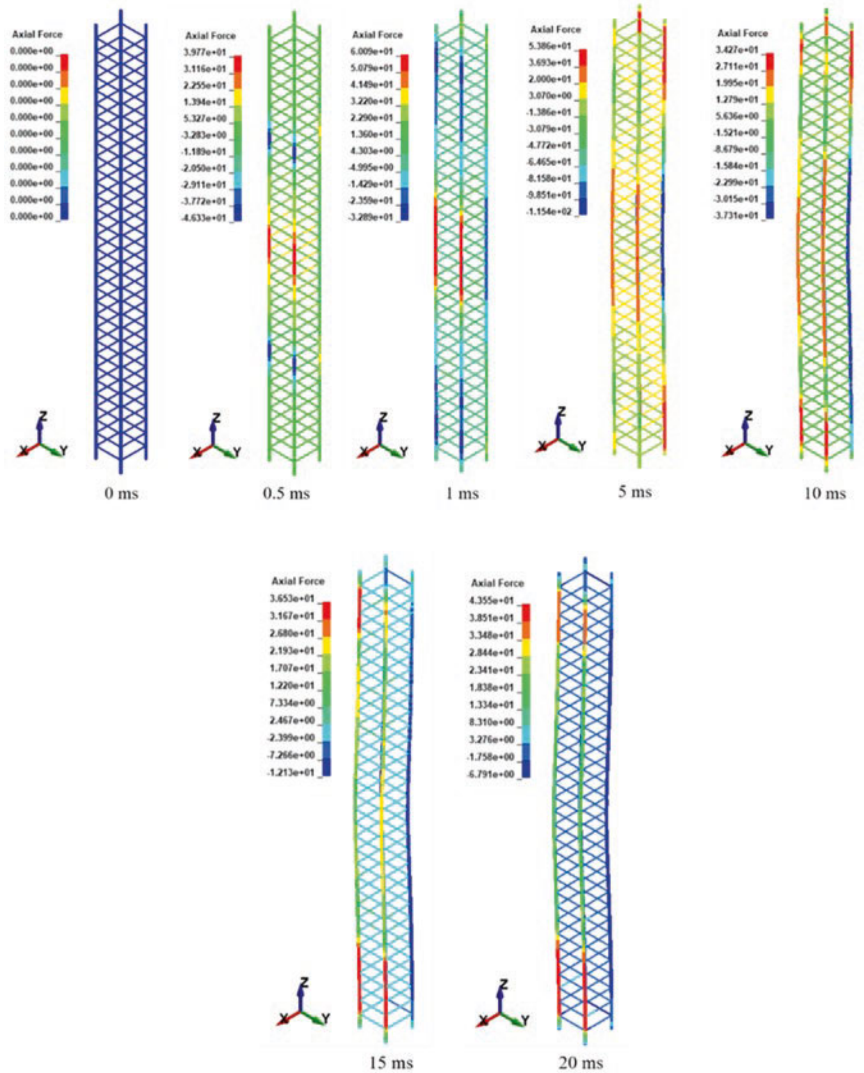

Fig. 19.7 Axial force (in kN) contours in reinforcements of control column

the thickness of CFRP layer is however not linear. From 0.5 mm to 1 mm a decrease of 15.86% in peak deflection is observed, however as we go from 1 mm to 2 mm a decrease of 24.85% is observed.

The reduction in peak deflection with the thickness of GFRP and AFRP on the other hand is almost linear when compared with CFRP. For polyurea and steel jacket the variation of peak displacement with the thickness of composite is slightly erratic because as opposed to the trend shown by FRP's the displacement increased from 31.670 mm for 0.5 mm polyurea to 36.506 mm for 1 mm polyurea before

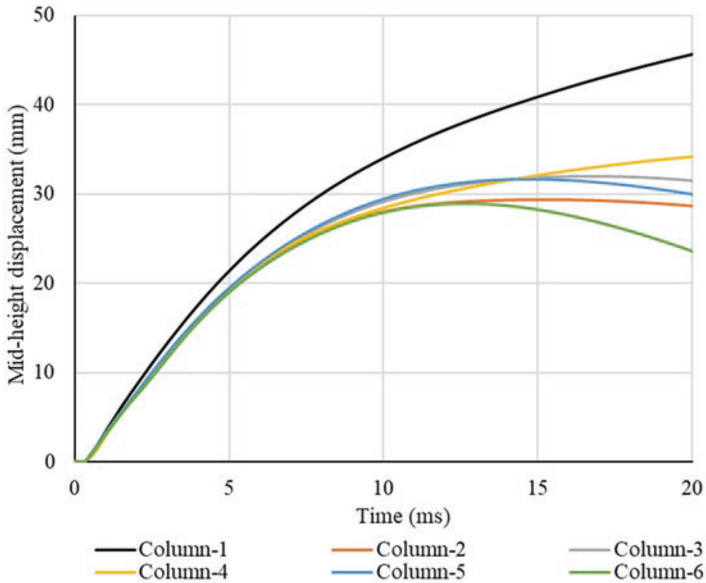

Fig. 19.8 Mid-height deflection history of columns retrofitted with 0.5 mm composite

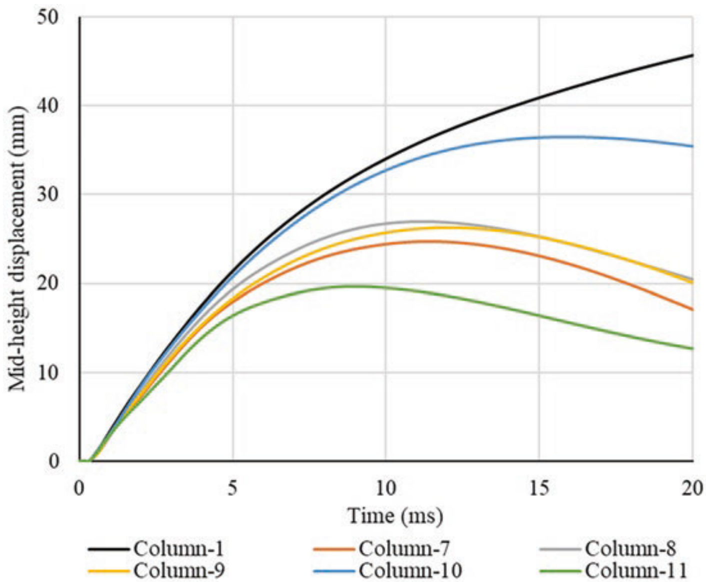

Fig. 19.9 Mid-height deflection history of columns retrofitted with 1 mm composite

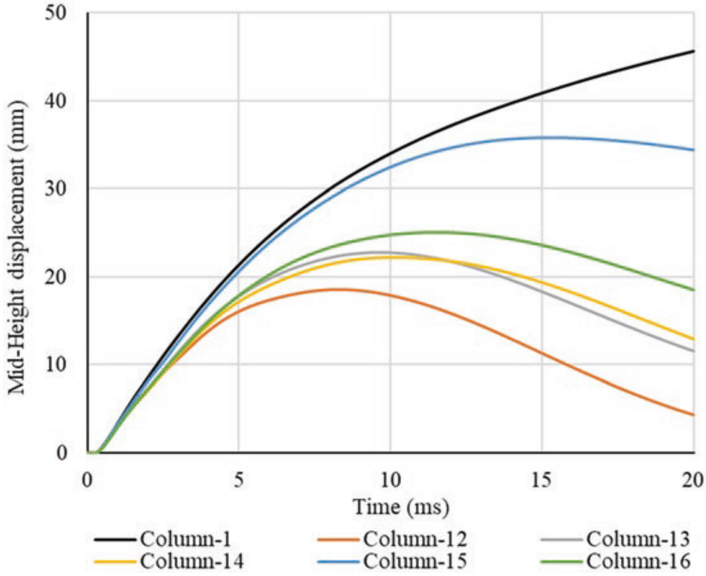

Fig. 19.10 Mid-height deflection history columns retrofitted with 2 mm composite

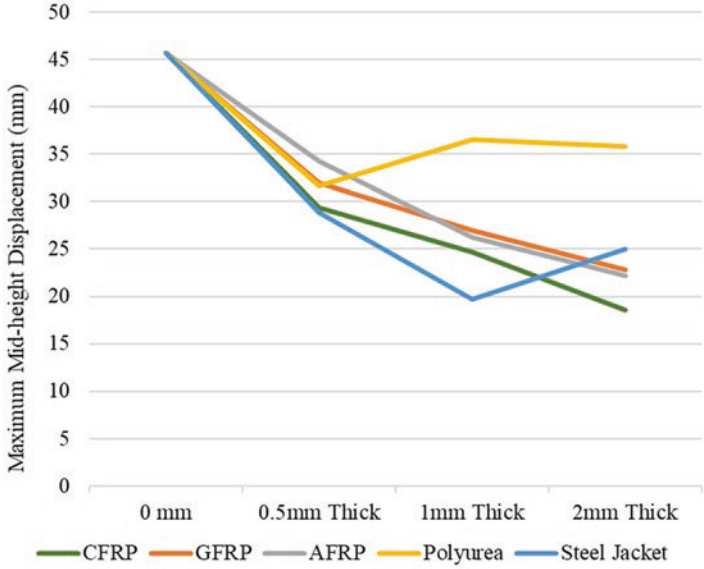

Fig. 19.11 Variation of maximum mid-height displacements of Column's with thickness of different composites

Table 19.6 Peak mid-height displacements and support rotations of investigated columns

Column specimen	Composite type	Composite thickness (mm)	Peak mid-height displacement δ (mm)	Percentage reduction of displacement	Support rotation (Θ^0)
Column-1	Control		45.665		1.744
Column-2	CFRP	0.5	29.367	35.69%	1.122
Column-3	GFRP	0.5	31.967	29.92%	1.221
Column-4	AFRP	0.5	34.208	25.11%	1.306
Column-5	Polyurea	0.5	31.670	30.65%	1.209
Column-6	Steel Jacket	0.5	28.872	36.77%	1.103
Column-7	CFRP	1.0	24.708	45.89%	0.944
Column-8	GFRP	1.0	26.946	40.87%	1.029
Column-9	AFRP	1.0	26.230	42.56%	1.002
Column-10	Polyurea	1.0	36.506	20.05%	1.356
Column-11	Steel Jacket	1.0	19.640	57.00%	0.751
Column-12	CFRP	2.0	18.566	59.34%	0.709
Column-13	GFRP	2.0	22.766	50.14%	0.869
Column-14	AFRP	2.0	22.200	51.38%	0.848
Column-15	Polyurea	2.0	35.836	21.52%	1.369
Column-16	Steel Jacket	2.0	25.034	45.18%	0.956

decreasing again to 35.836 mm for 2 mm polyurea coat. The steel sheets showed a linear trend of decrease to up to 1 mm thick sheet which then increased by 27.46% to give a peak mid-height displacement of 25.034 mm for 2 mm sheet.

When it comes to the type of composite for displacement control of columns, CFRP and steel jacket performed better than the rest. 2 mm thick CFRP wrapped column gave the least peak displacement of 18.566 mm followed by 1 mm thick steel sheet which gave a maximum lateral deflection of 19.640 mm.

19.4.2 Internal Energy of Concrete

The various parts of the RC column i.e., concrete, reinforcements and externally bonded composite layer absorbs the external energy received from the blast wave and converts it into kinetic and strain/internal energy. The magnitude of kinetic energy is negligible in comparison to the internal energy. Moreover, in control column the majority of energy is absorbed by the concrete which consequently causes the fracture and damage to concrete. Therefore, in addition to having adequate stiffness for displacement control, a blast retrofit composite material should also have good energy absorption capacities so that less energy from explosion is transferred to concrete due to which the concrete and eventually the column suffers smaller amount of deterioration. Figures 19.12, 19.13, and 19.14 illustrates the variation in internal energy time history of concrete for the 16 columns with thickness of laminate 0.5 mm, 1 mm, and 2 mm respectively. Figure 19.15 illustrates the variation of peak concrete strain energy with the thickness of each composite.

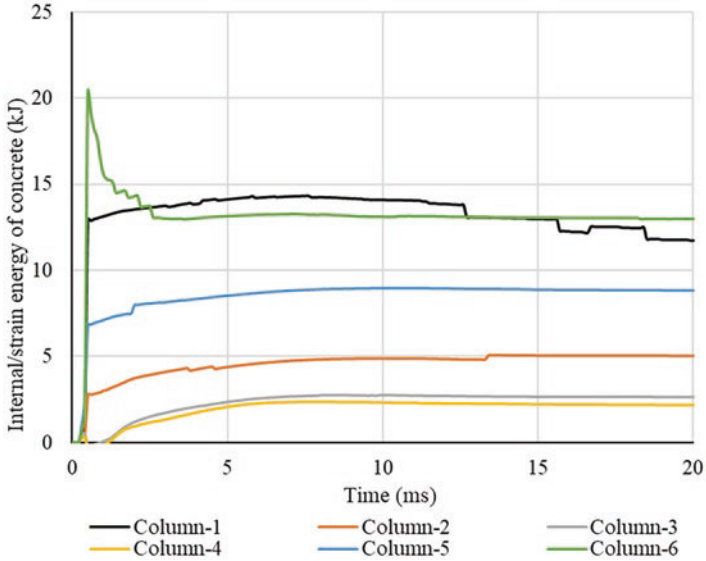

Fig. 19.12 Strain energy history of columns retrofitted with 0.5 mm composites

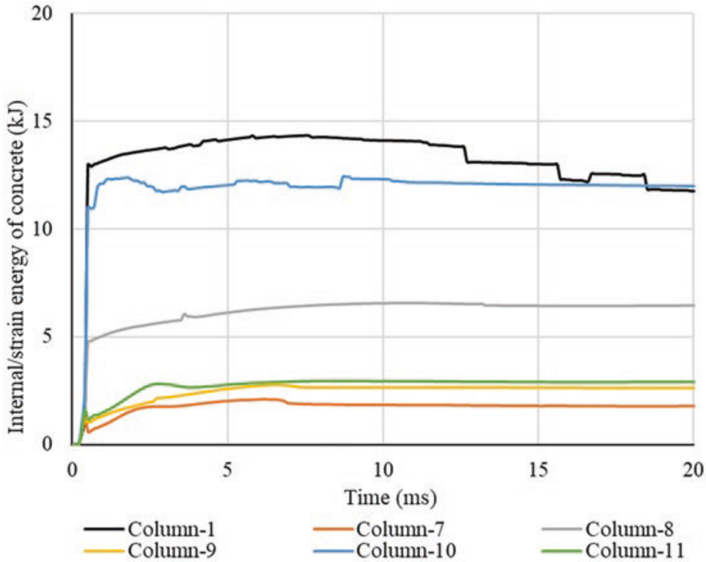

Fig. 19.13 Strain energy history of columns retrofitted with 1 mm composites

Peak internal energy of the column which was wrapped with 0.5 mm and 1 mm thick steel sheet was inexplicably more than the peak internal energy for column-1 that was unretrofitted however their residual internal energy did fall below the residual internal energy of column-1 owing to the energy dissipation due to spalling of cover concrete as shown in Fig. 19.16.

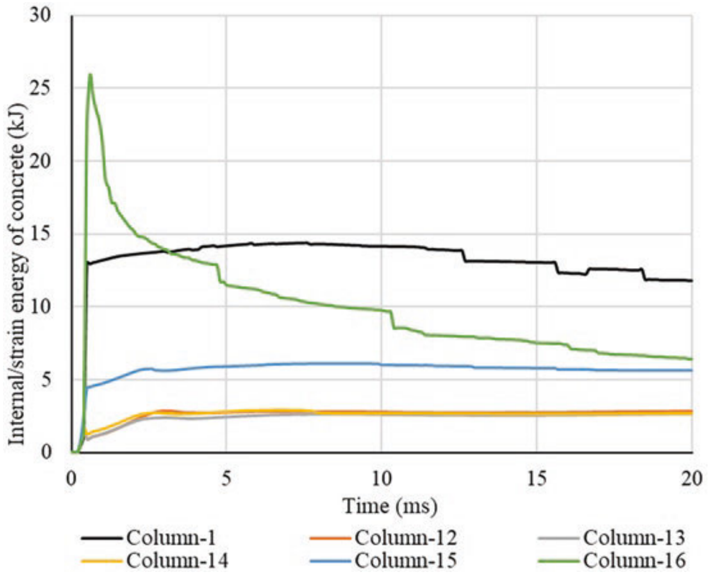

Fig. 19.14 Strain energy history of columns retrofitted with 2 mm composites

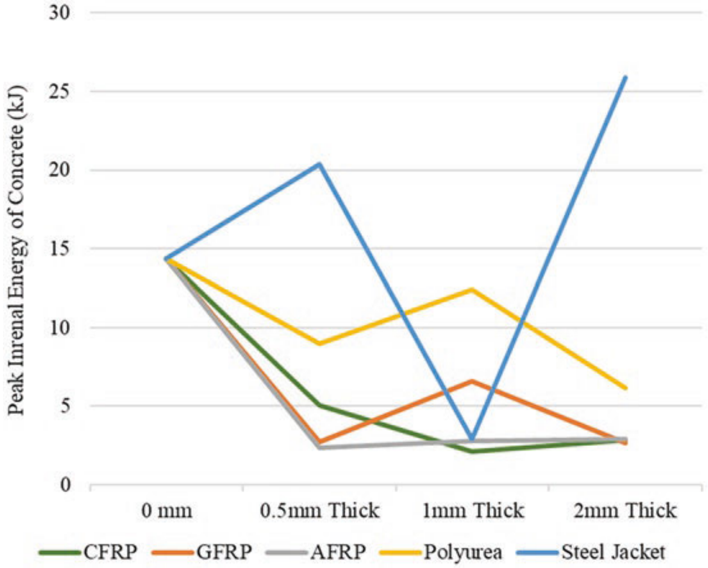

Fig. 19.15 Variation of peak internal energy of concrete with thickness of composites

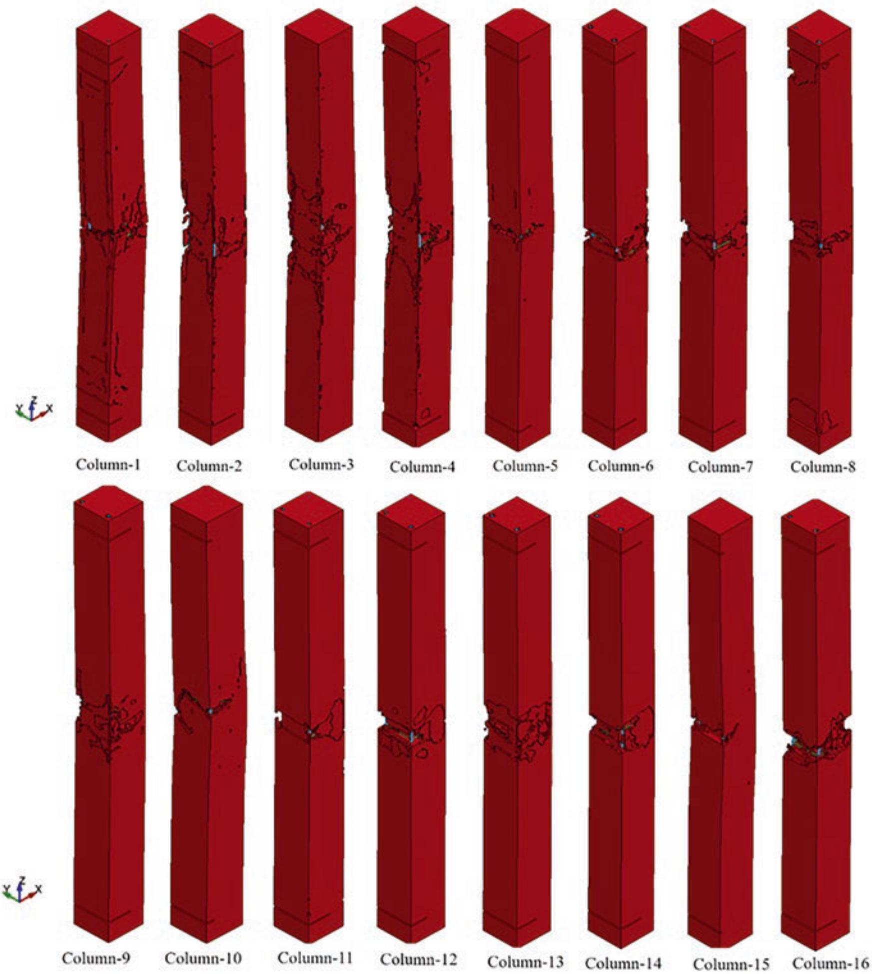

Fig. 19.16 Post blast erosion of the investigated Columns

The peak internal energy reduced by 2.84–6.81 times on the application of CFRP. Similarly, for GFRP it reduced by a factor of 2.18–5.35 and for AFRP it reduced by 4.92–6.05. Polyurea coating showed a moderate energy absorption with a maximum reduction of 2.34 times the maximum strain energy of control column.

Except for AFRP retrofitted columns whose peak internal energy of concrete declines slightly with the increase in thickness of AFRP, no other composite material showed a general increasing or decreasing trend. For GFRP and Polyurea the energy increased from 0.5 to 1 mm before decreasing again for 2 mm thick laminate. On the other hand, For CFRP and steel jacket an opposite trend was observed where the energy decreased from 0.5 to 1 mm before increasing for 2 mm thick laminate. The variation with thickness was however very less for FRP's in comparison to the variation showed by polyurea and steel sheet.

19.4.3 Post Blast Erosion of Investigated Columns

Figure 19.16 shows the erosion/deletion of the concrete elements whose principal strain exceeded the maximum principal strain of 0.1 defined in the keyword MAT_ ADD _EROSION for MAT 72 Rel3 material model. The amount of erosion in the investigated columns is also a good measure to ascertain the effectiveness of the composite wrap for blast protection. Compared to column-1, concrete erosion in the tensile face was eliminated for almost all the retrofitted columns except Column-16 which was externally reinforced with 2 mm Steel sheet. The excessive erosion of concrete for Column-16 can be explained by the fact that internal energy of concrete was maximum for that column. External reinforcement through composites also managed to contain the compression face crushing and side-spalling of concrete to the middle of the column which was otherwise observed along the full height for Column-1. The height of blast-face crushing and side-spalling decreased with the increase in thickness of FRP and the maximum reduction among FRP's was recorded for CFRP followed by GFRP and AFRP retrofitted columns. The best protection against erosion was however provided by polyurea which considerably reduced the front-face crushing as well as the erosion at supports due to direct and diagonal shear. The performance of steel sheet was the least satisfactory among all the composite materials.

19.4.4 Effective Stress (Von-Mises) in Concrete

Figures 19.17, 19.18, and 19.19 shows the effective stress time history of a concrete element at the mid-height of the control and laminated columns for thickness of laminate 0.5 mm, 1 mm, and 2mmrespectively. Figure 19.20 illustrates the variation of effective stress with the thickness of each laminate. For short duration dynamic loading such as blast or seismic loading where the principal stresses fluctuate between compression and tension, it makes more sense to describe the state of stress in terms of Von-Mises stress which is always positive and which takes into consideration all the normal stresses (tensile or compressive) and shear stresses acting on an element. The effective Von-Mises stress is given by Eq. 19.2 as

$$\sigma_{v-m} = \sqrt{\frac{\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_x - \sigma_z\right)^2 + \left(\sigma_z - \sigma_y\right)^2 + 6\left(\sigma_{xy}{}^2 + \sigma_{yz}{}^2 + \sigma_{xz}{}^2\right)}{2}} \tag{19.2}$$

From the figures it can be deduced that all the composite wraps effectively reduced the Von-Mises stresses in concrete with the reduction factor ranging from 4.07 for 2 mm Polyurea coated column to 7.17 for 0.5 mm AFRP wrapped column. AFRP and GFRP were particularly more effective than other composites followed

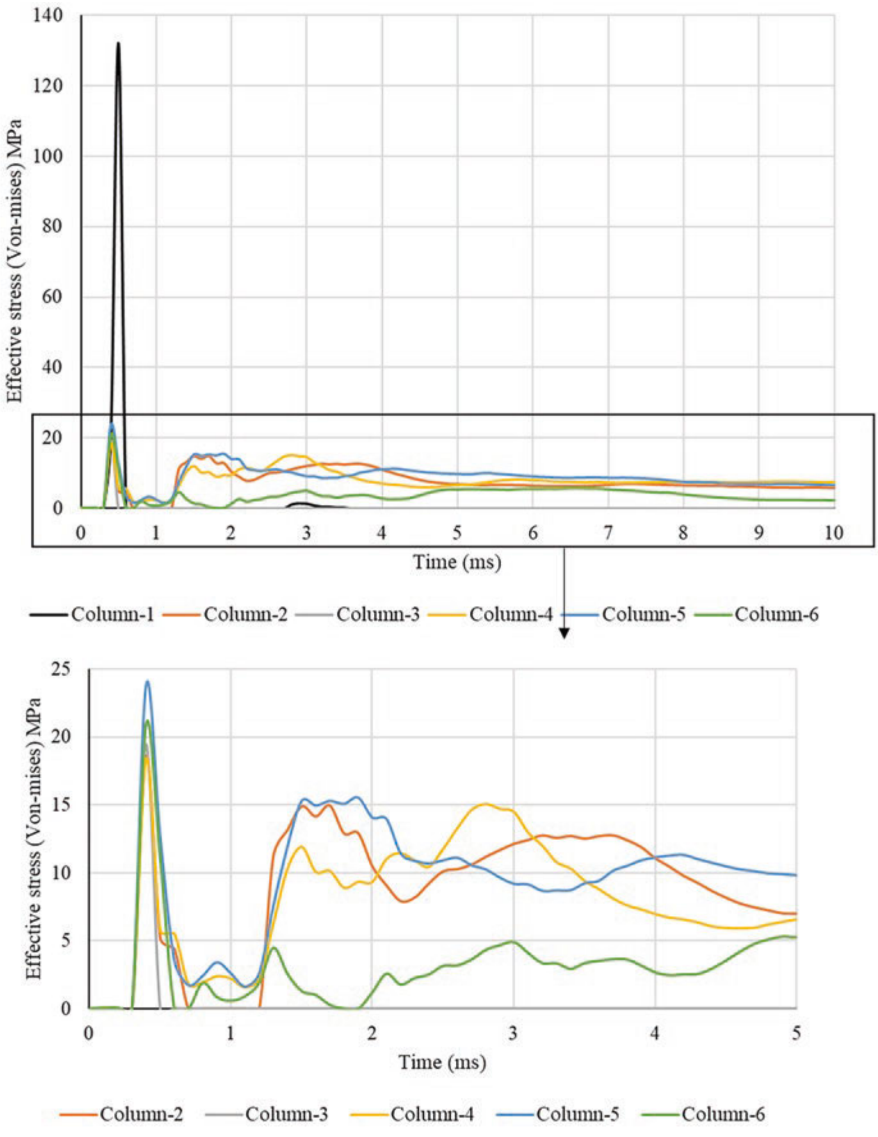

Fig. 19.17 Effective stress in bare and columns retrofitted with 0.5 mm composite

by GFRP, steel sheet and polyurea. The FRP wrapped column showed a consistent increase in Von-mises stress with the increase in the thickness of layers, however the variation was only marginal. Polyurea and steel jacketed columns on the other hand showed inconsistency in the variation of stresses with the thickness of layer.

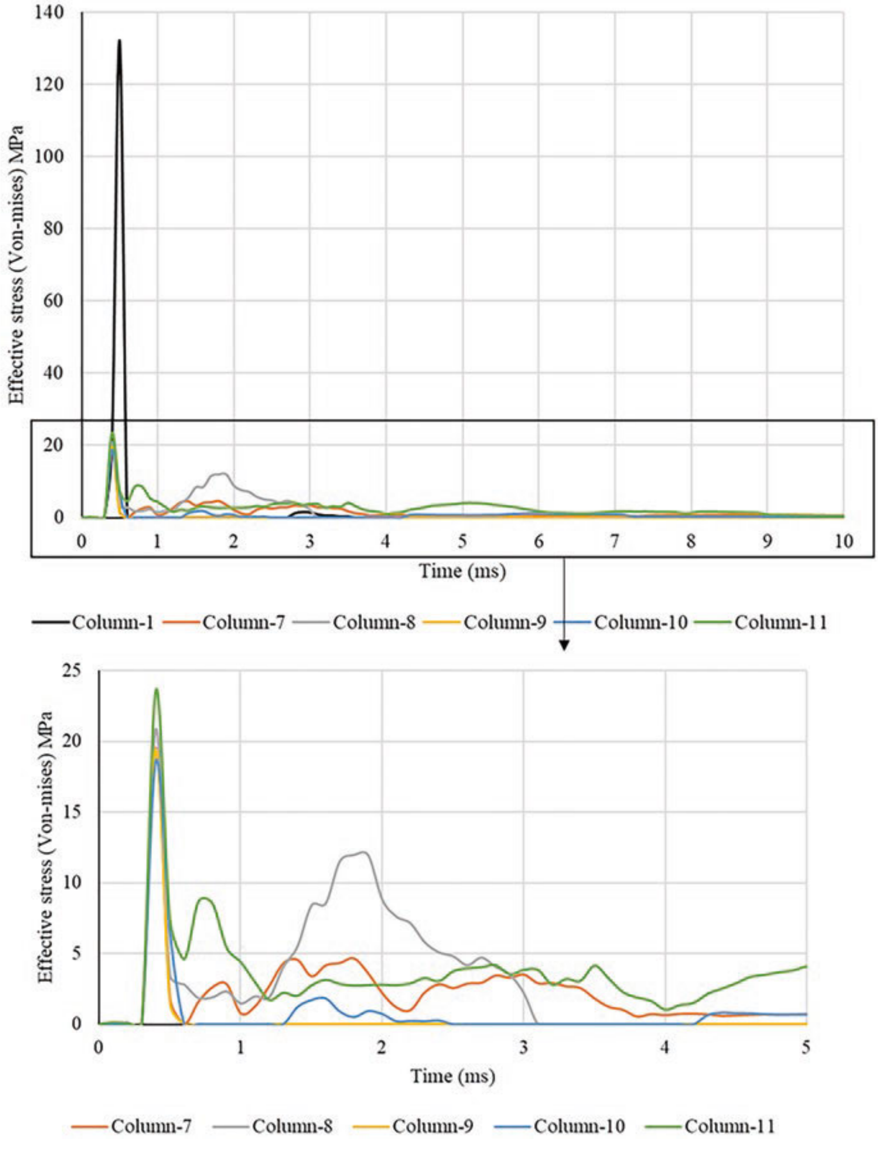

Fig. 19.18 Effective stress in bare and columns retrofitted with 1 mm composite

19.5 Conclusion

The following conclusions can be drawn from the undertaken research:

(i) LS-DYNA or other FE software's can be successfully employed to carry out blast load analysis of structures with certain advantages over field tests such as

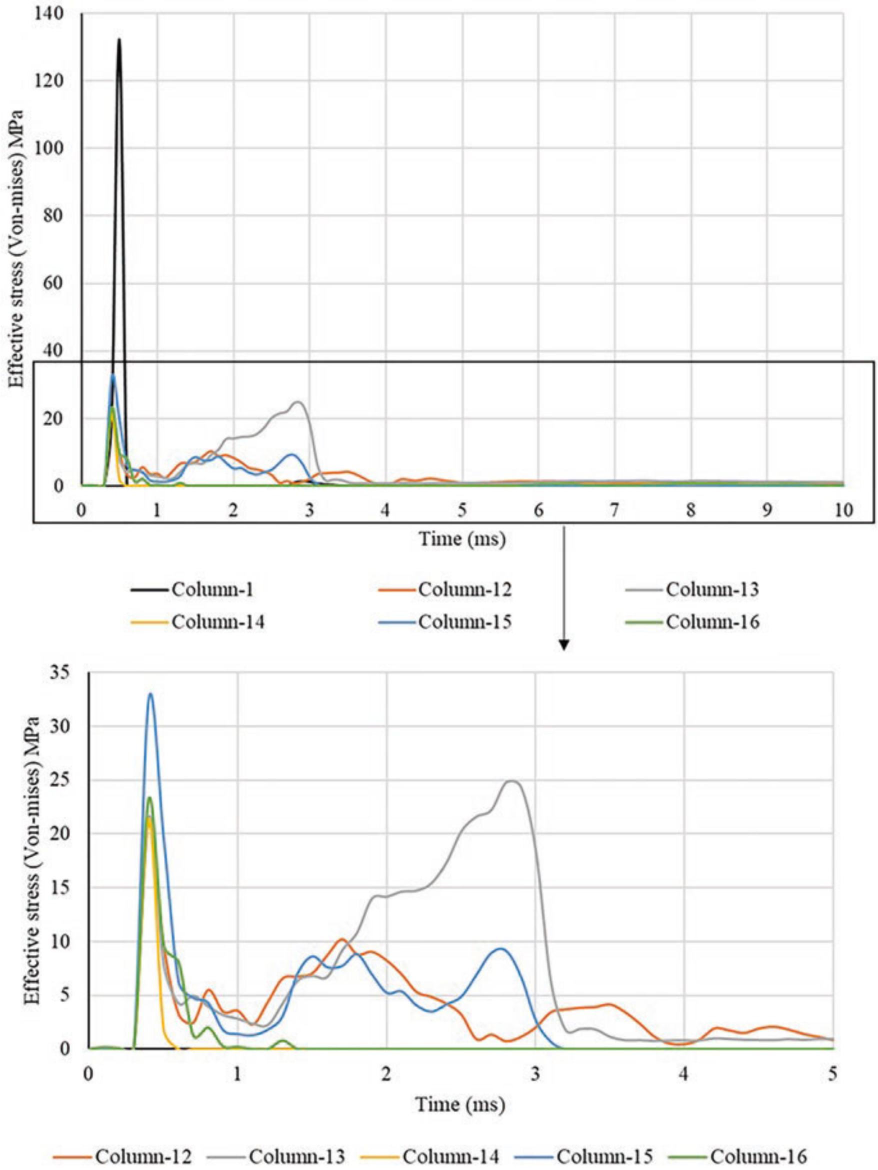

Fig. 19.19 Effective stress in bare and columns retrofitted with 2 mm composite

saving on cost and time. It is particularly advantageous for comparative studies as it is difficult to create exact blast loading conditions for successive test cases experimentally.

(ii) CFRP provides the most effective retrofit solution for RC columns against close-in detonation among the other available FRP's, polyurea spray and steel

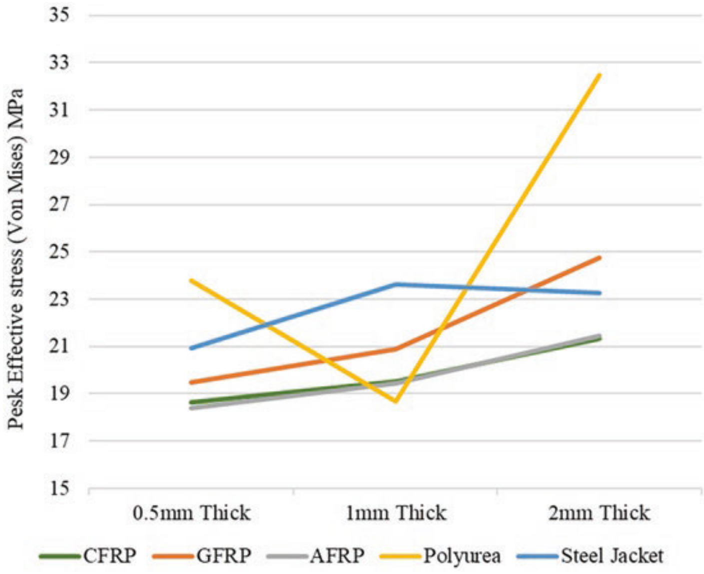

Fig. 19.20 Variation of Peak Effective stress with thickness of different composites

sheets in terms of displacement control, reduction in internal energy and stresses of concrete and sufficient protection against erosion with only polyurea outperforming it in terms of erosion control.

(iii) For FRP's the degree of blast mitigation generally increased with the thickness of FRP layer with only effective stress reduction showing a negative trend. This however was not the case for sprayed on polyurea and steel sheet whose behaviour was non-linear and erratic.

(iv) For low-cost blast retrofitting GFRP followed by AFRP should be preferred as their performance was nearly as good as that for CFRP. Also, it would be more economical to use larger thickness of GFRP or AFRP layer which gives an equivalent protection as that given by thin CFRP sheets.

(v) Further research can include the use of SHCC, metallic foams, SFRP, Hybrid FRP's such as CPU (CFRP plus polyurea) and other innovative materials for strengthening of RC columns against explosions.

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Chapter 20
Evaluation of Conventional Red Bricks with Compressed Stabilized Earth Blocks as Alternate Sustainable Building Materials in Indian Context

Aishwariaa Unni and G. Anjali

Abstract Sustainability has become crucial due to the increasing dependency on natural resources. With increased population growth, the housing sector constantly faces a deficit in providing for the masses. India has seen a steady increase in the construction of residential buildings to address its population of over one billion people. For decades, the country's construction sector has been using concrete, fired bricks, or cement blocks supported with reinforcement bars. Their utilization causes negative impacts such as: (i) increased carbon production, (ii) increased energy use, (iii) the toxicity of the by-products and (iv) non-renewable resources depletion. Employment of alternative and sustainable materials in construction is a viable solution to address some problems, but many are reluctant due to a higher cost margin. Therefore, it is vital to use resources in construction that can improve a building's sustainability while being cost-effective to not over-burden the residents. This paper aims to address the cost-effectiveness of using alternate building materials by comparing red bricks and compressed stabilized earth blocks (CSEB). The factors like ease of use, availability, and the impact of its usage on the environment were evaluated. Using CSEB significantly reduced construction cost and sale price, making it an attractive replacement for traditional materials.

20.1 Introduction

The government of India placed importance on increasing the housing stock from the first five-year plan (1951–1956) onwards. It was primarily geared towards housing for the industrial workers and economically weaker groups (3rd Five Year Plan

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2021). Various policies and programs have been employed to emphasize the importance of subsidizing houses for lower-income classes. However, the policies themselves have met varying levels of success because renting, buying, or constructing an adequate house is an expensive venture despite the availability of subsidies (D'Souza 2019). The lack of accessibility to aids becomes evident in the case of the Low-Income Groups (LIG) and the Economically Weaker Sections (EWS). An average housing unit in India with a carpet area of 30 square meters can cost anywhere from 12 to 22 lakhs. In contrast, a house with a carpet area of 40 square meters can cost up to 26 lakhs according to the property's geographic location (Apartments for sale in India 2021). Putting this into perspective, the EWS have a per capita income of fewer than 3 Lakhs per annum, and LIG has between 3–6 lakhs per annum. The subsidy offered via loans through PMAY (Pradhan Mantri Awas Yojana 2015) for EWS is a maximum of 6 lakhs with a 6.5% interest rate, and for LIG, the amount increases to 12 lakhs with a 4% interest rate (Government Housing Schemes India 2021). This would mean that to own a basic home, the individual or the household should give up the entirety of its income for at least 4 years. The cost is greater than the income level, and in cases where it is affordable, the quality of living drops significantly. The existence of slums, cluttered housing and the high levels of homelessness in the country give light to Indian housing problems (Roy and Meera 2020).

20.1.1 Affordability

Affordability can be defined as the ability of a person to pay for a particular product or service (Affordability 2021). The term affordable could be misleading. Affordable for one class may not be affordable for another; it is relative and subject to change concerning the socio-economic boundaries of a particular demographic (Perera and Lee 2021).

So, affordable housing requires context, and in most parts of the world, it has come to mean the same as social housing. Defining housing quality may be different based on geographic location, cultural or social norms. Even so, one can use a few broad scope indicators such as physical sustainability, spatial deficiencies, housing services, and extra amenities to act as a scale for comparison (Haque et al. 2020). There are still no clear goals or indicators set as checkpoints to determine what would be considered a sustainable housing development indicator, despite the efforts of various multinational organizations around the world (Winston and Pareja Eastaway 2007). Having said this, it would be prudent to investigate the global situation of the state of housing or housing crisis that exists in the world currently.

20.1.2 The World Deficit in Housing

Of the 7.9 billion people worldwide, 150 million people remain homeless, while another 20.5% live in destitution (Hegedüs and Horvath 2016). To them, housing is a luxury that they might never get to experience. It is a situation that undermines their fundamental right to have an adequate standard of living, one that does not compromise their health or wellbeing as is mandated by the fundamental human rights (United Nations 2021). The accessibility to adequate and affordable dwelling is an important indicator of the sustainable development of a country, according to the guidelines given by the United Nations Commission for Sustainable Development (Indicators of Sustainable Development: Guidelines and Methodologies-Third ed. 2021). To get a clear perspective, it would be practical to make some comparisons: For this purpose, six random countries from 37 countries were selected in the member list of the Organization for Economic Co-operation and Development (OECD). This is an international economic organization whose objective is to promote economic progress and trade around the world. Since the focus is economic progress, data sets related to such aims are readily available, so the comparison was based on the following criteria:

(A) *Price To Income Ratio:* The price of owning a residential property to the per capita income.
(B) *Gross Rental Yield (City Centre & Outside of Centre):* the annual rental income from the property, excluding the maintenance charge and of this property or taxes.
(C) *Price To Rent Ratio (City Centre & Outside Of City Centre)*: the price of a specific property to the average annual gross rent in the given location;
(D) *Mortgage As A Percentage Of Income:* The amount of income earned after setting aside the total mortgage to be paid (less than 28% of monthly income);
(E) *Affordability Index:* It is the ability of a mean income type family to afford an average priced home for the mortgage in a particular region. The benchmark represented here is 0.1, which indicates that any value above it would mean that the average citizen of that country can afford a more expensive house. If the value falls below 0.1, owning a house would be difficult or impossible for a median-income family, i.e., a decrease in affordability (Hassan et al. 2021).

The average price compared with rent in the selected OECD countries is shown in Fig. 20.1 The selected countries include Norway, Switzerland, United States, Canada, South Africa, China and India. Data from major cities of these countries were compiled and then averaged to finally form the tabulation shown in Fig. 20.1, which also shows the affordability index of that country. The non-uniformity observed in the prices of houses located in the same country but in different neighbourhoods, i.e., near the city versus the outskirts, is shown in Fig. 20.2.

It is essential to indicate the fact that the affordability can vary depending on the location and demographics. Of the chosen countries, the United States, Norway, Switzerland, and Canada come under the classification of developed countries,

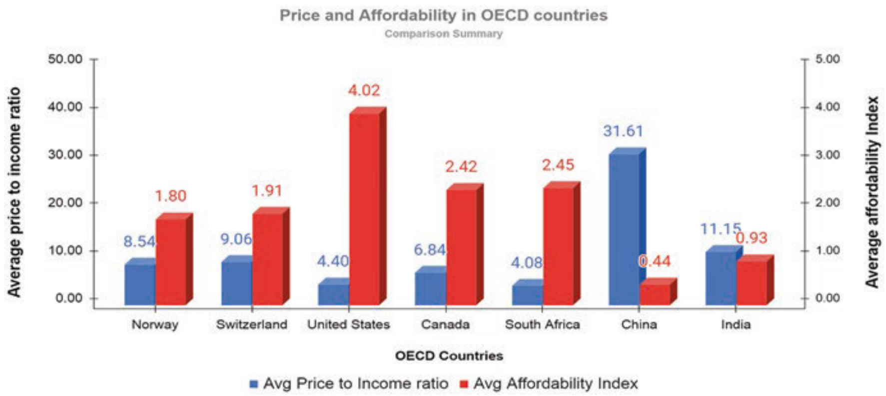

Fig. 20.1 Average Price and Affordability in OECD countries. (*The data was sourced from the statistical database Numbeo:* https://www.numbeo.com/cost-of-living/comparison.jsp)

Fig. 20.2 Average Affordability Index in OECD countries. (*The data was sourced from the statistical database Numbeo:* https://www.numbeo.com/cost-of-living/comparison.jsp)

while the other three are categorized as developing economies (World Economic Situation and Prospects 2014). This disparity can be deduced from the figures, as the affordability index is higher in developed countries, while the price to income ratio is more significant in developing economies. With this, we can establish the necessity of proper and cheap housing facilities (Metcalf 2018; Alabi and Fapohunda 2021). to aid in a country's growth and economic development.

20.1.3 The Current Scenario of Indian Housing

With economic development and urbanization opportunities, more and more people were migrating into cities that represented the hub of commercial growth. The population of Indian cities rose to unprecedented levels; however, the population increase was not simply limited to the cities. The neighbouring rural areas or outskirts were influenced by the expanding development that would not be contained in the city centre, thereby increasing the deficit of an already shrinking housing stock (Roy and Meera 2020). The housing stock shortage in India seems to be primarily concentrated in rural areas at 43.6 million units than urban areas at 26.3 million units (Housing Poverty in India: Tacklings Slums & Inequalities 2021). More than 35.2% of the country's total population live in slums, posing health issues, security risks, and psychological detriment (Population living in slums 2021). However, there have been efforts from government and non-government funded organizations to improve the living conditions of these people. The government policies and programs like Jawaharlal Nehru Urban Renewal Mission (JNNURM 2005), Rajiv Awas Yojana (RAY 2011), Pradhan Mantri Awas Yojana (PMAY 2015), Swachh Bharat Mission (2014) have all attempted to improve conditions of living of the economically weaker portions of the society by building upon existing infrastructure and providing basic amenities, along with subsidizing rates for homes constructed in redeveloped slum areas (Bharti and Divi 2019). Organizations such as Housing and Urban Development Corp Ltd. (HUDCO), Habitat for Humanity India are among the most notable for their contribution to enabling community participation in the design and building of social housing (Shelter for India's Urban Poor 2020), which has provided some relief to the situation of a few. However, the more significant problem of lack of available houses remains.

20.1.4 Achieving Sustainable Affordability

The process for building housing for the poor, slum clearance or building for Economically Weaker Sections (EWS) and Low-Income Groups (LIG) are generally undertaken on a larger scale or done as a Public-Private Partnership (PPP) (Public-Private Partnerships for Affordable Housing in India 2017). A combination of reinforced concrete, burnt clay bricks, or cinder blocks is used to construct buildings with 4 to 6 stories, and the housing units are usually arranged as a cluster with common corridors and open spaces (Warrier et al. 2019). As such, the project's focus is generally geared towards reducing the time taken in finishing the project or overall cost optimization and thus, the sustainability aspect is often neglected. The cause for not integrating sustainability into construction may be due to non-availability of locally produced sustainable material, misinformation, lack of knowledge, cultural significance or social acceptance (Isnin et al. 2012). There are several suitable successful examples of sustainable construction found in India and abroad, as shown in Table 20.1, giving examples of how sustainable affordability in housing can be achieved using products with the local community's input.

20.2 Materials

The diversity of the geophysical conditions in India has given rise to a wide variety of building materials that are used depending on the locality. The building materials would naturally depend upon the availability of materials required for the production process. Some of the most popular materials used in the Indian construction industry are cement, steel or wood. The technological improvements have brought about positive changes in the construction industry on a global level, where one can see the shift towards using more eco-friendly materials. Economically and ecologically viable materials are gaining importance as the population becomes more environmentally conscious due to global warming and climate change. Many of these building materials are rooted in the concept of either reusing or recycling existing products to reduce the strain on the already dwindling supply of non-renewable natural resources. These materials are produced to reduce one or more components that impact the environment (Ralegaonkar et al. 2016), such as embodied energy, operational energy, embodied carbon emissions, embodied water, etc. They are simultaneously viable economically, leading to long-term sustainability solutions, particularly in emerging economies around the globe. Building materials like earthen materials, wood, bamboo, insulated concrete forms, cordwood, straw bale, earthbags, slate/ stone roofing, composites, natural fibre, polyurethane, fibreglass, cellulose, cork, natural clay, fibre cement, etc., are among the many available for constructing buildings suitable for public, private, commercial, or residential sectors. While there are several options to choose from when it comes to sustainable materials, Table 20.2 lists out some of the more popular alternative building materials that are employed for construction in different parts of the globe, along with their total embodied energy usage and embodied carbon measures via their global warming potential (GWP) in terms of carbon dioxide.

There are several alternatives to choose from compared to the traditional building materials of brick masonry or reinforced concrete structures. Nevertheless, it does not add up that such materials being used are rare outside of pilot projects. There are several possibilities as to why clients and builders seem reluctant to use them; a few of the challenges are listed as follows:

1. *Client perception:* Certain materials are regarded as inherently cheap, with homeowners not preferring to use them (What is Customer Perception 2020).
2. *Unawareness:* Many available materials are not used in construction due to a lack of available knowledge or misconception about the material's cost (AlSanad 2015).

Table 20.1 Examples of successful models using green materials and technologies

Type of housing (reported literature)	Material used	Benefits achieved	Key points relevant to sustainable affordability
Rammed earth home in Salisbury Cove, Maine. England (Lookabaugh 2015)	– *Rammed earth*: Walls constructed by tightly compacting layers of soil mixture between frames (wooden) and removing them after the mix has set. (Environmental Advantages of Rammed Earth Construction n.d.)	1. High thermal mass that regulates the interior temperature. 2. Insulation property suitable for both hot and cold climates 3. The earth mixture made from the excavated soil makes it cheaper.	– Most of the wood incorporated in the house was salvaged. – To stabilize the walls, only 7% of cement was added. – A layer of insulation was incorporated to increase the insulation properties. – The house is equipped with solar panels that aim to reduce operational energy costs.
Empower Shack Project, Cape Town. South Africa (Engineering For Change n.d.)	– *Corrugated iron sheeting* – Used in roofing by layering and then securing with the use of screws. – *Concrete masonry units (CMU)* – Standard concrete blocks used for construction – *Plywood* – layers of wood sheets to form strong panels	1. Smaller footprint area used (38–84 m^2) 2. Denser construction leaves spaces for community interaction 3. The use of materials readily available reduces costs	– The roof sheets are durable and can be easily replaced. – CMU made with replaced materials are sustainable. – Plywood manufactured from sustainable forests ensures a steady supply of materials and income from forest management.
Livingboard, Karnataka. India. (Livingboard 2018)	– Prefabricated framework and panels: Made ex-situ using a variety of materials and assembled on site.	1. Basic amenities are pre-built in the substructure upon which residents can do their own super structure design. 2. The house is made of low-cost materials and is efficient due to its production in the factory	– Panels are installed for the generation and storage of electricity. – A pre-built conduit for grey water recycling is present. – The open-source aspect of the design encourages different residents to adopt their design

(continued)

Table 20.1 (continued)

Type of housing (reported literature)	Material used	Benefits achieved	Key points relevant to sustainable affordability
Viviendas del Hogar de Cristo, Guayaquil. Ecuador. (Down To Earth 1997)	– Bamboo panels: Primarily manufactured in local factories. – Zinc or corrugated iron sheets: Used for roofing purposes.	1. Bamboo is a green building material that can be grown, hence is sustainable. 2. Bamboo is grown in local plantations, and the panels are produced within the local factory, generating employment for the local community.	– Shows a good example for sustainable development of the community – The panels are premade, enabling reduced time of assembly during construction
CEB Homes, Jinja. Uganda. (Salami 2019)	– Compressed Earth Blocks (CEB): earth mixture with added stabilizing agent is compressed to form the blocks.	1. Employment is generated during the construction for the manufacture of the blocks. 2. Use of subsoil rather than topsoil reduces the degradation. 3. Reduction of consumption of fossil fuel during the manufacturing process.	– Reduced construction time due to employment of clear design. – Reduction of cost of materials – Emission of embodied carbon is reduced.

3. *Social acceptance:* Social acceptance is vital if a material gains popularity and is commonly used in the region (Alam et al. 2020; Aule et al. 2019).
4. *Lack of skill:* Some building materials require a specific skill set to use their full potential, requiring training or skilled labor (Bharti and Divi 2019).

These issues must be addressed for more people to adopt the usage of greener construction material.

20.3 Methodology

The study considers one alternative building material compared with a traditional building material to determine relevance to provide a sustainable but cost-effective solution to housing shortages in India. The state of Tamil Nadu was considered for building sustainable houses, and the reference for price, availability and geophysical conditions are provided as a base to the model. Tamil Nadu is located in the southeast part of India, with a total population of 78.8 million (Tamil Nadu Population 2021); as such, the cities are overly congested, so the model is to be

Table 20.2 Popular alternative building materials for construction

Sl. No.	Material	Key features	Embodied carbon emission (CO_{2eq}/m^2)	Embodied energy (GJ*/ m^3)	Used in	Typical cost (converted to INR)
1	Rammed earth	– Earth can be sourced locally – Production is simplified	0–13.8 (Maskell et al. 2014)	0.4–0.5 (Reddy and Kumar 2010)	– Walls (external and internal)	16,343.57 per face of wall
2	Bamboo	– Highly versatile – Durable, provides earthquake resistance	−0.8-0.8 (Van. Der Lugt and Vogtlandr 2015)	2.4 (Noerwasito and Nirwansyaha 2015)	– Walls (external and internal) – Panels (doors, separators) – Furniture	5800 / square meter
3	Cross-laminated timber	– Coming to be used as a replacement for steel	0.1–0.4 (Spear et al. 2019)	0.116 (Guo et al. 2017)	– Walls (external and internal) – Panels (doors, separators)	3120.14/ square meter
4	Plant-based polyurethane rigid foam	– Manufactured using materials like kelp, hemp, etc. – Used in insulation	7 (Transitioning To Low-GWP Alternatives 2011)	2.215 (Dissanayake et al. 2017)	– Insulation panel – Furniture	200/ kilogram
5	Compressed stabilized earth blocks	– Reduces the cost and time of construction – Does not require mortar between each layer	0.038	0.6–1.1 (Hammond and Jones 2008)	Walls (external and internal)	30–48/piece
					Concrete wall costs:	2150/ square meter

**GJ* gigajoules

located in a suburban area with well-connected road systems to enable proper connectivity. The low-cost housing model is a G + 4 building, with a height that does not exceed 18.3 m to avoid the installation of lift systems per the codal provisions of the state of Tamil Nadu, which is the assumed place of set up of the building, reducing the overall cost- initial and operational (Tamil Nadu Combined Development and Building Rules 2019).

The primary residential unit is designed to have one hall, one bedroom, kitchen, and bathroom in a total carpet area of 42.25 m^2. There would be eight units on each floor, with a total of 6 buildings in the entire plot of size 8314.6 square meters. The building itself is a reinforced concrete frame structure, with the wall being the central point for comparison. The two parameters considered during the selection of the materials are Cost and Sustainability. With this, one can judge if the building model is true to the concept of making houses that are both affordable and environmentally friendly. Burnt clay brick and Compressed stabilized earth blocks are the materials that make up the wall. CSEB was chosen because of its sufficiently satisfying embodied carbon and energy values and because it becomes easier to compare cost quantity with burnt clay bricks.

20.4 Results and Discussion

The costs for various steps during construction were computed using the real-time market price of the materials and services with the aid of field experts. As such, the land cost, fees paid to contractors, design cost, the cost for time delays during transportation were not considered during the calculations because they do not directly affect the cost of materials used in the duration of construction and due to the lack of primary data upon which the estimates can be made. The entirety of the calculation is summarized in Table 20.3 for both red bricks and CSEB. The maximum cost difference occurred in the plastering and painting of the wall and the use of mortar between each layer in the case of Red bricks compared to compressed stabilized earth blocks; however, the unit cost price of red bricks is lesser when compared to CSEB. The total cost of construction is significantly reduced for CSEB, which comes to INR 17,85,72,617.1 compared to the construction cost using red bricks at INR 22,50,20,344.1.

The CSEB blocks can be made in-situ or nearby the site if the soil is of good quality, reducing the cost and the energy used for transportation. The unit sale price would be INR 9,68,450 and INR 7,70,663 for a red brick house and CSEB house, respectively. The standard housing rates not distributed via government agencies are priced at about 12–21 lakh INR for a similar floor space depending on the location (rural to urban). However, the housing projects spearheaded by the government of India have managed to subsidize the housing and bring down the cost to about 9–12 lakh INR for a 30 square meter flat (Tamil Nadu Housing Board, n.d.).

Therefore, using materials like CSEB can reduce the total cost of construction that accommodates the needs of the economically weaker sections while being sustainable.

Table 20.3 Cost comparison analysis for red bricks and CSEB

Sl.no.	Description	Unit	Cost in INR Red bricks	CSEB
1	Earthwork	1 m^3	7170920	7170920
2	Providing sand filling	1 m^3	447750	447750
3	Providing PCC	1 m^3	5674280	5674280
4	Providing RCC works		65061480	66060048
5	Backfilling the foundation		400000	400000
6	Providing super structure			
(a)	In CSEB blocks	1 m^3		77883120
(b)	In brick masonry CM 1:6	1 m^3	114550968	
7	Providing sand filling with M sand base	1 m^3	893193.885	787578.885
8	Providing PCC 1:4:8 with 40 mm BG metal flooring	1 m^3	6339820.26	6339820.26
9	Mosaic tile flooring in CM 1:3, 20 mm th	1 m^2	7296120	7296120
10	Providing Wall plastering in CM 1:5, 15 mm th	1 m^2	6430872	–
11	Painting, varnish and primer	1 m^2	4242000	–
12	Door, window, ventilation, frames work	LS*	2639972	2639972
13	Provision for finishing	LS*	240000	240000
14	Provision for internal electrification	LS*	1300008	1300008
15	Provision for sanitary arrangements	LS*	1123000	1123000
16	Provision for rainwater harvesting arrangements	LS*	200000	200000
17	Provision for contingencies and unforeseen items	LS*	1010000	1010000
	Total cost		225020384.1	178572617.1

**LS* Lump Sum; All cost mentioned is in INR

20.5 Conclusion

While constructing houses for economically weaker communities, it is essential to use technologies and materials that would allow for the reduction of the overall project cost. However, it is also prudent to keep in mind that owning a house is more than having shelter because it is where people and families are nurtured. The importance of community participation during the design and the construction period can lead to a more interactive approach, improving the quality of life of those living in that area. People need to be informed about the availability of green materials that they can choose from without affecting the cost of their project. While literature about sustainable materials tends to focus on the effects of sustainability or the improvement of the materials to increase its sustainability aspect, a more demonstrative direction is to be taken to help integrate these materials into mainstream construction. Though this project does not give a detailed rundown on the sustainability aspects of green materials, a broad overview is mentioned compared to conventional materials. The cost comparison between burnt clay bricks and compressed stabilized earth blocks assumed to be built in a suburb in Tamil Nadu showed that CSEB is a cheaper alternative that can reduce the project's cost. Using CSEB for construction also generates employment for low-skilled workers; as such promoting awareness about the existence of such eco-friendly and economical materials might just be the approach required to achieve sustainable development in the country. Further research can be done to make these materials are more functional for different climatic conditions and gain acceptance under regional differences.

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Chapter 21
Experimental Study on Alternative Building Material Using Cement and Stone Dust as Stabilizers in Stabilized Mud Block

B. R. Vinod, H. J. Surendra, and R. Shobha

Abstract Soil is a construction material alternative to traditional materials such as steel and concrete. About 40% of the world's population in most of the regions uses soil as traditional constructional material. Blocks of Stabilized mud (SMBS) are the wetted mixture of stabilizer, soil and sand, which is compacted into a block of high-level density in a machine to produce stabilized mud block. The factors influencing the masonry strength in cement- mortar of various proportions were studied in a systematic experimental analysis. It has been observed, mud block strength increases with increase in corresponding cement content. The effect of alternative building technologies on energy and the environment is addressed, as well as the energy consumption and transportation of common and alternative building materials. The aim of this analysis was to make stabilized mud blocks with locally available red clay soil and ordinary Portland cement as a stabilizer. The mix proportions considered for the trials were 1:0.5 (Soil: Stone Dust), 6%, 7%, 8% cement. The two percentages of each stabilizer were used to make stabilized mud blocks, which were measured after 28 days. The best result was determined by compressive strength, water absorption and the required percent of each stabilizer was selected. The stabilized mud blocks had an average compressive strength of 3.8–4.04 MPa. Average water absorption 13.08–13.67%. This research has yielded a number of intriguing findings. Also, the rise in intensity was found to be constant, indicating that it would continue to grow over time.

Keywords Compressed stabilized mud block · Ordinary Portland cement · Stone dust · Compressive strength

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21.1 Introduction

The Stabilized Mud Block Technology is a masonry device that is both cost-effective and environmentally friendly. The soil stabilized block has application in architecture including: arched windows, roof, wall and corbels. Mud is the most extensively used material for construction, it is critical to investigate methods of stabilizing it that do not rely on an energy-intensive technique such as brick burning. Because of the inclusion of a small amount of binding agent, stabilized mud is now described as mud that does not melt when exposed to water. Raw earth is compacted with a stabilizer such as cement or lime to create stabilized mud blocks. Clayey sands are found in soil and are ideal for making bricks.

The quality of a soil-based building block is influenced by its density. Low-density blocks are fragile and incapable of delivering sufficient strength. As a result, in addition to applying the stabilizer, it is important to densify the soil when constructing stabilized bricks. As a result, the soil must be exposed to sufficient pressure while maintaining a reasonable moisture level. Compaction is the term for this operation. The stabilized mud block is current predecessor of the earth block of moulded category. For the past 30 years or so, stabilized mud blocks have been extensively used all over the world. Stabilized mud block technology provides a more affordable and high-quality alternative to traditional building construction. The Stabilized Mud Block is the most vital "modern building materials" because of its manufacturing stability, it can be seen in both formal and informal structural practices because of this. Efforts have been done to strengthen the material as a walling type unit since, early 1950s, as an alternative to new, more costly fired bricks and concrete blocks.

One of the most vital human requirements is adequate housing. Currently, the majority of developed countries are having difficulty finding ample numbers of decent and affordable housing. Shelter conditions have deteriorated in recent decades: services have existed inadequate, the demand for housing has increased, and the need to make available urgent realistic alternatives has increased. Compressive strength is a key factor for the stability assessment of blocks (mud). In comparison other parameters are easy to quantify. In addition to mud blocks, widely used materials are adobe block and packed earth blocks. The use of stabilized compressed earth blocks for residential buildings has grown in popularity over the last 40–50 years. They make the most of locally available materials and use relatively basic building techniques. Blocks that have been stabilized and have good thermal and acoustic insulation properties. Reduced energy use in industry and a decreased market for non-renewable products are two environmental advantages. In India earth is the most extensively used material for construction and it is embedded in the country's history. Mud building has traditionally varied greatly according to topography, climatic conditions, and regional needs. Poor compressive strength, strength loss due to erosion, saturation and shrinkage are only a few of the earth's biggest drawbacks for use as a construction material. However, by incorporating stabilizers, such restrictions can be solved, allowing for the fabrication of adequate earth blocks with enhanced mechanical reaction. In India, raw earth is now used for walls in about 55% of houses. It is due to the drawbacks such as high maintenance and low durability; it is now regarded as a poor man's content.

Many researchers worked in the area and few of their articles are highlighted here. The combination of cement with fibre and coir, play important role and used as a stabilized soil block (Vinu Praksah et al. 2016). The mud blocks with 10% cement and fine content used as a load bearing wall material (Suja and Halwatura 2016). The stabilized mud blocks are used as an alternative building material. It shows better performance for the combination of cement and fibres (Sajina and Suhasini 2015). The properties and effectiveness of the stabilized mud blocks are analysed using fly ash and quarry dust (Anil kumar et al. 2017). The suitable compressed stabilized earth block was found using fly ash and cement as a construction material (Islam et al. 2020).The alternative materials was identified for making the compressed earth block and found 6% cement as optimum content (Asmamaw 2008). Study of locally available materials have been used for stabilized block. Soil with 3% cement found better for the dry compressive strength (Krishnaiah et al. 2008). Comparison of the reinforced and non-reinforced earth block has been done. Result found that, reinforced earth block not having any effect on brick (Raymond Gentil Elenga et al. 2011).Experiment investigation was done to find the strength parameter in cement and lime mortar. Suggested suitable proportions to use of these materials (Dhanalakshmi and Gokulakrishnan 2018).Utilization of fibres in brick production was explained. It was found that, with addition of waste additives, properties of adobe bricks can be improved (Salih et al. 2020). Stabilization effect was evaluated using laboratory test. From the result found that, addition of plastic fibre improves the performance of Clay soil (Hassan et al. 2021).CBR test on soil specimen was performed. Here clay soil and fibres are reinforced in different combination results in improving performance of clay soil by experimental method (Kaushik and Tarun 2019).

In the present research work, cement and stone dust are used as a stabilizer material. Experiment was carried out to find the suitable materials combinations as alternative material for construction.

21.2 Materials Used

The main stabilizer used is cement, in combination with soil. Cement is most likely one of the most effective stabilizers for stabilized mud concrete blocks. Adding cement before compaction enhances the material's properties, especially its resistance to water. Since the soil in this sample comprises an 18% clay fraction, we use 5–7% cement by weight as a stabilizer, which is normally adequate. After 28 days of curing, we should assume a wet strength for stabilization mud block of 3–4 MPa with a cement content of 7% and a sand content of approximately 65%. Compressed stabilized mud block of size 240 mm × 140 mm × 120 mm by using manual press was used in this investigation. Properties of the soil adopted in the work is

Table 21.1 Properties of the soil

Sl.no	Test	Values
1	Relative density	2.6
2	Liquid-limit	58
3	Plastic-limit	27
4	Grain size analysis	
	Sand (%)	5
	Silt (%)	36
	Clay (%)	59
5	Compaction	
	Optimum moisture content (%)	22
	Maximum dry density (gm/cc)	1.6

Table 21.2 Properties of cement

Sl.no	Test	Value
1	Compression strength (N/mm^2)	33.8
2	Relative density	3.10
3	Consistency (%)	32
4	Setting time of initial (min)	55
5	Setting time of final(min)	270

Table 21.3 Properties of stone dust

Sl.no	Test	value
1	Compression strength (N/mm^2)	23.12
2	Specific gravity	2.5
3	Surface texture	Rough
4	Particle shape	Fine powder

mentioned in the Table 21.1. Properties of cement is represented in the Table 21.2. Properties of the stone dust is represented in the Table 21.3.

21.3 Methodology

To make standard-sized mud blocks, compaction may be achieved within a mould. Thus, making of stabilized mud blocks include two steps:

- A specific stabilizer must be used to mix the right soil type.
- It should be compacted with the correct moisture content into a block having high density.

The following measures are included in the production of stabilized mud concrete blocks:

- Sieving.
- Proportioning.
- Mixing.
- Compaction.
- Block Ejection and Stacking.
- Curing.

The oversized material can be sieved out using sieve with crusher pendulum or any other process. The optimum percentage of soil, water and stabilizer should be determined for the production of high-quality blocks.

The current research attempted to prepare reinforced mud concrete blocks with the following cement, soil, and stone dust proportions:

- 1:0.5 (Soil: Stone dust) with 5% cement.
- 1:0.5 (Soil: Stone dust) with 6% cement.
- 1:0.5 (Soil: Stone dust) with 7% cement.

It is important that the mixing be as rigorous as possible in order to achieve high-quality blocks. Both of the ingredients should be properly combined. Water is applied a little at a time after drying, adding all of the ingredients until the wet soil-cement achieves the desired consistency. It is much easier to spray a little water on top of the mix at a time. This procedure should be replicated until all of the water has been incorporated.

The block pressing process is carried out by performing several distinct operations in the following order and compaction machine used is shown in the Fig. 21.1.

Fig. 21.1 Compaction machine

- The machine should be anchored in place with sand bags or bolted to the base concrete, and the toggle should be locked so that it functions like a basic lever. The lever has been pushed forward to make it easier to lift the lid. The bottom plate is now inserted into the mould.
- Now dump the stabilized soil mixture into the mould.
- The machine's door has been closed, and the toggle lever has been shifted to the lid after it has been unlocked.

Two people are now pulling down on the lever before the compaction stroke is complete.

When the lever is returned to its vertical position, it is locked onto a single lever. The mud block is now ejecting from the mould as the fast lever is pushed back. The mud block and the thin base plate have now been separated from the mould and piled up. The device is now ready to move on to the following block. Stabilized blocks of concrete mud need a damp curing time, which keeps them humid to achieve optimum strength. After 28 days, the blocks are compressed and checked in a compression measuring machine.

21.4 Mix Design

Water content, soil, stone dust and cement proportions used in the various samples are represented in the Table 21.4.

- Total mass of the Block: 9.5 kg
- Mould Size: 23X19X10 = 4370 cm^3
- Density: 2.17gm/cc

Table 21.4 Mix design details of various Samples

	Sample		
	1	2	3
Ratio	1:0.5 (soil: stone dust), cement = 5%	1:0.5 (soil: stone dust), cement = 6%	1:0.5 (soil: stone dust), cement = 7%
Water content	22%	22%	22%
Soil	2.8kgs	2.8Kgs	2.8Kgs
Stone dust	1.7kgs	1.7Kgs	1.7Kgs
Cement	1.06kgs	1.42Kgs	1.78Kgs

21.5 Results and Discussion

21.5.1 Compressive Strength of Blocks

After the blocks have been cured for 7, 14, 21, 28 days, they are tested in a compression testing machine to find their strength. It can be found out using the following formulae:

$$\text{Compressive Strength}\left(\text{MPa}\right) = \text{Extreme Load}\left(\text{KN}\right) / \text{Area of Cross Section}\left(\text{mm}^2\right)$$

21.5.2 Stabilization of Mud Blocks with Ratio 1:0.5 and 5% Cement

Table 21.5, represents the blocks which are made of 5% cement in specific dimensions and have been cured 7, 14, 21 and 28 days. Their compressive strength was later determined using a compression testing machine. Results shows that after 7 days of curing the block showed a strength of 1.45 MPa, for 14 days of curing showed results of 2.15 MPa compressive strength value, during 21 days of curing results showed were 3.28 MPa, and on 28 days of curing compressive strength value was 3.66 MPa. It was found that, number of curing days increases, result to the increase of strength of the mud blocks of 5% cement.

21.5.3 Stabilization of Mud Blocks with Ratio 1:0.5 and 6% Cement

Table 21.6 represents the blocks which are made of 6% cement in specific dimensions and have been cured for 7, 14, 21 and 28 days. Their compressive strength was later determined using a compression testing machine. Results shows that after

Table 21.5 Compressive strength of blocks at 7, 14, 21, 28 days of curing with ratio 1:0.5 and 5% cement

Sl.No	Sample No.1	Dimensions (mm)			Compressive strength (MPa)			
					7 Days	14 Days	21 Days	28 Days
1	**S1B1**	230	190	100	1.40	2.15	3.25	3.63
2	**S1B2**	230	190	100	1.43	2.12	3.27	3.66
3	**S1B3**	230	190	100	1.45	2.1	3.28	3.65
Average					**1.43**	**2.12**	**3.28**	**3.65**

Table 21.6 Compressive strength of blocks at 7, 14, 21, 28 days of curing with ratio 1:0.5 and 6% cement

Sl.No	Sample No.1	Dimensions (mm)			Compressive strength (MPa)			
					7 Days	14 Days	21 Days	28 Days
1	**S1B1**	230	190	100	1.5	2.36	3.35	3.79
2	**S1B2**	230	190	100	1.5	2.40	3.39	3.79
3	**S1B3**	230	190	100	1.52	2.38	3.36	3.80
Average					**1.51**	**2.38**	**3.36**	**3.79**

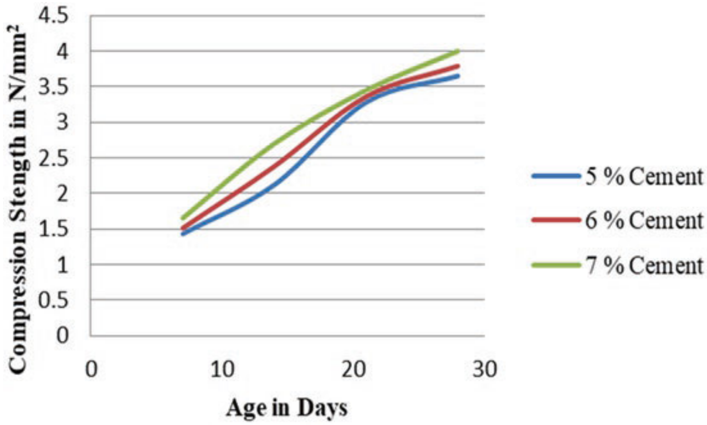
Table 21.7 Compressive strength of blocks at 7, 14, 21, 28 days of curing with ratio 1:0.5 and 7% cement

Sl.No	Sample No.1	Dimensions (mm)			Compressive strength (MPa)			
					7 Days	14 Days	21 Days	28 Days
1	**S1B1**	230	190	100	1.67	2.72	3.44	3.99
2	**S1B2**	230	190	100	1.67	2.68	3.48	4.00
3	**S1B3**	230	190	100	1.62	2.70	3.43	4.04
Average					1.65	2.70	3.45	4.00

7 days of curing the block showed a strength of 1.52 MPa, for 14 days of curing showed results of 2.40 MPa compressive strength value, during 21 days of curing results showed were 3.39 MPa, and on 28 days of curing compressive strength value was 3.80 MPa. It was found that, number of curing days increases, result to the increase of strength of the mud blocks of 6% cement.

21.5.4 Stabilization of Mud Blocks with Ratio 1:0.5 and 7% Cement

Table 21.7 represents the blocks which are made of 7% cement in specific dimensions and have been cured for 7, 14, 21 and 28 days. Their compressive strength was later determined using a compression testing machine. Results shows that after 7 days of curing the block showed a strength of 1.67 MPa, for 14 days of curing showed results of 2.72 MPa compressive strength value, during 21 days of curing results showed were 3.48 MPa, and on 28 days of curing compressive strength value was 4.04 MPa. It was found that, number of curing days increases result to the increase of strength of the mud blocks of 7% cement. Graph 21.1, shows the compressive strength for different combination of cement.



Graph 21.1 Age in days' verse compressive strength N/mm^2

Table 21.8 Water absorption of blocks Cement 5%, 6% and 7%

Sl.no	Cement (%)	Wet mass (Kg)	Water absorption (%)	Average water absorption (%)
1	5	9.24	12.94	13.08
		9.2	13.02	
		9.48	13.28	
2	6	10.33	13.05	13.26
		9.99	12.89	
		9.78	13.86	
3	7	10.5	13.94	13.67
		10.69	13.53	
		10.20	13.55	

21.5.5 Moisture Content

Water absorption for different combination of cement say 5,6 and 7% are represented in the Table 21.8. Which can be find using the expression below.

$$\text{Water Content}(W) = \underline{M2} - \underline{M3}100(\%)$$

M3–M1

(i) Weight of container with contents of it with lid (M_1).
(ii) Weight of container filled with appropriate amount of moist sample with lid (M_2).
(iii) Weight of the container with lid and dry soil sample after keeping it in the oven (M_3).

21.6 Conclusions

Increased cement content increases the strength (compressive) of the blocks and prisms of the masonry. The use of Portland cement to stabilize mud concrete blocks achieves a variety of goals that are needed to create a long-lasting foundation from locally available soil. None of these have improved mechanical properties as well as particle cohesion. Sample maximum strength (compressive)was found to be 4.04 MPa for 28 days curing period. Similarly, it was tested by adding 7% cement using testing machine. The minimum average compressive strength was measured at 1.43 MPa after 7 days of curing with 5% cement, and the mean average compressive strength was measured at 4 MPa after 28 days of curing with 7% cement. Water absorption has been observed with a peak value of 13.67% for 7% cement used in the mud block and the minimum value of 13.08% for 5% cement added to the mud block. As per IS 1725 the average water absorption should be less than 15%. All the mud blocks satisfy the criteria as per IS recommendation. Several different influences are essential to preserving a strong bond between the cement and the objects embedded inside it, according to this study analysis. Such requirements include not just the ingredients used in the blend, how they're handled, and how they're shipped into their final shape, but even the finished product's curing times and environmental factors. The water content of the soil-cement mixture must be carefully controlled. Enough moisture is needed for the cement to adequately hydrate. It should not be so much that it reduces the final density, raises porosity, or lowers the final pressure. The strength of a block to absorb moisture is proportional to its hardness. Study excluding stone dust and cement is not possible as it will not withstand in the soil. Hence the advantage of by-products is highlighted as a binder and filler materials, which gives the stabilized mud blocks.

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Chapter 22
Utilizing the Potential of Textile Effluent Treatment Sludge in Construction Industry: Current Status, Opportunities, Challenges, and Solutions

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Abstract Rapid urbanization and industrialization, and population growth have led to an increased demand for infrastructure and the manufactured products. The textile, pharmaceuticals, paper, etc., are the few industries with the increasing demand and have imposed enormous waste management challenges on the human being. The textile industry is also described by high water and chemical consumption and hence generates highly toxic coloured effluent. The textile finished fabric is prepared after several dry and wet processes. Various chemicals, synthetic dyes, and additives such as salts are used along with water to produce the finished goods at each step. The effluent generated from such industries is vast and is estimated that about 70–120 l of water is consumed to fabricate 1 kg of finished good. This effluent is collected in the Central Effluent Treatment Plant (CETP) for its treatment for safe disposal or recycling and reusing back in the industry. The sludge generated from the treatment plant comprises salts, reactive dyes, organic and inorganic pollutants. The sludge is collected at the TSDF (Treatment, Storage, and Disposal Facility) sites. This sludge is a hazardous material and is challenging to manage. The low calorific value makes it untuneful for the incineration purpose. The transportation of sludge adds cost to the treatment, and the low specific gravity makes it further difficult to transport. The most sustainable solution is to find an alternative that can utilize the textile sludge. One such way is to use it in the construction industry. The study explores current status, opportunities, and challenges, and the best practices to be adapted for efficient ways of waste management. Solutions review the potential of utilizing the textile effluent sludge in the construction industry.

Keywords Textile effluent · Microstructural · Natural fine aggregate · Bricks · Toxicity

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22.1 Introduction

The textile industry is one of the oldest and hence, employs a large section of society in India. Large quantities of water and chemicals are consumed in the textile industry during various phases of textile processing, thereby generating huge quantity of effluent mostly consisting of utilized chemicals, salts, reactive dyes, and organic, inorganic pollutants (Dasgupta et al. 2015). The effluent generated from the textile processing units is not suitable for its disposal into the environment without its prior treatment (Agarwal and Singh 2022). Therefore, the liquid effluent is collectively treated from the different industrial units in the Common Effluent Treatment Plants (CETPs) (Shah et al. 2021).

Sludge is generated from these treatment plants during various biological or physio-chemical treatment processes. About 200 tons/day of sludge can be generated from the treatment of 830 units of wastewater by chemical coagulation and flocculation and liquid/solid separation (Balasubramanian et al. 2006). Although for sludge disposal engineered landfill sites called Treatment, Storage and Disposal Facilities (TSDF) are developed, but much of it is openly disposed of posing the threat for residents and leads to soil, air, surface water contamination (Singh et al. 2017; Behera et al. 2021). There is a growing need for finding a sustainable solution for textile sludge management. The ever-growing demand for concrete/mortar in the construction sector causes the increase in the production of cement hence increases the emission of CO_2 and carbon footprints. The production of cement clinkers is responsible for the depletion of limited raw material (limestone) and the generation of an enormous amount of CO_2 while de-carbonation of limestone during clinker production. The lime is non-renewable, and its availability is limited. Therefore, the incorporation of alternate materials can help in reducing the cement demand and hence reducing the burden on nature (Charitha et al. 2021). Along with cement, there is a growing need for Natural Fine Aggregate (NFA) i.e., river sand. The mining of river sand from riverbeds has a deteriorating impact on the environment. Therefore strict regulations have been imposed and at certain places, the mining has been restricted (Santhosh et al. 2021). The growing need for both cement and NFA has led to the emergence of the use of alternate materials such as marble slurry, sewage treatment plant sludge, copper tailings, textile effluent treatment plant sludge (Yusuf et al. 2012; Vieira et al. 2016; Dandautiya and Singh 2019). The Textile Effluent Sludge (TES) is used as the substitution for NFA and cement but up to optimum replacement level (Balasubramanian et al. 2006). The TES is also used as the replacement for clay in bricks (Anwar et al. 2018).

Over the years, researchers have investigated the reuse potential of the TES as a partial replacement material for building materials such as cement, clay and NFA in different binder systems. The study is organized into three sections. The first section consists of the physical, chemical, and microstructural properties of the TES followed by its utilization in the construction sector. The third section includes the opportunities and challenges and the best practices to be adapted for efficient ways of waste management. The last section includes the conclusion.

22.2 Physical, Chemical, and Microstructural Characteristics of TES

22.2.1 Physical and Chemical Properties

The detailed study on the physical and chemical properties of the TES will help us to identify the possible variation in the properties of concrete, mortar, and bricks. These properties of the different TES are given in Tables 22.1 and 22.2. The physical and chemical properties of TES is governed by the type of chemicals used, the type of textile processing and the type of treatment process of effluent (Holkar et al. 2016). The diversified processes adopted in the textile industry are mainly responsible for the difference in physical and chemical properties of TES. The physical properties such as pH, specific gravity, water content, fineness vary with the type of textile process and the wastewater treatment process. The specific gravity of different elements in concrete/mortar/bricks influences its workability. It is evident from Table 22.1 that the specific gravity of TES is less than that of Ordinary Portland Cement (OPC) and almost like that of clay. The lower specific gravity increases the volume of sludge for the same weight as the material. For instance, on replacing the cement on a weight basis, the weight of the sludge used to replace the cement will be the same, but the volume of sludge will be more. The increased volume of binder requires more water but at constant water content, the flowability of cement-TES paste decreases (Goyal et al. 2019). The higher water content of sludge has higher water absorption capacity as indicated by different investigators (Anwar et al. 2018; Rahman et al. 2017; Balasubramanian et al. 2006). The higher water absorption is an undesirable property for the strength and long-term durability. The low specific gravity and the higher fineness of sludge than the cement increases the water/cement ratio for adequate consistency. The excess of water creates air voids on evaporation resulting in reduced strength.

Table 22.1 Physical properties of TES

References	Water content (%)	Specific gravity	pH	Blaine fineness	Total volatile solids (%)
Balasubramanian et al. (2006)	28.72	2.40	9.13	–	31.85
Baskar et al. (2006)	–	2.32	10.5	–	–
Patel and Pandey (2012)	10.50	0.94	8.70	–	36.60
Begum et al. (2013)	3.34	2.21	7.14	–	9.52
Zhan and Poon (2015)	75.24	1.14	–	–	–
Rahman et al. (2017)	35–75.64	2.30	4.5–5	–	35.95
Chen and Wu (2018)	35.98	–	6.04	–	–
Anwar et al. (2018)	80.00	–	–	–	70
Goyal et al. (2019)	–	2.32	–	426	–

Table 22.2 Chemical constituents of TES

References	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_4	MgO	LOI
Balasubramanian et al. (2006)	108.22	–	–	180.5	0.0012	154.30	–
Baskar et al. (2006)	28.4	7.1	0.698	9.10	–	–	–
Zhan and Poon (2015)	0.87	3.40	6.20	60.45	24.95	–	11.81
Rahman et al. (2017)	2.50	12.15	53.14	15.65	3.00	–	–
Goyal et al. (2019)	33.5	3.80	0.30	18.90	–	–	40.60

The chemical composition of the replacement compound helps in determining and analyzing its reactivity in different binder systems. The percentage composition of TES consists of CaO, SiO_2, Al_2O_3, Fe_2O_3, SO_4 and MgO and are presented in Table 22.2. The presence of low SiO_2 and Al_2O_3 and high CaO content as compared to cement and other supplementary cementitious materials may contribute to any pozzolanic activity. Along with this, the Zn and Pb surround the cement particles and forms a calcium hydroxyl zincate membrane thereby creating hindrance in hydration and reducing the strength (Balasubramanian et al. 2006; Patel and Pandey 2012; Goyal et al. 2019). The presence of high Loss on Ignition (LOI) indicates a significant amount of organic matter present.

22.2.2 Microstructural Characteristics of TES

The microstructural characteristics are significant as they will influence the performance of TES mixed cementitious and clay systems. The study of the microstructure of this sludge will help in predicting the behaviour when blended with cement. The TES particles are in agglomerates with the predominance of spherical particles (Patel and Pandey 2009) whereas the fibrous material with different particle sizes and shapes is observed in another TES sample (Begum et al. 2013) (Fig. 22.1).

22.3 Utilization of Textile Sludge in Different Types of Binder Systems

22.3.1 Replacement of Cement with TES in Cement/Mortar

The sludge has been used by the researchers as supplementary cementitious materials. The presence of CaO in the sludge indicates that sludge may impart certain pozzolanic activity. Standard consistency, flow time, initial setting time and final setting time of cement-TES paste are the few tests performed to study the performance i.e., workability of the mixes. The increase in the setting time (initial and final) of the mix is reported with the increase in sludge content. The consistency (%) of the mix also increases with an increase in TES in the mix. This is due to the high

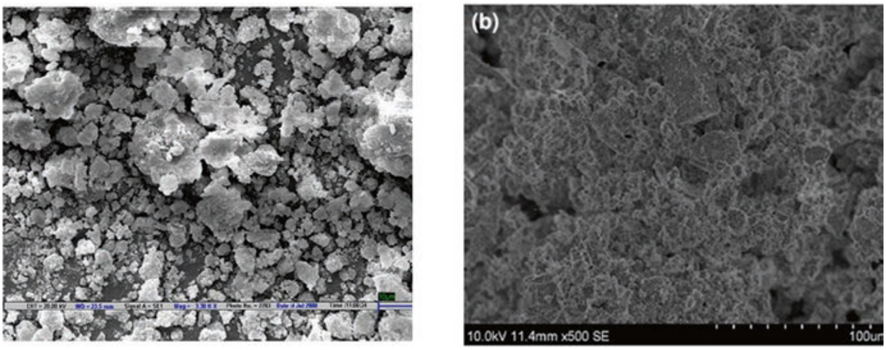

Fig. 22.1 (**a**) SEM of sludge at 3300 magnification (Patel and Pandey 2012), (**b**) SEM of sludge. (Begum et al. 2013)

fineness of TES and the low specific gravity (Balasubramanian et al. 2006). The workability of TES blended concrete in terms of flow behaviour shows increase in the flow time at higher sludge content as compared to the control mix (Goyal et al. 2019). The delayed setting time is also reported with increasing sludge content is mainly due to the presence of the organic compound in sludge and higher LOI (Rahman et al. 2017).

The TES is used as a partial replacement of cement in concrete and mortar. The mechanical properties such as compressive strength and tensile strength and the test such as leaching of heavy metals are analyzed by the researchers. The compressive strength of blended mortar at the 28 days of curing at different replacement % of TES is shown in Fig. 22.2. The addition of TES in concrete/mortar as a substitute to cement does not impart any negative impact on the properties of concrete up to the certain level of replacement i.e., optimum replacement level, beyond optimum level, the compressive strength decreases drastically. The considerable loss of compressive strength of mortar cubes on 20% partial replacement of cement by sludge is observed however the compressive strength at 5% replacement is almost similar to that of control mix (Balasubramanian et al. 2006). The cement sludge blocks with 30–70% partial replacement of PPC cement by sludge shows the variation in unconfined compressive strength from 3.62–33.37 MPa (Patel and Pandey 2012). The sludge is used in the ratio of 0–50% by weight for the partial cement replacement in mortar. The reduction in compressive strength from 27–5 MPa is observed (Rahman et al. 2017). The cement is substituted by the textile sludge up to 0–20% by weight and the compressive strength results shows that there is a minimal decrease in compressive strength in cement-mortar mix up to 5% replacement but with increasing sludge content, the considerable loss of strength is observed (Goyal et al. 2019). It was observed that 0–20% of cement substituted by TES to produce hollow load-bearing blocks and up to 30% replacement of cement in solid concrete blocks for non-load bearing structures (Balasubramanian et al. 2006).

The chemical composition of textile sludge differs based on its source industry as the different industries use different chemicals and follow different textile

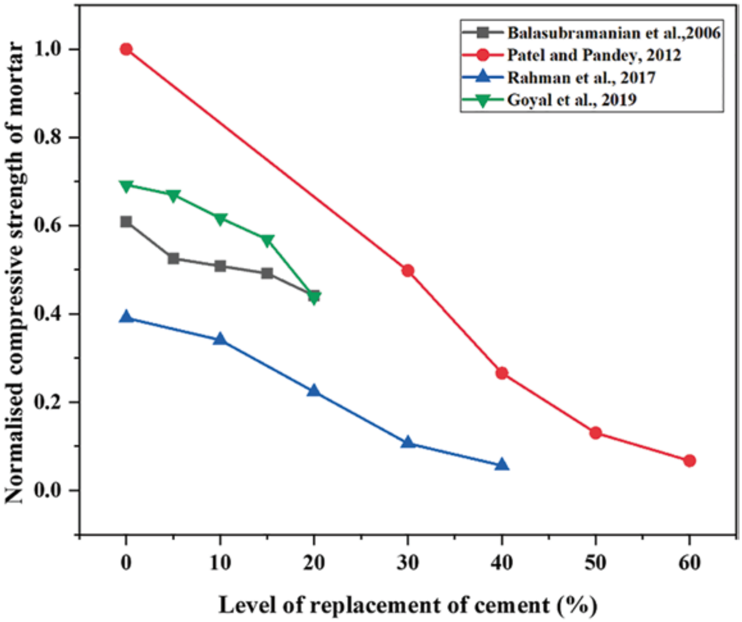

Fig. 22.2 Normalised compressive strength of TES blended mortar

processing steps. The sludge also changes with the chemicals used for treating the textile industry effluent. The CaO varies from 108.22–0.87%, SiO_2 from 3.4–12.15%, Fe_2O_3 ranges from 9.1–180.5%, and Al_2O_3 0.3–53.14%. The high difference in Fe_2O_3 and Al_2O_3 composition of sludge is due to the different types of coagulants used for the textile effluent treatment process. The higher Al_2O_3 and low CaO content reported in Rahman et al. (2017) are one of the main reasons for a 50% reduction in strength at 10% replacement of cement by TES. However, in mortar with 10% by weight replacement of cement with TES resulted in only 10% reduction in compressive strength and is reported by Goyal et al. (2019). The heterogeneity in sludge characteristics is responsible for different strength reductions at the same replacement level.

The impact of substitution of cement with TES on the split tensile strength in cement/mortar shows the similar pattern as that of compressive strength (Rahman et al. 2017; Goyal et al. 2019). Permeation properties such as water absorption and sorptivity were also studied by the researchers. The improvement in the properties for 5% replacement of cement by TES indicates the dominance of filler effect of sludge in voids but as the sludge content increases, the hydration of cement reduces, and hence large voids develop. The increased content results in development of large voids increases the water absorption and sorptivity in mortar and concrete (Balasubramanian et al. 2006; Goyal et al. 2019).

22.3.2 Replacement of Natural Fine Aggregate (NFA) with TES in Concrete/Mortar

Along with partial replacement for cement, the TES is also used as the partial substitute for NFA in concrete and mortar. Generally, concrete/ mortar consists of 30% of fine aggregate. A large quantity of natural fine aggregate is required, and its demand has increased drastically over the past few decades. The river sand is obtained from the mining of riverbed and is accountable for the riverbed deterioration, change in the direction of river flow hence increasing the number of floods. Owing to these problems associated with river sand mining several states have banned it in India such as Uttar Pradesh, Tamil Nadu, Maharashtra, Rajasthan, Bihar. As the procurement of river sand has become difficult, the need for an alternate solution to meet the growing demand has increased (Santhosh et al. 2021). Therefore, the application of TES as a fine aggregate will reduce the pressure on river sand mining and could be used as an alternate material for river sand. However, the presence of hazardous materials in sludge makes it difficult to replace NFA in a higher percentage for the concerned design strength. The pretreatment of TES by lime was adopted to reduce the excess of ammonia present in sludge. The pre-treated sludge is used for replacing the fine aggregate by 0–30% by weight in concrete. The pre-treatment process has a positive effect on the mechanical property such as compressive strength of concrete blocks. The compressive strength of concrete cubes prepared with 10% replacement of NFA by pre-treated TES is 43.3 MPa (Zhan and Poon 2015). The TES sludge is used to replace the NFA by 0–80% by weight in the mortar and 0–100% by weight in concrete. The reduction in compressive strength in mortar specimens from 27–9 MPa is observed and 24–3 MPa is observed (Rahman et al. 2017). There is a need for detailed studies such as durability and permeation study along with microstructural analysis for replacing the natural fine aggregate in cement and mortar.

22.3.3 Replacement of Clay with TES in Bricks

Most of the researchers have been interested in using TES as partial substitute for clay in manufacturing of bricks. The benefit of using the sludge is that it can replace the natural clay, will also act as immobilizing agent for stabilization of inorganic elements i.e., heavy metals present in the sludge. The high carbon matter and decent calorific value makes the TES incorporated bricks more sustainable firstly by reducing the clay content and secondly by decreasing the energy required for brick firing (Anwar et al. 2018). The sludge is used as the partial replacement for clay from (3–30%). It was observed that firing time, the temperature of firing, sludge content are the important parameters that determine the brick's quality. The bricks produced by the addition of TES up to 9% at the firing temperature of 800 °C and for the time of 8 h has satisfied the requirements for Indian Standards of minimum strength of burnt clay bricks is 3.5 MPa (IS1077 1992; Baskar et al. 2006). It is reported in the literature that the substitution of clay from 10–30% by TES shows that bricks with 10% replacement can be used for load-bearing structure while the bricks developed with 30% replacement can be used for non-load bearing structure (Balasubramanian et al. 2006). The bricks incorporating the textile sludge from 0–50% shows that the substitution of 15% and 30% by TES can produce first-class bricks and second class bricks respectively according to Indian Standards (Begum et al. 2013). The study on lightweight bricks manufactured using TES, coal ash and ground soil indicates up to 20% replacement level of clay with TES. The bricks showed the compressive strength of 13.7 MPa. Another study on the use of textile sludge in bricks with different mixtures 0.5–5.25% was evaluated for compressive strength. About 77% increase in compressive strength of TES incorporated clay fired bricks than conventional bricks is observed (Anwar et al. 2018). The use of TES in bricks can solve the environmental problem of the sludge disposal as well as reduce the consumption of clayey soil.

22.3.4 Leaching and Toxicity Study of TES in Different Construction Elements

The raw TES samples are analyzed for measuring the composition of inorganic elements i.e., heavy metals. The heavy metal composition of TES varies depending on the type of textile processing, chemicals used in industry, the dosage of chemicals and the process/steps followed for the treatment of textile effluent (Anwar et al. 2018). The presence of heavy metal indicates the sludge cannot be discarded into the environment directly without treatment/stabilization due to its possibility of leaching into the soil and hence contaminating the surface water and groundwater. The heavy metals present in TES sludge and are reported by the researchers is given in Table 22.3.

The existence of heavy metals in the raw ETP sludge also leads to the study of leaching of heavy metals after their utilization in the construction industry for environmental considerations. The brick/mortar/concrete sample prepared from the ETP sludge of the textile industry are studied for the leaching of heavy metals. The test for leaching of heavy metals is performed as per US EPA method 1311 (Patel and Pandey 2012; Zhan and Poon 2015; Rahman et al. 2017). Cement-sludge blended solid blocks up to 70% replacement level of cement with TES were tested for leaching of heavy metals such as Pb, Cd, Cr, Cu, Ni, Co, and Zn from the solidified cement-sludge blocks and were reported to be in the stipulated limit (Patel and Pandey 2012). The heavy metal leaching from the concrete blocks (up to 10% partial replacement of fine aggregates by ETP sludge) was found to be within the prescribed limits and therefore can be used for developing structural and non-structural members (Zhan and Poon 2015). The mortar/concrete specimens are tested for leaching of heavy metals as well for other parameters such as BOD/COD/SO_4^{2-}/

Table 22.3 Heavy metals concentration in (mg/kg) in raw TES sludge

References	Cd	Cu	Cr	Zn	Ni	Pb	Co
Balasubramanian et al. (2006)	3.96	57.4	2.98	91.60	0.64	12.1	–
Patel and Pandey (2012)	5.1	225	231	186.4	89.6	44.7	11
Zhan and Poon (2015)	18.3	455	110	291.4	63.3	304	–
Rahman et al. (2017)	0.66	–	2.98	–	–	–	–
Anwar et al. (2018)	5.6	58	10	131	32	12	–

Cl^- and are found to be within the limit prescribed by the Department of Environment in Bangladesh (Rahman et al. 2017). Therefore, it can be said that utilization of hazardous textile sludge in building components could be the one way of stabilizing the contaminants into stable products and will also help in reducing the uncontrolled exploitation of natural resources (Goyal et al. 2019).

22.4 Challenges/Opportunities/Best Practices to Be Adapted for an Efficient Way of Sludge Management

The traditional disposal techniques such as open dumping at unlined areas is not suitable for TES due to their hazardous composition. The leaching of recalcitrant pollutants poses risk for human health. The open dumping may also lead to the leaching of heavy metals in the surface and groundwater (Dandautiya et al. 2018). The low specific gravity makes it more vulnerable to mixing with the dust during storms. Another method of solid waste management is incineration which will also induce air pollution and hence has negative impacts on the environment. Hence there is the requirement for stabilization of this sludge in the most sustainable way. This can be done by finding the alternative that can utilize this sludge without any leaching of heavy metals and hazardous compounds. One such way is to use it in the construction industry. The studies show the negligible leaching of heavy metals and other compounds on mixing with cement and clay. This will add not only environmental benefits by reducing the consumption of cement, NFA and the top fertile layer of soil i.e., clay but also facilitate to develop better fresh water resources' potential without its contamination through huge quantity of sludge (Singh 2008). However, the difference in the chemical composition of textile sludge makes it essential to conduct a proper and systematic study on its utilization in the construction sector. The availability of limited studies on the use of TES in the construction industry makes it more opportunistic for the researchers to explore different pretreatment methods for the sludge, conduct more comprehensive studies and find new ways for sludge stabilization.

22.5 Conclusion

The physical, chemical and microstructural properties of TES is review. The impact of the addition of TES on workability, mechanical properties and permeation properties in blended mortar/concrete/bricks are reported and comprehensively reviewed. Based on the literature review following conclusions are drawn:

- The very low silica content in sludge decreases the chances of any pozzolanic activity after its addition but the presence of high calcium oxide increases the chances of its reactivity on addition.
- The low specific gravity and high fineness modulus show that on replacement of sludge with cement by weight, the volume of sludge will be more and hence for the constant water/cement ratio, the workability will decrease. With increasing sludge content, an increased quantity of water is required for making the paste of standard consistency.
- The addition of TES in concrete/mortar has no effect on compressive strength for 5% substitution of cement but beyond this, the compressive strength decreases rapidly.
- The presence of ammonia in some of TES sludge is deteriorating for the concrete. The pre-treatment of TES by lime for ammonia removal shows the constructive impact on the mechanical properties of concrete. The TES can be used to replace NFA up to 10%.
- The improvement in permeation properties mainly water absorption and sorptivity of mortar/concrete for up to 5% replacement of cement with TES are reported.
- The first-class bricks and second-class bricks can be produced after substitution of clay with TES up to 10–15%and 30% respectively satisfying the minimum requirements as per Indian Standards IS-1077.
- It is also evident from the literature review that cement and clay can act as a stabilizer for hazardous TES. The minimum leaching within the prescribed standards is reported in the studies.

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Chapter 23
Identification of Suitable Solid Waste Disposal Sites for the Arba Minch Town, Ethiopia, Using Geospatial Technology and AHP Method

Muralitharan Jothimani, Radhakrishnan Duraisamy, Ephrem Getahun, and Abel Abebe

Abstract In developing nations, government authorities are mainly concerned with tackling the growing problems of solid waste disposal. However, most people living in Ethiopia's town and village continue to dispose of solid waste randomly, resulting in severe environmental and public health issues. The present study aimed to find suitable sites for solid waste disposal produced in the Arba Minch town, Ethiopia. Geospatial technology and Analytical Hierarchy Process (AHP) method are more cost-effective and reliable for identifying solid waste disposal sites. When choosing a suitable location to ensure environmentally sustainable solid waste disposal, many factors must be considered. Distance from drainage, groundwater level, lithology, land use/land cover (LULC), lineament density, geomorphology, precipitation, elevation, slope, soil type, distance from the road, and wind direction (aspect) were considered in the present study. The theme layers listed above were created using optical satellite images, a digital elevation model, a high-resolution Google Earth image, field data, and collateral data. The AHP method was used to calculate the ranks and weights of the aforementioned thematic layers and their sub-themes. Finally, chosen factor layers were overlayed using raster-based weighted linear combinations (WLC) in ArcGIS for site suitability evaluation. The present research area is 63.5 km^2. The current study results show, 6.84% (4.34 km^2) of the region, is very appropriate for solid waste disposal, 10.19% (6.47 km^2) is moderately acceptable, and 82.97% (52.69 km^2) is unsuitable for solid waste disposal. The suitability map of the solid waste disposal location shows the method's effectiveness. The current study's findings are crucial for Arba Minch's planners and administrators.

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Keywords AHP · Arba Minch Town · Ethiopia · Geospatial · Solid waste disposal site selection

23.1 Introduction

Solid waste is not liquid or gaseous and is generated by households, towns, supermarkets, buildings, and companies (Kapilan and Elangovan 2018). Solid waste is becoming significant health and environmental concern in developed and developing countries (UNEP 2005; United Nations 2017). Tirusew and Amare (2013) report that open dumping of solid trash is prevalent in Ethiopia. In developing countries, population growth and anthropogenic behaviours have alarmingly increased waste generation (Ebistu and Minale 2013; Abedi-Varakiand and Davtalab 2016). Ground and surface water contamination, air pollution, and methane release may result from haphazard solid waste disposal (Visvanathan and Glawe 2006). In addition, solid waste dumped indiscriminately around the human environment often causes aesthetic issues and disturbance. In Ethiopia, most waste disposal sites are noticed on the periphery of town, near to surface and groundwater bodies, agricultural land, dwellings, and road sides (EGSSAA 2009).

Due to rising population and urbanization, municipal solid waste (MSW) management has become a major concern in most developing nations (Khan and Samadder 2014). Collection, separation, processing, transfer, and final disposal of municipal solid waste are all part of solid waste management. Waste management options for municipal solid waste (MSW) include landfilling, combustion, recycling, and burning. On the other hand, landfill is one of the most effective and environmentally friendly means of waste disposal (Rahmat et al. 2016). When selecting MSW locations, environmental, aesthetic, technological, health, socio-economic, standard living improvement, population growth rate, and government participation must be considered (Sharholy et al. 2008).

As a result, a suitable solid waste disposal location isfar from natural resources, built-up areas, surface and groundwater resources, highways, lineaments, geological faults, and communities crucial for proper waste administration. The following researchers have considered (Tirusew and Amare 2013; Hamzeh et al. 2015; Genemo and Yohanis 2016; Semaw 2018; Mussa and Suryabhagavan 2019; Weldeyohanis et al. 2020) slope angle, topography, possible landslide locations, LULC, population density, water table, drainage density, distance from the well locations, utilities, types, and soil texture, rock type, road network, and distance from the settlement in many regions of the world, including Ethiopia, to identify proper solid waste disposal places.

The criteria for selecting optimal locations for waste disposal sites have been established by the following organizations worldwide: the Minnesota Pollution Control Agency (MPCA 2005), Alberta Environmental Protection Agency (AEPA 2010), Iranian Environmental Protection Agency (IEPA 2010), Ethiopian Ministry of Urban Development and Construction (EMUB&C 2012), British Colombia

Ministry of Environment (BCME 2016). The selection of a sanitary landfill necessitates spatial data collection and processing regarding various parameters that govern the suitability study. Remote sensing data may be used to get data with varying spectral, geographical, and temporal resolutions, and it is also very economical. Furthermore, multiple information inputs may be retrieved from remote sensing data to determine the best location for solid waste disposal. Geographic Information Systems (GIS) have been increasingly important in the decision-making process in recent years. It is advantageous to use a geographic information system (GIS) to select solid waste disposal sites since it saves both time and money.

Satellite remote sensing images may be used to extract information on geological features such as lineaments and folds, land use and land cover (LULC), drainage networks, elevation, slope, and aspect data, among many other factors (Emun 2010). Geographical information system (GIS) create, analyze, and present significant spatial and attribute data for selection processes of solid waste dumping sites. GIS provides an inventory of digital data to long-term solid waste management facilities (Kontos et al. 2005). GIS applications have been used in various places across the world to locate possible garbage disposal sites (Chen and Kao 2008; Sumathi et al. 2008; Zamorano et al. 2008; Khan and Samadder 2014). Among the various MCDM approaches, the analytical hierarchy process approach (AHP) is likely the most effective method for facilitating decision-making (MCDM) for waste disposal sites selections. The following researchers used GIS and the AHP method to select waste disposal sites (Al-Anbari et al. 2016; Kapilan and Elangovan 2018; Khan et al. 2018; Santhosh and Sivakumar 2018; Yıldırım et al. 2018; Demesouka et al. 2014; Muralitharan et al. 2021).

In Arba Minch town, Ethiopia, solid waste management issues arise due to economic development and population growth, high urban waste production, and a lack of landfill sites. The steep slope mountains on Arba Minch's western border and the Abya and Chamo lakes on its eastern border make finding appropriate solid waste disposal sites difficult. Alluvial deposits cover a significant part of the town, and their areal extent is 52% of the study area (Abbate et al. 2015; Kryštof Verner and Leta Megerssa 2018). These alluvial deposits are occurring around the Kulfo River and the northern part of the town. The high porosity and permeability of alluvial deposits make them unsuitable for disposal due to leachate issues. The present research region also has various geological features such as lineaments and faults (Abbate et al. 2015; Kryštof and Leta 2018). These structures function as a conduit, allowing leachate to pollute the groundwater system. Hence the site is not suitable where the mentioned above structures are present.

Several major and minor drainages are flowing through the Arba Minch town. The sites near drainages are also not suitable because they are highly vulnerable to surface water pollution. These are important factors to consider while choosing solid waste disposal locations in Arba Minch. The current study employed GIS and the AHP method to find a viable solid waste disposal site model in Arba Minch, Ethiopia. No such studies have been carried out using the present methodology from the current study area before this study. As a whole, the current study is the most detailed in the present location of research. Drainage distance, water level, geology, geomorphology, LULC, lineament density, elevation, slope, precipitation, soil type, and road distance were all evaluated in this study while choosing appropriate solid waste disposal spots.

23.2 Materials and Methods

23.2.1 Study Area Details

Arba Minch is a town in Ethiopia's Southern Nations, Nationalities, and Peoples Region (SNNPR), also in the Rift Valley. The latitudes of the research area range from 5°55′N to 6°9′N, while the longitudes range from 37°30′ to 37°39′. The present research area includes Abaya and Chamo lakes. Figure 23.1 depicts a geolocation map of the current research area, and it covers 63 km^2. The current study area is situated 500 km south of Addis Ababa, Ethiopia's capital. Major rock types include alluvial sediments, basalt, colluvial deposits, and ignimbrite. The present research area has a rough topography due to highly elevated mountains on the northwestern side. The primary LULC types in the current research region include shrubland, woodland, settlements, bushland, and barren terrain.

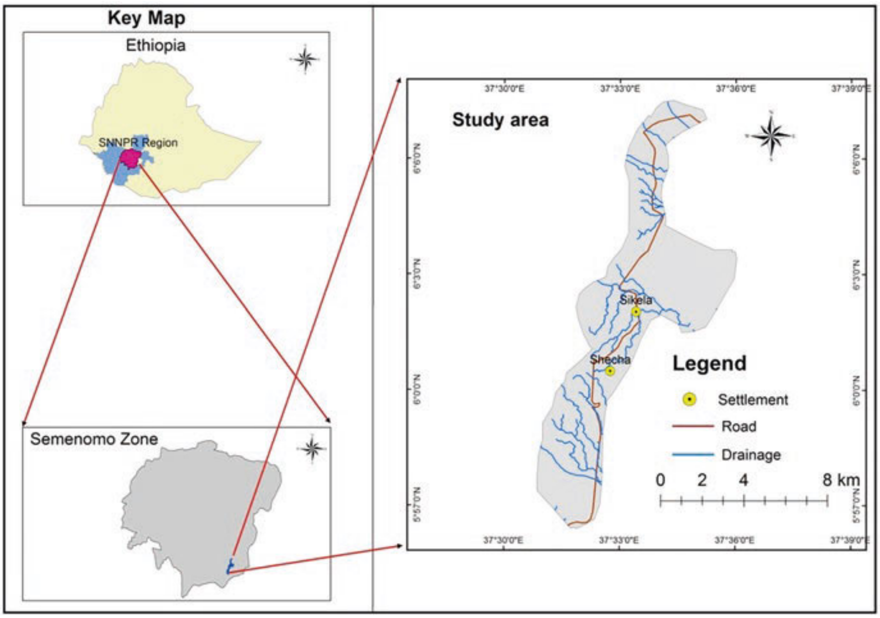

Fig. 23.1 Location map

23.2.2 Data and Their Sources

Cloud-free Sentinel 2 satellite optical data, dated 08-March-2019, with 10 m spatial resolution, has been downloaded from the (http://earthexplorer.usgs.gov/) used to prepare the following thematic layers like land-use/land-cover, geomorphology, and lineaments. Details from the Ethiopian Geological Survey's geological map was used to generate the lithology layer, plus data from the Sentinel 2 satellite was used to evaluate the weathering status of the rock. It was possible to extract the road network from the high-resolution Google Earth image. The drainage network, elevation, aspect, and slope layers were generated using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER-DEM) at a spatial resolution of 30 m. NASA's climatological data was used to download rainfall data. The soil database for the current research region was built using data from the Food and Agricultural Organization (FAO 2006). Table 23.1 shows the data used in this study and their sources. The above-mentioned thematic criteria were produced using the following steps: obtaining the satellite image, scanning, georeferencing the toposheets, and digitizing the resulting information. Groundwater level, distance from the road, rainfall, lineaments, lineament density, and drainage distances were also created using Arc GIS 10.8 procedures like buffer, interpolation, and clip.

Table 23.1 Data and its sources

S.No	Data	Data sources
1	Drainage	Sentinel 2 satellite imagery, ASTER-DEM, and toposheets
2	Groundwater level	Hydrogeology map prepared by Czech Republic, sheet number 0637-D3, at a scale of 1:50,000.
3	Lithology	Geological map of Ethiopian geological survey and Sentinel 2 satellite imagery
4	Lineament	Geological map of Ethiopian geological survey and Sentinel 2 satellite imagery
5	Geomorphology	Sentinel 2 satellite imagery, ASTER-DEM
6	Land use/land cover	Sentinel 2 satellite imagery and fieldwork
7	Slope	ASTER-DEM
8	Elevation	ASTER-DEM
9	Aspect	ASTER-DEM
10	Precipitation	NASA climatological data
11	Soil	Food and Agricultural Organization
12	Road	Google earth image and toposheets
13	Wind direction	https://weatherspark.com/

Table 23.2 Scale for pair-wise comparison

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Saaty (1980)

23.2.3 Method

The AHP technique was used to normalize the values of the twelve thematic maps and sub-themes chosen to identify suitable solid waste disposal locations in the research region. The twelve-factor layers and their sub-factors' weights were calculated using AHP techniques, including pair-wise comparison matrix, weight standardization, and consistency ratio. In the pair-wise comparison matrix, the identified twelve-factor layers and their sub-factors have been compared against each other to show the relative preference. According to (Saaty 1980), a scale for comparison matrix containing values between1 to 9 and describe the strength of rank, in the comparison matrix 1 expresses "equal importance" between factors, and 9 represents "extreme importance" over another factor (Table 23.2).

The following section describes the formulas and steps to get the present research's factor layers and sub-layers final weights. Using the following formula, the values of each column in the pair-wise matrix have been added.

$$Lij = \sum_{n=1}^{n} Cij \tag{23.1}$$

Where *Cij* is a factor layer.

A normalized pair-wise matrix was created by dividing every element in the matrix by the sum of its row sums, as shown in formula (23.2).

$$Xij = \frac{Cij}{\sum_{n=1}^{n} Cij} \tag{23.2}$$

The standard final weights are obtained by dividing the sum of the normalized row of the matrix by the number of factor layers (N) using the following formula (23.3).

$$Wij = \frac{\sum_{j=1}^{n} Xij}{N} \tag{23.3}$$

The consistency index (CI) was calculated by using the following formula (23.4)

$$\mathrm{CI} = (\lambda - \mathrm{n}) / (\mathrm{n} - 1) \tag{23.4}$$

λ is the consistency vector, and n is the total number of thematic maps, and here it is 12. Table 23.3 shows the random inconsistency values. Consistency ratio was calculated by using the following formula (23.5).

$$\mathrm{CR} = \mathrm{CI} / \mathrm{RI} \tag{23.5}$$

The consistency ratio for all factor layers and sub-factors is less than 0.1 in this study. Consequently, it demonstrates the precision of the pair-wise comparison matrixes constructed in the current study.

The AHP analysis has been carried out in Microsoft Excel. The pair-wise comparison matrix, weights standardization, and consistency analysis of the selected factor layers and their sub-factors are discussed in detail in the following sections. The final weights were entered in the relevant shapefiles and converted to a raster file format. Figure 23.2 shows the methodology flow chart of the present study. Weighted Linear Combination (WLC)method by adopting Eq. (23.6) to integrate the required thematic maps and sub-themes into ArcGIS to find suitable waste disposal sites in the current study location.

$$\begin{aligned}\mathrm{WSSI} &= (\mathrm{Ddlw} * \mathrm{Ddfw}) + (\mathrm{Grlw} * \mathrm{Grfw}) + (\mathrm{Lilw} * \mathrm{Lifw}) + (\mathrm{Ldfw} * \mathrm{Ldfw}) \\ &+ (\mathrm{Lulw} * \mathrm{Lufw}) + (\mathrm{Gelw} * \mathrm{Gefw}) + (\mathrm{Sllw} * \mathrm{Slfw}) + (\mathrm{Elw} * \mathrm{Efw}) \\ &+ (\mathrm{Prlw} * \mathrm{Pfw}) + (\mathrm{Solw} * \mathrm{Sofw}) + (\mathrm{Rdlw} * \mathrm{Rdfw}) + (\mathrm{Aslw} * \mathrm{Asfw})\end{aligned} \tag{23.6}$$

WSSI = waste site suitability index, Ddlw = distance from the drainage layer weight, Ddfw = distance from the drainage features weights, Grlw = ground water level layer weight, Grfw = ground water level features weights, Lilw = lithology layer weight, Lfw = lithology features weights, Ldlw = lineament density layer weight, Ldfw = lineament density features, Lulw = land use/land cover layer weight, Lufw = land use/land cover features weights, Sllw = slope layer weight, Slfw = slope

Table 23.3 Random inconsistency values

n	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Saaty (1980)
n number of criteria, and *RI* random inconsistency

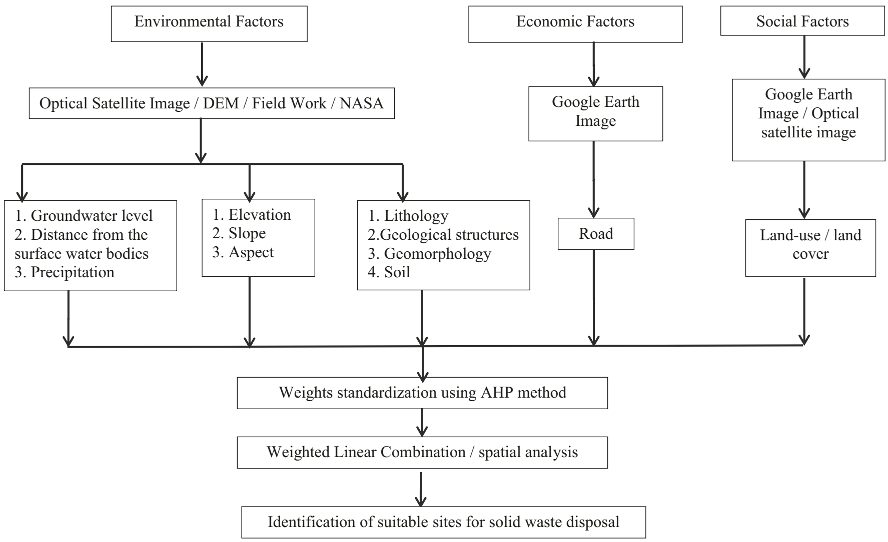

Fig. 23.2 Methodology flow chart derivation of sub-factors weights

features weights, Elw = elevation layer weight, Efw = elevation features weights, Prw = precipitation weights, Prfw = precipitation features weights, Solw = soil layer weight, Sofw = soil features, Rlw = distance from road layer weight, Rfw = distance from road features weights, Asw = aspect layer weight, and Asw = aspect features weights.

23.3 Results and Discussion

23.3.1 Derivation of Weights for Factor Layers

The initial pair-wise comparison matrix has been built to assign relative relevance weights to the twelve thematic layers that have been selected in the present study. A pair-wise comparison matrix was constructed based on investigations done in Ethiopia by the following scholars (Genemo and Yohanis 2016; Duguma et al. 2018; Semaw 2018; Mussa and Suryabhagavan 2019; Weldeyohanis et al. 2020) (EMUB&C 2012) guidelines and field observations. Table 23.4 shows a pair-wise judgment matrix of the twelve-factor layers used in the present study.

The distance to the drainage and distance to the road layer got the maximum and minimum final weights. Table 23.5 shows the weights, rank, and priority of the selected twelve-factor layers. 0.025 is the consistency ratio value, and it is <0.10.

Table 23.4 Factor layer's Pair-wise comparison matrix

	A	B	C	D	E	F	G	H	I	J	K	L
A	1	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00	7.00	8.00	9.00
B	0.50	1	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00	7.00	8.00
C	0.50	0.50	1	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00	7.00
D	0.33	0.50	0.50	1	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00
E	0.33	0.33	0.50	0.50	1	2.00	2.00	3.00	3.00	4.00	4.00	5.00
F	0.25	0.33	0.33	0.50	0.50	1	2.00	2.00	3.00	3.00	4.00	4.00
G	0.25	0.25	0.33	0.33	0.50	0.50	1	2.00	2.00	3.00	3.00	4.00
H	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1	2.00	2.00	3.00	3.00
I	0.17	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1	2.00	2.00	3.00
J	0.14	0.17	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1	2.00	2.00
K	0.12	0.14	0.17	0.20	0.25	0.25	0.33	0.33	0.50	0.50	1	1.00
L	0.11	0.12	0.14	0.17	0.20	0.25	0.25	0.33	0.33	0.50	1.00	1
Total	3.9	5.79	7.67	10.53	13.36	17.16	20.91	25.66	31.33	38	46	53

A = distance from drainage, B = groundwater level, C = lithology, D= lineament density, E = LULC, F = geomorphology, G= slope, H = elevation, I = precipitation, J = soil, K = road, and L= wind direction (aspect)

Table 23.5 Factor layers weights and rank

S.No	Thematic layers	Weights	Rank
1	Distance from the drainage	0.23	1
2	Groundwater level	0.18	2
3	Lithology	0.14	3
4	Lineament density	0.11	4
5	Land use/land cover	0.09	5
6	Geomorphology	0.07	6
7	Slope	0.05	7
8	Elevation	0.04	8
9	Precipitation	0.03	9
10	Soil	0.03	10
11	Road	0.02	11
12	Wind direction (aspect)	0.02	12

23.3.1.1 Distance from the Drainage

The ASTER-DEM data was used to create a drainage network for the current research region, which was then extracted using the Archydrotools included in the ArcGIS through standard procedures. Additionally, the Sentinel-2 satellite image and toposheets were used to verify and update the drainage networks. It is not recommended that solid waste disposal sites be located near drainage systems (Kontos et al. 2005; Nas et al. 2008). Thus, the drainage network of the present research region was buffered, and the results were categorized into five buffer zones (0–250 m, 251–500 m, 501–750 m, 751–1000 m, and 1001–1250 m), (Fig. 23.3).

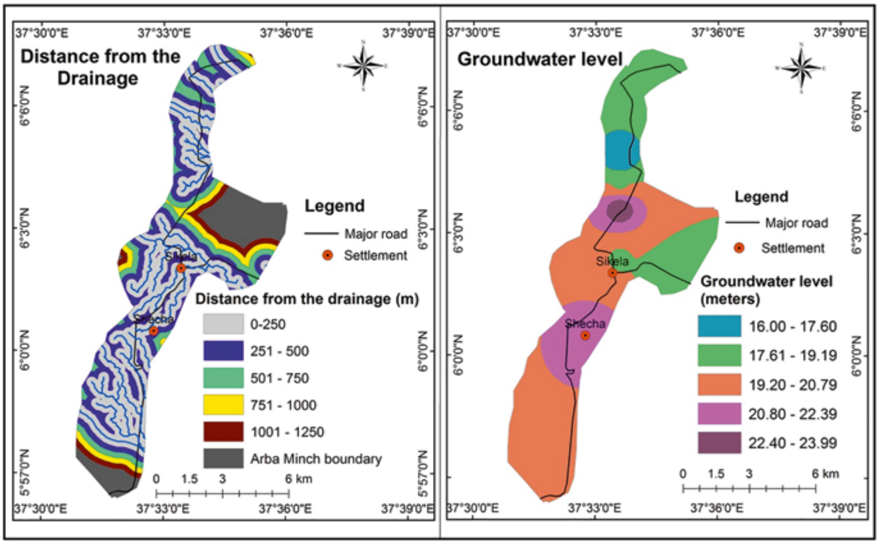

Fig. 23.3 Distance from the drainage and groundwater level maps

Table 23.6 Normalized weights and comparison matrix (drainage buffers)

	I	II	III	IV	V	Weights	Rank	Priority
I	1	0.5	0.33	0.25	0.17	0.419	1	41.9%
II	2	1	0.5	0.33	0.25	0.263	2	26.3%
III	3	2	1	0.5	0.33	0.16	3	16.0%
IV	4	3	2	1	0.5	0.097	4	9.7%
V	6	4	3	2	1	0.062	5	6.2%

I = 1250–1001 m, II = 1000–751 m, III = 750–501 m, IV = 500–251 m, and V = 250–0 m

The drainage buffer categories of 1001–1250 m and 0–250 m drainage buffer were allocated the highest and lowest initial weights, respectively, to create the pair-wise comparison matrix. Drainage's buffer pair-wise comparison matrix, weights, rank, and priority are shown in Table 23.6. The consistency ratio, in this case, is 0.015.

23.3.1.2 Groundwater Level

The groundwater levels in Arba Minch town were determined using the Czech Republic cooperative hydrogeology map for Arba Minch town, sheet number 0637-D3, at a scale of 1:50,000. The water level contours were created using interpolation and then transformed as a polygon in Arc GIS software for further analysis. The groundwater levels in the current research region range between 16 meters and 23.99 meters. Further, the data on groundwater levels were categorized into five groups, as seen in Fig. 23.3. The analysis determined the most and least appropriate

Table 23.7 Normalized weights and comparison matrix (groundwater levels)

	I	II	III	IV	V	Weights	Rank
I	1	2	3	4	5	0.42	1
II	0.5	1	2	3	4	0.26	2
III	0.33	0.5	1	2	3	0.16	3
IV	0.25	0.33	0.5	1	2	0.10	4
V	0.2	0.25	0.33	0.5	1	0.06	5

I = 23.99–22.40 m, II = 22.39–20.80 m, III = 20.79–19.20 m, IV = 19.19–17.61 m, V = 17. 60–16 m

regions for landfill siting based on shallow and deep groundwater tables. A pair-wise comparison matrix for groundwater level categories was developed using initial weights (Table 23.7).

23.3.1.3 Lithology

The rock type of the area is vital in deciding where to dispose of solid waste. The lithological map of the present research region was created using information from the geological map prepared by the Ethiopian geological survey and field observations in the study area. In addition, Sentinel 2 satellite data has been used to determine the weathering nature of the rock. High porosity and permeability alluvial and colluvial deposits induce leachate penetration and groundwater pollution, making them unsuitable for landfill sites. Thus, these sediments cannot be used as sitting landfills. Therefore, rock with lesser porosity and permeability is ideal for landfill siting. Thus, unweathered to slightly weathered ignimbrite has the highest rating, whereas alluvial deposits have the lowest (Table 23.8). 0.043 is the consistency ratio of the lithological features.

23.3.1.4 Lineament Density

Lineaments are an excellent sign of groundwater presence. Furthermore, lineaments may facilitate the passage of leachate into the groundwater system (Sener et al. 2010). The ASTER-DEM, Sentinel-2 optical satellite data, and Ethiopian geological map evaluated and mapped the lineaments. The density of lineaments was estimated using the line density tool in ArcGIS. The lineament density of the present study area range from 0 to 3.96 km/sqkm, and it has been divided into three groups (Fig. 23.4). The high lineament density makes the region unsuitable for disposal sites. The AHP analysis was carried out for lineament classes; normalized weights and pair-wise comparison is shown in Table 23.9.

Table 23.8 Normalized weights and comparison matrix (lithology)

Lithological features	Ignimbrite	Basalt	Colluvial deposits	Alluvial sediments	Weights	Rank
Ignimbrite	1	3	5	7	0.565	1
Basalt	0.33	1	3.00	5.00	0.262	2
Colluvial deposits	0.20	0.33	1	3.00	0.118	3
Alluvial sediments	0.14	0.20	0.33	1	0.055	4

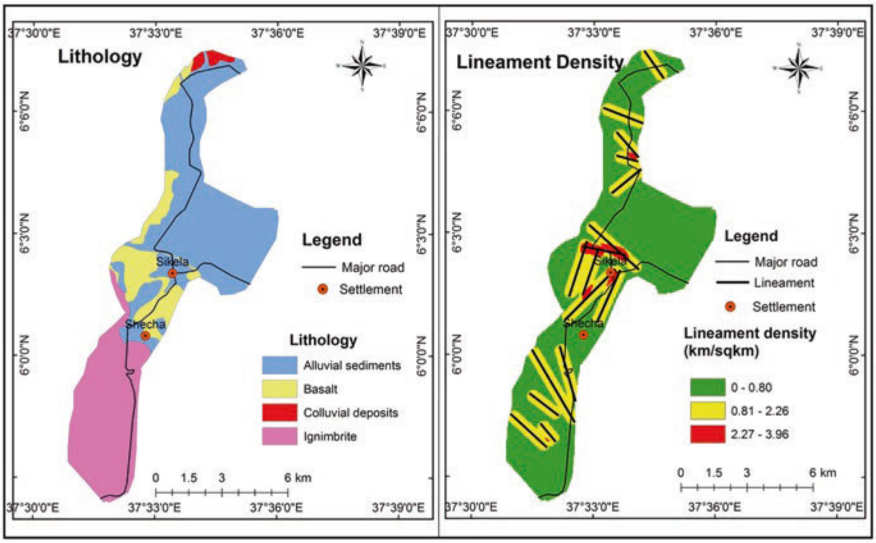

Fig. 23.4 Lithology and lineament density maps

Table 23.9 Normalized weights and comparison matrix (lineament density)

Lineament density (km/sqkm)	0–0.80	0.81–2.26	2.27–3.96	Weights	Rank
0–0.80	1	2	3	0.52	1
0.81–2.26	0.50	1	2	0.36	2
2.27–3.96	0.33	0.50	1	0.12	3

23.3.1.5 Geomorphology

Landforms are essential in the selection of waste disposal sites. The current research area is covered mainly by plain. Various landforms were identified in the current research region include conical hills, plateaus, and liner ridges. Positioning of disposal sites is most appropriate on plains and plateaus, while conical hill, linear ridges, valley fill, and escarpment are much less or inappropriate for placement of disposal sites. Geomorphology of the present research areawas created using satellite images from Sentinel-2 and a 3-D model of the ASTER –DEM. Figure 23.5 shows the study area geomorphology map. A comparison of geomorphology classes

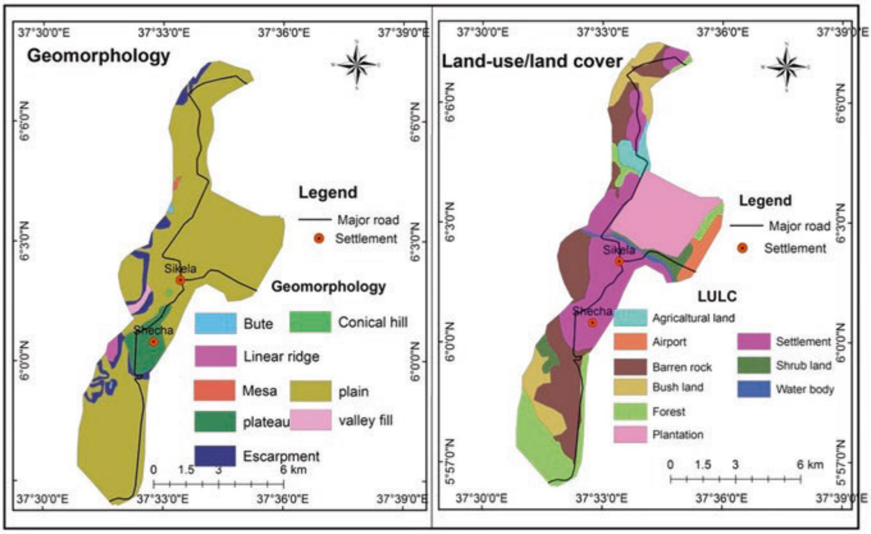

Fig. 23.5 Geomorphology and LULC maps

Table 23.10 Normalized weights and comparison matrix (geomorphology)

Geomorphological features	Plain	Plateau	Mesa	Butte	Valley fills	Conical hill, linear ridge, and escarpments	Weights	Rank
Plain	1	2	3	4	5	6	0.37	1
Plateau	0.50	1	2	3	4	5	0.25	2
Mesa	0.33	0.50	1	2	3	4	0.16	3
Bute	0.25	0.33	0.50	1	2	3	0.10	4
Valley fills	0.20	0.25	0.33	0.50	1	2	0.05	5
Conical hill, linear ridge, and escarpments	0.17	0.20	0.25	0.33	0.50	1	0.03	6

is shown in Table 23.10, along with their weights and rankings. Conical hill, linear ridge, and escarpments received low weights and grades, in contrast to the plain geomorphological area, which received high weights.

23.3.1.6 Land Use/Land Cover (LULC)

To locate waste disposal sites, a LULC study of the present research area is necessary. A LULC map of Arba Minch was created by visual interpretation of false colour composite (FCC) of Sentinel 2 satellite data with 10 m spatial resolution. Barren land, agricultural land, settlement, bushland, forest, and other LULC types have been recognized in the Arba Minch Town (Fig. 23.5). The same was prioritized according to its relevance in determining the location of the waste disposal facility.

Table 23.11 Normalized weights and comparison matrix (land use/land cover)

	I	II	III	IV	V	Weights	Rank
I	1	3	5	7	9	0.50	1
II	0.33	1	3	5	7	0.25	2
III	0.20	0.33	1	3	5	0.11	3
IV	0.14	0.20	0.33	1	3	0.05	4
V	0.11	0.14	0.20	0.33	1	0.03	5

I = Barren land, II = Bushland, III = Shrubland, IV= Forest, V = Settlement, Agricultural land, plantation area, water body, and airport

The barren land, settlement, agricultural land, shrubland, plantation, bushland, and forest were allocated the highest, lowest, and intermediate ranks (Table 23.11). LULC consistency ratio is 0.04.

23.3.1.7 Slope

The slope of the current research area was determined using ASTER-DEM and categorized into 0–6.58°, 6.59–15.72°, and 15.73–54.18° (Fig. 23.6). Slopes that are too steep might result in floods, runoff, and erosion. Additionally, they are economically unviable as a waste disposal location because of the construction cost of road and site development (Kontos et al. 2005; Yousefi et al. 2018). As a result, min and max weights were assigned to slope classes 0–6.58° and 15.73°–54.18°, to facilitate the selection of viable landfill sites. Table 23.12 presents the slope categories, their pair-wise comparison matrix, and their normalized values.

23.3.1.8 Elevation

When locating solid waste disposal sites, an appropriate elevation range must be chosen to minimize leachate percolation down the landfill column and to avoid flooding and erosion over the landfill area (Demesouka et al. 2014). The present research area's elevation was determined using ASTER–DEM, and it ranges between 1086 and 1589 m above mean sea level. It was classified into three elevation subgroups: 1086–1225 m, 1226–1323 m, and 1323–1589 m (Fig. 23.6). A pair-wise matrix was generated by assigning minimum and maximum weights to the elevation classes 1323–1589 m and 1086–1225 m, respectively. Table 23.13 presents the elevation categories, their pair-wise comparison matrix, and their normalized values.

23.3.1.9 Precipitation

Rainfall plays a role in the transportation of solid waste. Significant rain produces excessive solid waste flow. This study used NASA's website (https://power.larc.nasa.gov/) to obtain annual mean rainfall data from 1981 to 2019. As shown in

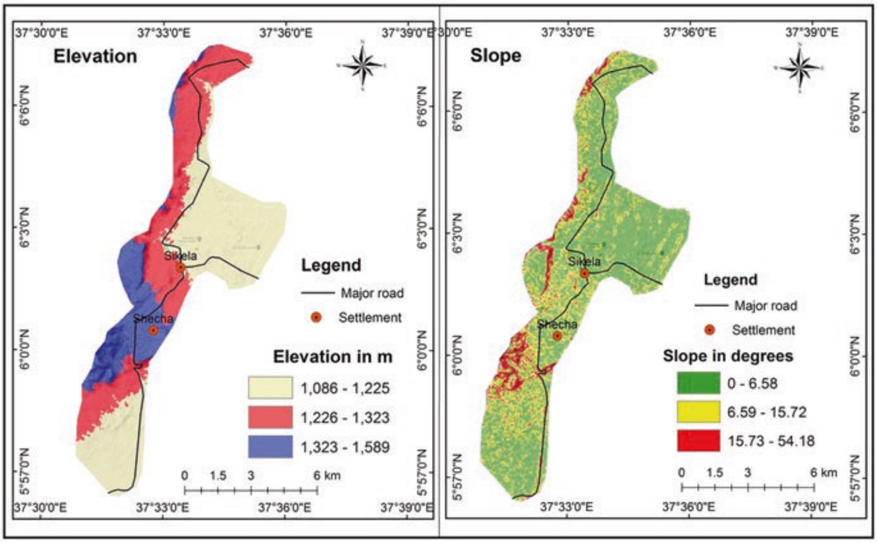

Fig. 23.6 Elevation and Slope maps

Table 23.12 Normalized weights and comparison matrix (slope)

Slope in degrees	0–6.58	6.59–15.72	15.73–54.18	Weights	Rank
0–6.58	1	2	3	0.52	1
6.59–15.72	0.50	1	2	0.36	2
15.73–54.18	0.33	0.50	1	0.12	3

Fig. 23.7, an ArcGIS interpolation tool was used to generate a rainfall contour map. Lower and higher weights were allocated to the rainfall ranges of 934–1037 mm and 1140–1242 mm, respectively, during the pair-wise comparison matrix formulation phase. Rainfall categories and their pair-wise comparison matrix and normalized values are shown in Table 23.14.

23.3.1.10 Soil

Selection of dump location requires soil type analysis. The type of soil influences the vertical flow of leachate. Clay soil has less porosity and permeability, making it perfect for landfills. Clay soil, in general, is resistant to leaching and is also utilized to line sanitary landfills. Soil map of Arba Minch Town created by Czech Republic cooperation (map sheet number 0637-D3) at a scale of 1:50,000. Soils identified in this study include clay, clay loam, silt, sand, and silty clay. Clay and silt soil types have been identified as acceptable for the solid waste disposal location, whereas sand soil types have been identified as unsuitable. Soil types have been allocated initial weights, AHP analysis was carried out, and final weights of soil types have been calculated, and the same is shown in Table 23.15. Figure 23.7 shows the soil type of the study area.

Table 23.13 Normalized weights and comparison matrix (elevation)

Elevation (m)	1086–1225	1226–1323	1323–1589	Weights	Rank
1086–1225	1	2	3	0.52	1
1226–1323	0.50	1	2	0.36	2
1323–1589	0.33	0.50	1	0.12	3

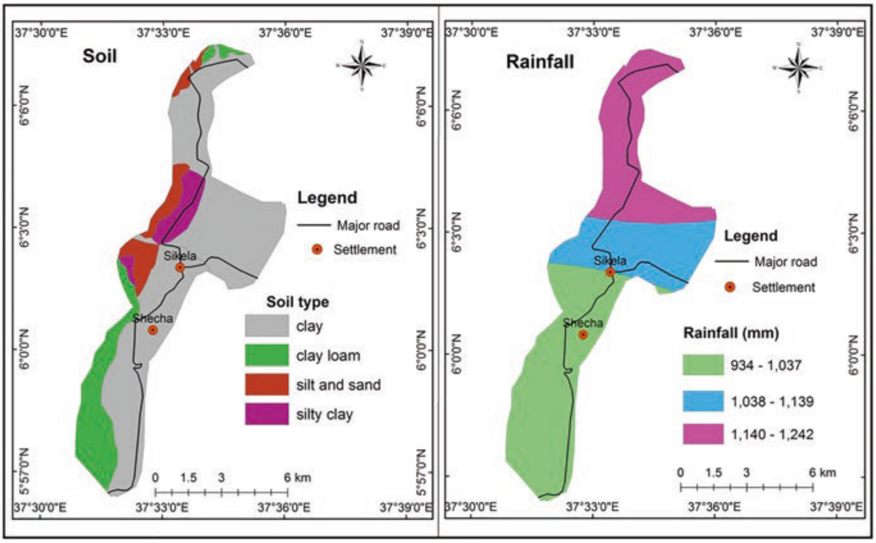

Fig. 23.7 Soiland rainfall maps

Table 23.14 Normalized weights and comparison matrix (rainfall)

Rainfall (mm)	934–1037	1038–1139	1140–1242	Weights	Rank
934–1037	1	2	3	0.52	1
1038–1139	0.50	1	2	0.36	2
1140–1242	0.33	0.50	1	0.12	3

23.3.1.11 Distance from the Road

A road map was created using a high spatial resolution Google Earth imagery, and a buffer analysis was performed; the results were classified into three buffer classes (Fig. 23.8). Therefore, it was determined that the region between 0–150 meters from the major road was not viable for waste disposal. Commuters will suffer health consequences if the dumping site is located near the road. If the dumpsite is located a long distance away from a road network, the cost of collecting and transporting the trash may be higher (Nas et al. 2008). For this reason, it is considered that the land area situated between 151 and 300 m road distance is the most acceptable site in the current study location. Table 23.16 shows the normalized weight and rank of the distance from the road categories.

Table 23.15 Normalized weights and comparison matrix (rainfall)

Soil types	clay	clay loam	silty clay	silt and sand	Weights	Rank
Clay	1	3	5	7	0.565	1
Clay loam	0.33	1	3.00	5.00	0.262	2
Silty clay	0.20	0.33	1	3.00	0.118	3
Silt and sand	0.14	0.20	0.33	1	0.055	4

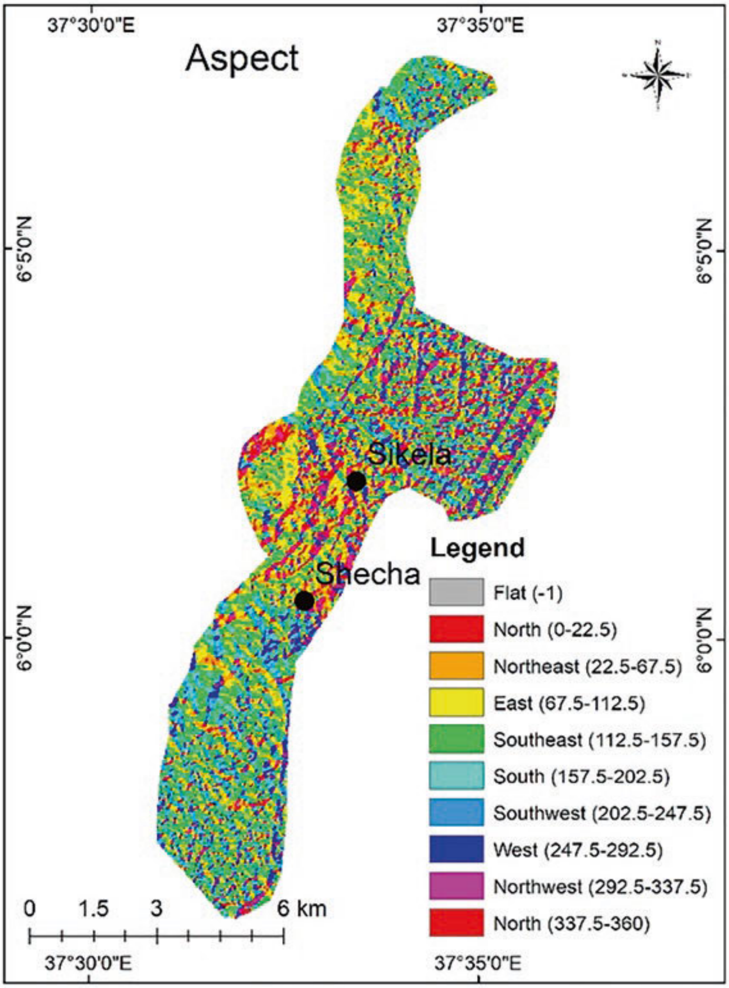

Fig. 23.8 Wind direction (Aspect) map

23.3.1.12 Wind Direction (Aspect)

When determining where to site a solid waste disposal facility, it is important to consider the direction of the wind (Aspect). The downwind regions may be

Table 23.16 Normalized weights and comparison matrix (distance from the road)

Road buffer (m)	450–301	300–151	150–0	Weights	Rank
450–301	1	2	3	0.52	1
300–151	0.50	1	2	0.36	2
150–0	0.33	0.50	1	0.12	3

Table 23.17 Normalized weights and comparison matrix (Aspect)

Aspect	I	III	III	IV	V	VI	VII	VIII	IX	Weights	Rank
I	1	2	3	4	5	6	7	8	9	0.312	1
II	0.50	1	2	3	4	5	6	7	8	0.222	2
III	0.33	0.50	1	2	3	4	5	6	7	0.155	3
IV	0.25	0.33	0.50	1	2	3	4	5	6	0.108	4
V	0.20	0.25	0.33	0.50	1	2	3	4	5	0.074	5
VI	0.17	0.20	0.25	0.33	0.50	1	2	3	4	0.051	6
VII	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3	0.035	7
VIII	0.12	0.14	0.17	0.20	0.25	0.33	0.50	1	2	0.025	8
IX	0.11	0.12	0.14	0.17	0.20	0.25	0.33	0.50	1	0.018	9

I = Flat, II = North, III = Northwest, IV = West, V = Northeast, VI = Southeast, VII = Southwest, VIII = South, and IX = East

subjected to objectionable dust, odours, harmful/toxic fumes, and flying litter, which may be a significant source of nuisance to neighboring settlements (Ajay Singh 2019). Aspect is a means of defining the direction in three-dimensional space that each grid cell in a DEM faces, and it is expressed herein degrees respect to the true north of earth. In this investigation, the aspect layer is used instead of the wind direction. It was feasible to build an aspect map layer from the DEM of the study area by using ArcGIS Spatial Analyst extension, as presented in Fig. 23.8. The primary hourly wind direction at Arba Minch varies. From April 22 to October 10, the wind is mainly from the south, with a peak percentage of 81 on June 13. From October 10 to April 22, the wind is primarily from the east, with a peak of 64% on January 1, source (https://weatherspark.com/y/100150/Average-Weather-in-Arba-Minch-Ethiopia-Year-Round#Sections-WindDirection). As a result, slopes facing east and south were given lower ratings and weights than other slopes. Table 23.17 shows the normalized weights and rank of the aspect categories.

23.4 Results and Discussions

23.4.1 Choosing Solid Waste Disposal Sites

The end weights were calculated by multiplying the weights of thematic layers by the weights of sub-themes (Table 23.18), and then entered into appropriate shapefiles using ArcGIS software. The resultant map of suitability for solid waste sites was created by using a raster-based weighted linear combination approach. The

Table 23.18 Thematic layers and their sub-factors final weights

S. No	Factor layer	Factor layer's weights	Sub-criteria	Sub-factor's weights	Final weight (Factor layer's weights* Sub-factor's weights)
1	Drainage distance (m)	0.23	1250–1001	0.42	0.10
			1000–751	0.26	0.06
			750–501	0.16	0.04
			500–251	0.10	0.02
			250–0	0.06	0.01
2	Groundwater level (m)	0.18	23.99–22.40	0.42	0.08
			22.39–20.80	0.26	0.05
			20.79–19.20	0.16	0.03
			19.19–17.61	0.10	0.02
			17.60–16	0.06	0.01
3	Lithology	0.14	Ignimbrite	0.57	0.08
			Basalt	0.26	0.04
			Colluvial deposits	0.12	0.02
			Alluvial sediments	0.06	0.01
4	Lineament density	0.11	0–0.80	0.52	0.06
			0.81–2.26	0.36	0.04
			2.27–3.96	0.12	0.01
5	Land use/land cover	0.09	Barren land	0.50	0.045
			Bushland	0.25	0.023
			Shrubland	0.11	0.010
			Forest	0.05	0.005
			Settlement, agricultural land, plantation area, water body, and airport	0.03	0.003
6	Geomorphology	0.07	Plain	0.37	0.026
			Plateau	0.25	0.018
			Mesa	0.16	0.011
			Butte	0.10	0.007
			Valley fills	0.05	0.004
			Conical hill, linear ridge, and escarpments	0.03	0.002
7	Slope (degree)	0.05	0–6.58	0.52	0.026
			6.59–15.72	0.36	0.018
			15.73–54.18	0.12	0.006
8	Elevation (m)	0.04	1086–1225	0.52	0.021
			1226–1323	0.36	0.014
			1323–1589	0.12	0.005
9	Precipitation (mm)	0.03	934–1037	0.52	0.016
			1038–1139	0.36	0.011
			1140–1242	0.12	0.004

(continued)

Table 23.18 (continued)

S. No	Factor layer	Factor layer's weights	Sub-criteria	Sub-factor's weights	Final weight (Factor layer's weights∗ Sub-factor's weights)
10	Soil	0.03	Clay	0.57	0.017
			Clay loam	0.26	0.008
			Silty clay	0.12	0.004
			Silt and sand	0.06	0.002
11	Distance from the road (m)	0.02	450–301	0.52	0.010
			300–151	0.36	0.007
			150–0	0.12	0.002
12	Wind direction (aspect)	0.02	Flat	0.312	0.006
			North	0.222	0.004
			Northwest	0.155	0.003
			West	0.108	0.002
			Northeast	0.074	0.001
			Southeast	0.051	0.001
			Southwest	0.035	0.001
			South	0.025	0.001
			East	0.018	0.001

results rated the study area as highly suitable, moderately acceptable, and unsuitable for solid waste disposal (Fig. 23.9). According to the findings of this study, 6.84% (4.34 km^2), 10.19% (6.47 km^2), and 82.97% (52.69 km^2) of the area are highly, moderately, and problematic areas for the construction of a solid waste disposal site in Arba Minch town. The highly suitable place found the southern part of the study area where slope and elevation are less. The area is covered by ignimbrite lithologically and less to medium lineament density. Further, the highly suitable area is covered by plain area, and significant LULC is barren land withfewer drainages and low precipitation.

23.5 Conclusion

Management of municipal solid waste (MSW) is a significant issue in most developing countries due to population and urbanization expansion. In Arba Minch town, Ethiopia, solid waste management issues arise due to population growth and economic development, high urban waste production, and a lack of landfill sites. It is challenging to find appropriate solid waste disposal sites in Arba Minch town due to the presence of high slope mountains on the town's western border and Abya and Chamo lakes on the town's eastern border, as well as the town's complex lithology and LULC, as well as variations in groundwater level and rainfall, among other

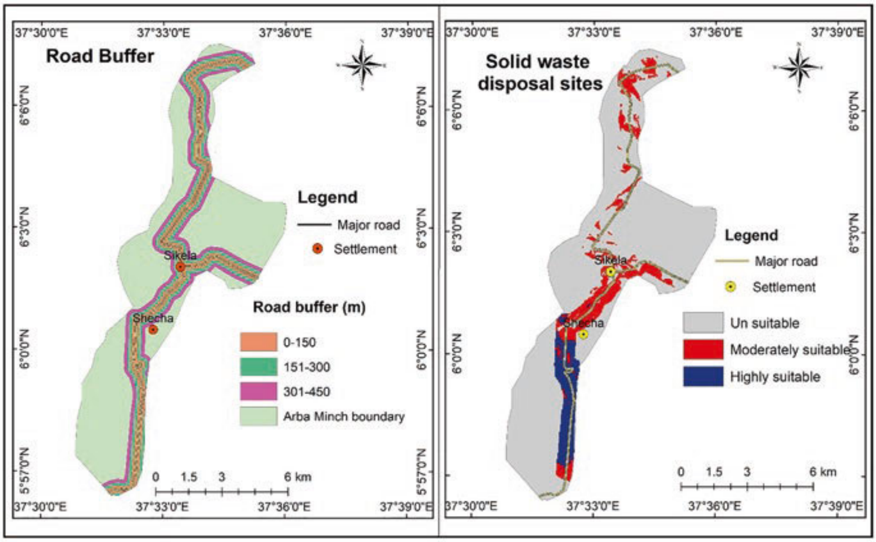

Fig. 23.9 Road buffer and solid waste site disposal site suitability maps

factors. In the present study, twelve important thematic layers and their sub-themeswere considered for solid waste disposal sites selection.

The weights of the chosen twelve thematic layers and their sub-themes were computed using the AHP method to create the final solid waste site suitability map. The final map was created using a raster-based WLC approach. According to the findings of this study, 6.84% (4.34 km^2), 10.19% (6.47 km^2), and 82.97% (52.69 km^2) of the area are highly, moderately, or unsuitably appropriate for the development of a solid waste disposal site in Arba Minch town, respectively. The results of this study may assist administrators and planners in Arba Minch town, Ethiopia, in selecting appropriate solid waste disposal sites.

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Chapter 24
Framing Conceptual Design of Adopting Interlocking Bricks Technology in Construction

P L. Meyyappan and R. Krishnakumar

Abstract Nowadays, construction cost is increasing rapidly due to increase in building materials cost, accounting construction waste, delay in construction activities etc. In this technique, the walls are erected without the use of cement mortar for jointing purpose. Each brick is made to lock itself to adjacent bricks using a key-cut-and-lock mechanism. A brief comprehensive review of the different shapes and functions of interlocking bricks was made. An attempt was made to analyze the cost-effectiveness based on the material requirements of a one-story building constructed using various materials such as conventional bricks, solid cement blocks, and interlocking bricks of ISSB "T" and ISSB "SA" type. The building has one room measuring 3 × 3 m. Material requirements and construction cost have been calculated based on current market rates. In a comparative analysis, it was noted that the use of traditional bricks costs more than other materials. If the solid blocks and interlocking bricks are replaced individually, the cost is reduced up to 6.41% and 11.78%, respectively. In the interlaced type, ISSB "T" is better than ISSB "SA" in terms of cost reduction. It is also noted that the cost of the ISSB "SA" interlock is almost the same as that of solid cement blocks. Based on comparative analysis, the design strategy and its specifications have been incorporated into the design of the conceptual framework which can be understood when this interlocking technology is adopted in the construction sectors.

Keywords Interlocking bricks · Clay bricks · Cost analysis · Conceptual design · ISSB 'T' brick · ISSB 'SA' brick

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24.1 Introduction

The rapid expansion of the modern building industry has necessitated civil engineers in search of an innovative building practice that may lead to a greater, more efficient and lasting economy as an alternative to the traditional brick building system (Deepak 2012). Moreover, there is a great demand for rapid construction, shortage of manpower and cost-effective building systems, and these factors have led to a change in the concept of traditional building systems (Praveenkumar et al. 2014). These changes paved the way for the development of interlocking bricks and this concept/design is addressed to improve constructability, performance, cost etc. These bricks are similar to traditional bricks but consist of binders such as cement, flyash and chemical setting agent with additional features such as groves on the top surfaces. These interlocking stones had outstanding features to hold them against each other and did not require cement mortar to join the brick course. This self-locking is achieved using a shear wrench and its own locking mechanism (Yuri 2015). This lock design concept made a stable structural configuration reducing the cost and lead time of construction/preparation practices to approximately 30–40% (Emmanuel et al. 2018). Moreover, assembling these stones do not require some kind of additional training/skills and it can be done faster and very efficiently. It is more suitable for temporary structures because the dismantling activity can be carried out easily without destroying the bricks. Several previous researches indicate that interlocking bricks are better than the traditional type of masonry structures in terms of compression, shear strength, modulus of elasticity, water absorption, dimensional testing, etc. (Jaafar et al. 2016), hence an attempt was made to check the cost-effectiveness on different types of brick materials and their structural design strategy in the one-story building.

24.2 Objective of the Study

The following objectives are formulated for this investigation study.

(i) To arrive the material requirements for this building made up of various bricks such as conventional bricks and interlocking bricks.
(ii) To estimate the cost analysis of the building made up of various bricks such as conventional bricks and interlocking bricks
(iii) To arrive the conceptual framework design by incorporating the dependable factors related to interlocking mechanism/strategy in the building construction.

24.3 Analytical Study

In order to check the quantity requirement and cost analysis for the adoption of interlocking brick mechanism, the one-story building (plan and height) is considered as shown (Fig. 24.1). The building has one room and with a distance of 3 m × 3 m. One window of 1.2 × 1.0 m and one door of 0.9 m × 2.0 m were placed in this building in order to meet the requirements of daily lighting and ventilation factors. The building has 4 square columns RC (grade M20) 250 mm × 250 mm in each corner. The height and thickness of the wall is taken as 3 m and 023 m. The bulkhead wall is 0.7 cm high and the ceiling slab is 150 mm thick. The normal cost for rooftop cement tiles is around 25 rupees/sqft. The labor cost for this building is 200 rupees/

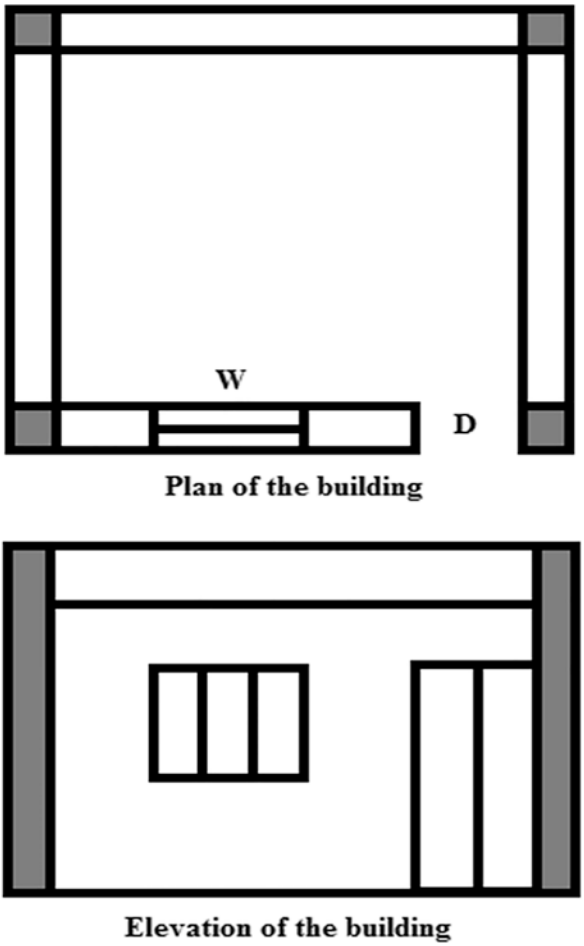

Fig. 24.1 Building plan and elevation

sqft. Here the study was formulated to arrive at material requirements and cost analysis for this building using different bricks such as conventional brick, Tanzanian standard interlocking brick (ISSB‘T’), South African interlocking standard interlocking brick (ISSB‘SA’) and conventional solid brick based on the cost of and current market specifications.

24.4 Results and Discussion

In this section, the specifications, material requirements and cost comparison of four different bricks for the one storey building was discussed in the first part. In the next part, conceptual design strategy was discussed with the various factors related to the concept of interlocking of brick type of construction techniques.

24.4.1 Specification and Cost Comparison

Specifications for different types of bricks such as traditional bricks, standard fixed interlocking bricks of Tanzania (ISSB “T”), standard fixed interlocking bricks of South Africa (ISSB “SA”) and traditional solid bricks are shown (Table 24.1). Standard dimensions are reached for this brick based on previous etiquette. The required number of bricks per cubic meter is calculated based on standard dimensions. It is estimated that 500 digits, 33, 40 and 18 digits are required for 1 cubic meter of brick wall composed of conventional mud brick, ISSB’T, ISSB’SSA and Solid, respectively. Based on the nature of bricks and their interaction in masonry wall construction, plastering is necessary for conventional clay bricks and traditional solid bricks while for ISSB ‘T’ and ISSB ‘SA’, plastering is not required due to the interlocking mechanism between bricks.

Based on these specification details as mentioned (Table 24.1), the material estimate for this one-story building is calculated. Based on the amount of materials required, a cost analysis was arrived at for this building. The current market price of conventional clay bricks, ISSB’T, ISSB’SSA, and conventional solid bricks are taken as Rs 7/piece, Rs 27/piece, 24 rupees/piece and Rs. 54/piece straight. Material

Table 24.1 Specification details for various types of bricks

S. No	Type of bricks	Dimension (mm)	Nos. of bricks per m^3 of brick wall	Plastering
1	Conventional clay bricks	190 × 90 × 90	500	Needed
2	ISSB ‘T’	300 × 150 × 100	33	Not needed
3	ISSB ‘SA’	230 × 220 × 115	40	Not needed
4	Solid Conv. Brick	450 × 230 × 150	18	Needed

Table 24.2 Materials and cost estimation of bricks

S. No	Type of bricks	Nos. required	Cost/piece	Building cost (Rs.)
1	Conventional clay bricks	5094	7	92,490
2	ISSB 'T'	1452	27	81,588
3	ISSB 'SA'	1772	24	86,723
4	Solid Conv. Brick	792	54	86,555

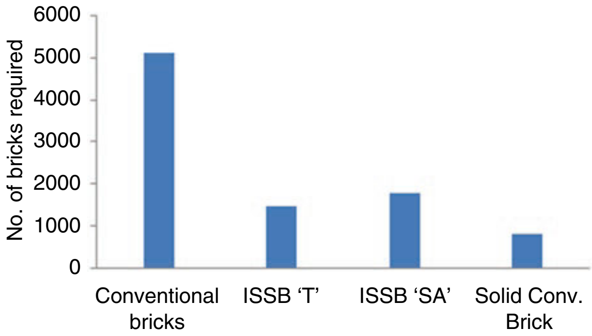

Fig. 24.2 Brick requirements w.r.t various types of bricks

and cost estimate is obtained from MS prepared Excel calculator. Based on this calculation, the number of bricks required for a one-story building made of conventional mud brick, ISSB'T conventional brick, ISSB'SSA brick and solid brick, total cost of the building is mentioned (Table 24.2). Brick requirements w.r.t different types of bricks and their cost comparison are shown (Figs. 24.2, 24.3 and Table 24.2). The number of conventional clay bricks required for this building is estimated to be a maximum of 5094. If the same building is made of traditional solid brick, the numbers required are estimated as the lowest quantity of 792 numbers. The cost analysis of the traditional mud brick and traditional solid brick building came to Rs 92,490 and Rs 86,555 respectively. If the building itself is made of interlocking bricks of types ISSB "T" and ISSB "SA", the materials are counted and estimated at 1452 and 1772 numbers respectively.

It is estimated at Rs 81,588 of which the cost has been reduced by 11.78% because plastering activity is not required due to the interlocking mechanism. If the same building is constructed with ISSB'SSA type bricks, the cost is estimated as Rs. 86,723 Cost reduction by about 6.23% compared to traditional clay bricks. The cost of an ISSB'SSA brick dorm is roughly the same as that of a standard traditional brick.

24.4.2 Conceptual Design

Based on the specification and comparative cost analysis of different types of bricks, the conceptual framework work is designed by integrating factors related to the interlocking of brick strategy (Fig. 24.4). Once the building type, plan and

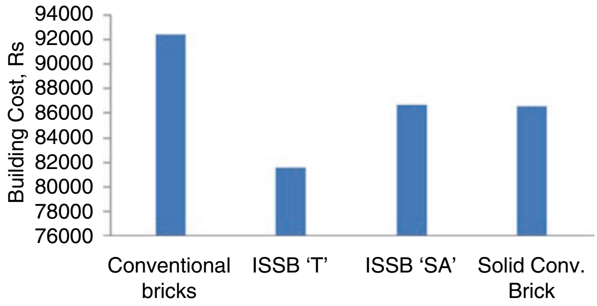

Fig. 24.3 Comparison of building cost for various types of bricks

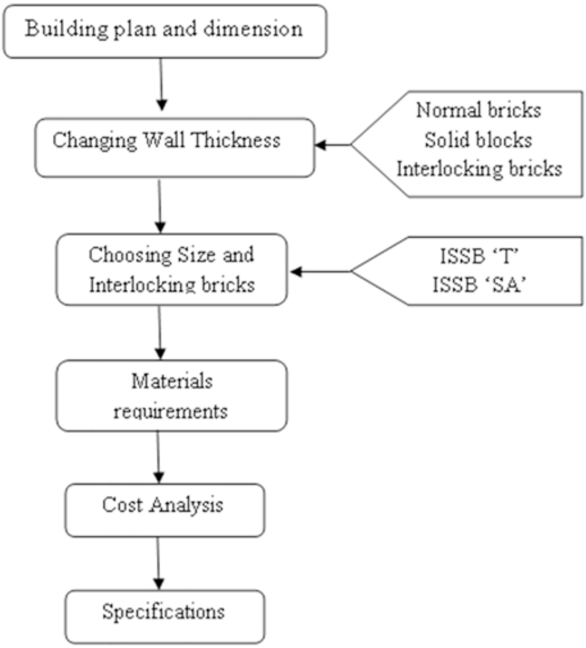

Fig. 24.4 Conceptual design flow chart

dimensions are reached, the suitability of different types of bricks such as traditional clay bricks, standard traditional bricks and interlocking bricks can be reached based on the selection of variable wall thickness parameters. Then the size and type of interlocking bricks can be determined by either ISSB 'T' or ISSB 'SA'.

24.5 Conclusion

The following conclusions were arrived based on this work:

(a) The materials required and the total cost of the building (single room) are provided for different types of bricks such as conventional clay bricks, ISSB'T, ISSB'SA and standard conventional bricks and their cost is compared with each other.
(b) It is observed that traditional mud bricks in those one-story buildings cost higher. If it is replaced by standard traditional brick, the construction cost is reduced to 6.41% and also if interlocking blocks are used, the whole construction cost is reduced to 11.78%.
(c) In interlocking bricks ISSB "T" type appears to be better than ISSB "SA" in terms of cost reduction as 5.92%.
(d) The overall design strategy and its specifications are arrived at in the form of a conceptual framework after incorporating the factors that affect the suitability of the meshing mechanism.

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Chapter 25
Arriving Factors in the Conceptual Design Framework of 3D Printing Techniques for Building Construction

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Abstract Recently, the construction industry is facing practical problems such as poor productivity, lack of labor, lack of safety, more construction waste and so on. Based on the literature, it was noted that a technical invention like 3D printing had a practical solution to those construction issues mentioned above. Especially in developing countries like India, 3D printing technology is still in the realization stage, but in developed countries, huge works have been done with this technology. It is necessary to have access to the construction cost and its calculation procedure for the method of 3D printing technology. A The study was accomplished with an open source tool "Omni calculator" to access the material cost and labor cost of this 3D printing of different filament materials such as Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polyethylene Terephthalate (PETG) and T-filament Glase (PETT) and High Impact Polystyrene (HIPS). The cost will be arrived at by considering 3D printing machine filament diameters 0.1 cm, 0.2 cm, 0.3 cm, 0.4 cm and 0.5 cm and the job duration is 1 h, 2 h, 3 h, 4 h and 5 h. In the analysis, it was observed that the larger the filament diameter, the significantly higher the cost of 3D printing about 2.83 times. It is also noted that the duration of the work hour increased the cost of 3D printing very marginally by 1.19 times. Among the different filament materials, ABS materials bear the best result in terms of economic cost. The conceptual framework work is designed by incorporating the reliable factors of 3D printing technology into the build sequence. Hence based on this study, it has been determined that the cost of materials with suitable filament plays a vital role in the adoption of this 3D printing technology in the construction sector.

Keyword 3D printing · Filament · Job duration · Labour cost · Market cost · Quality control

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25.1 Introduction

The major problems have been identified in the construction industry such as poor productivity, shortage of labour, lack of safety etc. (Wang and Wang 2014; Song and Hu 2015) in India. In order to solve those identified problems, the adoption of 3D printing technology will have a lot of scope in the Indian construction industry (Gao et al. 2015). In India, 3D printing technology is still in the establishment stage, but in overseas countries it has been well implemented like China, UAE, Australia and USA (Sakin and Kiroglu 2017). 3D printing is the task that is accomplished through framed computer programming control by layer-by-layer installation of material arrangement in creating a 3D shape of the object/work, it is simply an additive method of product manufacturing (Xia and Sanjayan 2016; Paul et al. 2018). It is mostly useful for prototyping and assembling engineering complex components. It was initially developed in the early 1980s, but was not popular at the time due to the high operating cost (Ngoa et al. 2018). It was first introduced by James B Gardiner in 2011 and made it possible to create buildings using these new 3D printing technologies. Chinese company Yingchuang and Huashang Luhai Ltd. have built their official buildings in Dubai and Beijing with the help of these 3D printing technologies. To be precise, the cost of molds is greatly reduced because 3D printing technology does not need to use molds for the purpose of concrete pouring (Al-Ahmari et al. 2018). It is necessary to know the calculation method and estimate the cost of construction. The estimated cost of conventional construction is fully developed worldwide, while 3D printing has many benefits such as no controlled access to bill of quantities, estimation target, cost access basis etc. (Kazemian et al. 2017). Factors affecting and influencing to reach the cost of 3D printing. Based on these factors, a conceptual framework is designed by integrating those factors to implement 3D printing technology in construction sectors.

25.2 Objective of the Study

The objectives of this work are given below:

1. Arriving the cost of the 3D printing for different material by varying the filament diameter of 3D printing machine from 0.1 cm to 0.5 cm.
2. Arriving the cost of the 3D printing for different material by varying the duration of 3d printing job from 1 h to 5 h
3. Incorporating the influencing and non-influencing factors in the conceptual design framework of adopting 3D printing techniques for construction of buildings.

25.3 Analytical Study

In order to gain access to the factors affecting the cost of 3D printing, an open source tool "Omni 3D Printer Calculator" is used. For this study, work is planned in two categories. For these two categories, the five different filamentous materials are taken and their details are given (Table 25.1). For category 1, an attempt was made to arrive at the 3D printing cost of different filament materials by varying the different filament diameter such as 0.1 cm, 0.2 cm, 0.3 cm, 0.4 cm and 0.5 cm and keeping the running time and labor cost constant. For this attempt, the length of the filament is 100 cm, the operating time is 5 h, and the labor cost is 1500 rupees/hour. For class 2, an attempt was made to arrive at the 3D printing cost of different filament materials by varying the duration of the operating hours such as 1 h, 2 h, 3 h, 4 h and 5 h and keeping the filament diameter 0.5 cm and length 100 cm steadily. 3d printing calculator cost is up to material cost, operation cost, labor cost and markup fee of 10%.

25.4 Results and Discussion

The cost comparison results for the 3D printing model composed of different filament diameters such as 0.1 cm, 0.2 cm, 0.3 cm, 0.4 cm and 0.5 cm for different materials is shown (Table 25.2). It shows that the cost of 3D printing is high for material PETT and low for material ABS.

For 0.1 cm filament diameter, the cost for 3D printing of material ABS, PLA, PETG PETT and HIPS is Rs. 87799.38, Rs. 91,629.38, Rs. 93,774.66, Rs. 96,260.49 and Rs. 93770.25 respectively. It is clear that the cost of 3D printing increases significantly if the diameter of the filament increases and this is evident regardless of the different materials which are clearly shown (Fig. 25.1). It is observed that when the diameter is increased from 0.1 cm to 0.5 cm, the cost of 3D printing for different materials increased from 1.23 to 3.45 times. For ABS materials, the cost of 3D printing increased to 1.23 times, 1.61 times, 2.14 times and 2.82 times, if the filament diameter increased to 0.2 cm, 0.3 cm, 0.4 cm and 0.5 cm, respectively.

Table 25.1 Filament materials and its density

S. No	Filament material	Density (g/cm^3)
1	Acrylonitrile Butadiene Styrene (ABS)	1.05
2	Polylactic Acid (PLA)	1.27
3	Polyethylene Terephthalate (PETG)	1.25
4	T-Glase filament (PETT)	1.45
5	High Impact Polystyrene (HIPS)	2.04

Table 25.2 Cost comparison for various diameter of filament

S. No	Material name	D = 0.1 cm	D = 0.2 cm	D = 0.3 cm	D = 0.4 cm	D = 0.5 cm
1	ABS	87799.38	107866.17	141311.06	188134.06	248334.42
2	PLA	91629.38	116561.37	158114.68	216289.32	291085.29
3	PETG	93774.66	118924.80	160841.18	219524.58	294974.22
4	PETT	96260.49	125785.13	174993.65	243885.26	332459.97
5	HIPS	93770.25	115013.08	150417.78	199983.58	263712.04

For filament diameters of 0.2 cm, 0.3 cm, 0.4 cm and 0.5 cm composed of PLA materials, the cost of 3D printing increased to 1.27 times, 1.73 times, 2.36 times and 3.17 times, respectively. For material PETG and PETT, the cost increased to 1.26 times to 3.14 times and 1.31 times to 3.45 times, if the filament diameter increased from the diameter to 0.2 cm and 0.5 cm, respectively. For HIPS materials, the cost of this 3D printing is 2.81 times from 1.22 times for 0.5 cm filament diameter from 0.1 cm respectively. It is also seen that the cost variance is lower for 0.1 cm and 0.2 cm filament diameters but the cost variance is in a sharp increasing trend for 0.3 cm to 0.5 cm diameter filaments (Fig. 25.1).

The 3D printing model cost comparison results for different duration of operation such as 1 h, 2 h, 3 h, 4 h and 5 h for different materials is shown (Table 25.3). It shows that the cost of 3D printing is high for PETT materials and low for ABS materials regardless of process time. For 1 h, the cost of 3D printing of material ABS, PLA, PETG, PETT, HIPS is Rs. 165593.97, Rs. 17324.42, Rs. 180914.88, Rs. 188575.33 and Rs. 196235.79 respectively. It is clear that the cost of 3D printing increases very slightly if the duration of the process is increased from 1 h to 5 h and this is evident regardless of the different materials which are clearly shown (Fig. 25.2). It is noted that, when the duration of the operation is increased from 1 h to 5 h, it increases The cost of 3D printing for different materials is 1.03–1.19 times. For material ABS, the cost of 3D printing increased to 1.04 times, 1.09 times, 1.14 times and 1.19 times, if the operation time increased to 2 h, 3 h, 4 h and 5 h, respectively. For 3D printing consisting of PLA and PETG materials has almost the same cost and the cost increase per hour is also the same for both materials. The cost increased 1.03 times, 1.07 times, 1.12 times and 1.15 times for 2 h, 3 h, 4 h and 5 h, respectively. The cost of 3D printing of the material HIPS is more than ABS but lower than other materials such as PLA, PETG and PETT over the lifetime. For PETT materials, the cost of 3D printing increased from 1.04 times to 1.19 times during the run time of 1–5 h, respectively. From Fig. 25.1, it is also clear that 3D printing cost variance is directly and much influenced by different filament diameters and runtime is not an influencing factor.

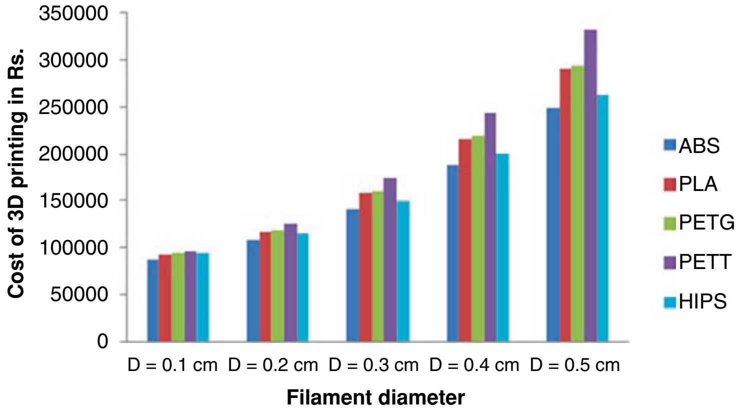

Fig. 25.1 Cost of 3D printing vs filament diameter

Table 25.3 Cost comparison for various diameter of filament

S. No	Material name	Duration 1 h	Duration 2 h	Duration 3 h	Duration 4 h	Duration 5 h
1	ABS	165593.97	173254.42	180914.88	188575.33	196235.79
2	PLA	203359.27	211199.97	219040.67	226881.38	234722.08
3	PETG	206128.00	214197.62	222267.23	230336.84	238406.46
4	PETT	242996.56	251241.91	259487.26	267732.62	275977.97
5	HIPS	179900.26	188298.82	196697.38	205095.95	213494.51

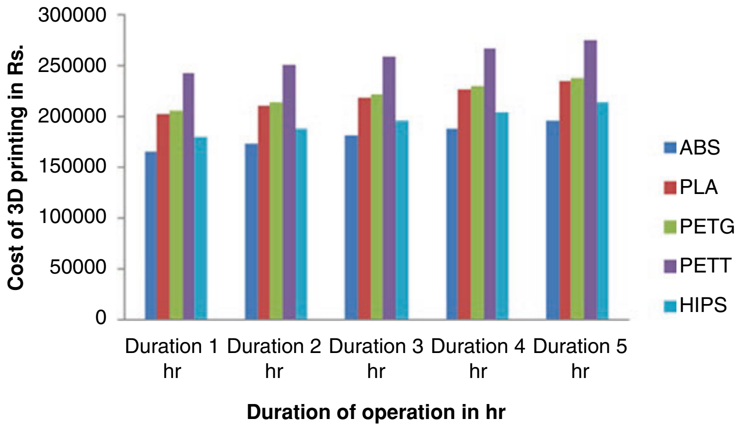

Fig. 25.2 Cost of 3D printing vs duration of operation

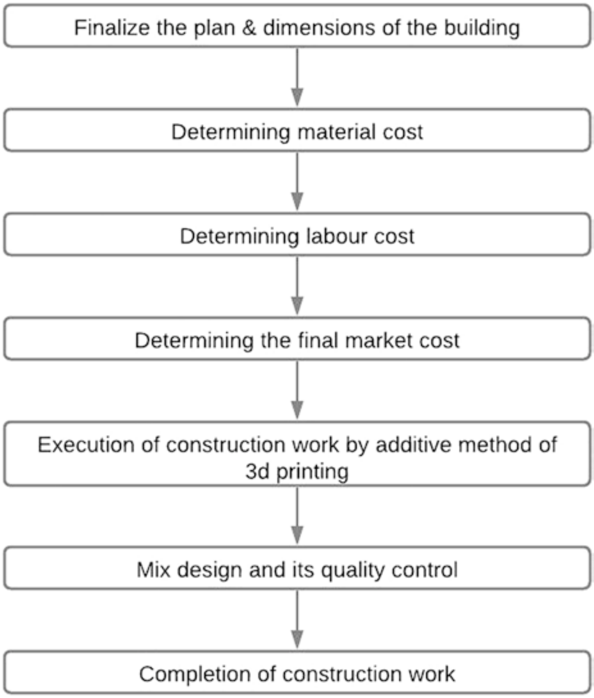

Fig. 25.3 Conceptual design frame work

25.5 Conceptual Design

Based on the above understanding about the influencing factors, the design strategy is described in framing the conceptual design framework for 3D printing technologies in building construction and is as follows in the flowchart (Fig. 25.3). If we adopt 3D printing techniques in construction, then 3D printing cost considering the effect of influencing and impacting factors like material, labor, market cost etc., once the plan and its dimensions for the building are completed. Finally, this process is carried out with strict concrete mix control and concrete quality control.

25.6 Conclusion

The following conclusions were arrived based on this work:

(a) As the diameter of the filament increases from 0.3 cm to 0.5 cm, the cost of 3D printing varies and increases significantly from 1.23 times to 2.83 times. But for 0.1 cm and 0.2 cm diameter, the cost difference is lower.

(b) If the operating time increases, the cost of 3D printing increases very marginally. The increase is in the range of 1.03 to 1.19 times if the maximum duration is increased to 5 h.
(c) It is known that the most influential and non-influencing factor in reaching the cost of 3D printing is the cost of materials with the appropriate filament size and duration of operation respectively.
(d) A conceptual design framework for 3D printing technologies for building construction is described.

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Chapter 26
Scenic Evaluation of the Hills for Tourism Development – A Study on the Hills of Tamilnadu, India

K. Katturajan and H. Sivasankari

Abstract Hill areas are the places of tourist attractions mainly for the climate and landscape. The study area of Tamilnadu has both Western ghats and Eastern ghats mountain ranges which accommodates six major hill stations with several tourist spots in each of them.

This work evaluates the impact of hill areas in the development of tourism. The assessment is done in two ways the physical and the tourist. Physical factors taken into consideration are slope, aspect and altitude which are collated with the tourist factors like the tourist flow and the number of tourist spots in each hill stations to analyze the impact of hill areas in the tourism development.

The GIS software is used to analyze the physical factors and the tourist components such as tourist flow and number of tourist spots in the hill stations are obtained from the tourist office.

It is found that both the geographical factors and the tourist factors are directly related with one another, when there is an increase in the scenic beauty there are a greater number of tourist spots in the hills which attracts larger number of tourists.

There are numerous Geographical features which when converted into tourist attractions will attract a greater number of tourists there by paving a way for the economic development of a country.

Keywords Altitude · Aspect · Slope · Tourist flow · Geotourism

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26.1 Introduction

The landscape or the scenery which contains the mountains, lakes, waterfalls, glaciers, forest, and deserts are strong geographical factors attracting people to a particular destination. Of the above factors mountain tourism or the hill tourism is very popular among the tourist to escape from the heat of the plains during summer.

The evaluation for tourism purpose was first done by Pearce (1981). He listed seven factors for tourism resources and climate is one among them. In many parts of the world climate is an important factor promoting Tourism.

26.1.1 Study Area

The study area of this paper, Tamilnadu covers an area off 130,058 sq. kms. The North, South and Western side are hilly region, and it is also rich in vegetation. Nilgiris is the popular place in Tamilnadu where the Western and Eastern ghats meets. There are six popular hill stations in Tamilnadu. The present study is carried out to gauge the role of hill stations in tourism development with the help of physical factors and the tourist factors and suggesting few locations for the tourism development.

26.1.2 Reviews of Literature

Many authors have studied about mountain tourism and the pattern of development in mountain tourism.

Linton (1968) has pointed out that the scenic quality of the landscape was generally reckoned to increase with relative relief, altitude slope etc.

Mc Intosh and Goeldner (1985) have analyzed the principles, practices and philosophies of tourism.

Bhatia (1997) has listed out the components related to Geography with reference to tourism and climate is one of the important factors.

Pran Seth (2004) has analysed the impact of geography on tourism. Tourism has three main components from geographical point of view. They are the countries of origin of tourists called as generating areas, the destination areas namely the tourist receiving countries and the route travelled between these two locations.

Kamra and Chand (2004) has studied about different approaches to the study of tourism, Geographical approach is one among them.

Lakshumanan et al. (2012) in the research paper Land use land cover dynamics study in Nilgiris district has investigated the land use land cover of the Nilgiris district using remote sensing and GIS.

Pattukandan and Rajawat (2015) in the research paper Use of hazard and vulnerability maps for landslide planning scenario A case study of the Nilgiris, India with the help of remote sensing and GIS has studied the spatial vulnerability of landslides planning scenario.

Narasimmaraj in his thesis has studied about the carrying capacity and the importance of community participation for sustainable nature-based tourism in Ooty. The importance of community participation has been highlighted.

Selvam et al. (2015) describes about the scenic beauty of the hill stations in the research paper. The study of Hill tourism in Tamilnadu – A geographical perspectives.

26.1.3 Aim and Objectives

This work evaluates the influence of hill areas in the development of tourism. The assessment is done in two ways the physical and the tourist. Physical factors taken into consideration are slope, aspect, and altitude. The tourist factors like the tourist flow and the number of tourist spots in each hill stations are considered.

26.1.4 Data Source and Methodology

For analyzing the physical factors like slope, altitude, and relative relief SRTM data from USGS has been used to prepare the altitude, slope and relative relief map of the districts in which the hill stations fall. Elevation map and slope map has been generated using a grid based digital elevation model by using ARC GIS. The tourist statistics and tourism related data were collected from Tamilnadu Tourism Development Corporation. The study materials are collected from the libraries.

26.2 Tamilnadu Hills

Tamilnadu is a tropical region, located in the Southern part of India. Bounded by Karnataka, Andhra, Telangana in the north and Kerala in the West. The Eastern and Western ghats meets in Tamilnadu and run along its eastern and western borders. All the famous hill stations like Udagamandalam, Kodaikanal, Kotagiri, Coonoor, Yercaud and Elagiri are situated in this region.

26.3 Scenic Evaluation of the Hills

Scenic evaluation is one of the most used indicators in Geotourism purposes. Tessema et al. (2021). Landscape is an environmental resource for tourism and for the evaluation the Linton method gives quick results (Moss and Nickling 1980).

The scenic evaluation of the hills is based on the Linton (1968) method with following factors, the higher altitude, higher relative relief, and steep slope are the indicators of scenic beauty (Figs. 26.1, 26.2, and 26.3). The following districts Nilgiris, Dindigul, Salem and Vellore are considered where the hill stations are located for the evaluation purposes (Table 26.1).

The evaluation is done in three phases. Chhetri and Arrow Smith (2003) used Geographic Information System for the evaluation of scenic attractiveness. The first phase deals with defining the factors like altitude, slope (moderate 8–16 degrees and steep slope 16–32 degrees) and relative relief (Figs. 26.1, 26.2, and 26.3). The second phase deals with derivation of value scale ranging from 0 to 100, transforming the measurement scale into value scale (Table 26.2) The third phase of the analysis is the derivation of the index of scenic evaluation. The index of scenic evaluation is the average of the value scale (Table 26.3) figures of all the three parameters. Based on the average of the value scale of all parameters, the hierarchy order is given for

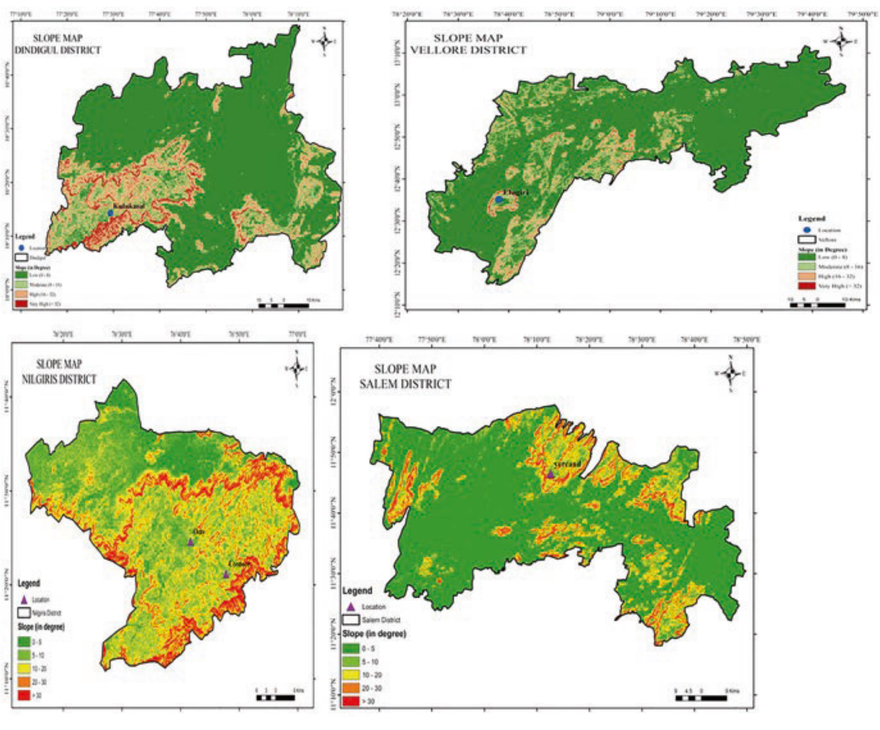

Fig. 26.1 Slope of the hill areas

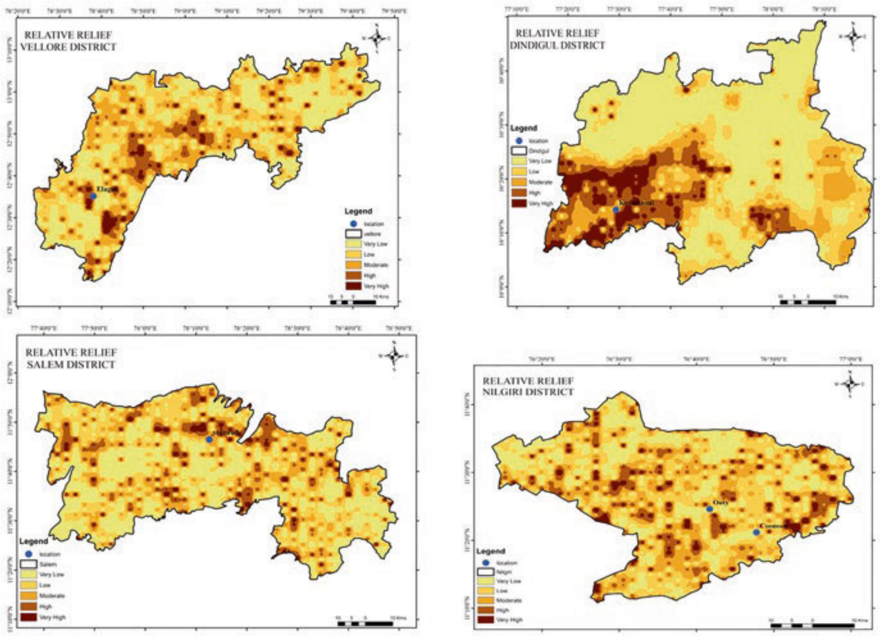

Fig. 26.2 Relative relief of the hill areas

the hill areas (Table 26.3). Very high scenic beauty with index of scenic evaluation values from 70 to 100 is placed in hierarchy (Table 26.3) order of I, high scenic beauty with index of scenic evaluation values from 50 to 70 is placed in hierarchy order of II, moderate scenic beauty with index of scenic evaluation values from 25 to 50 is placed in hierarchy order of III, low scenic beauty with index of scenic evaluation values (Table 26.3) less than 25 is placed in hierarchy order of IV

26.4 Collating Physical Factors with Tourist Factors

To analyze the impact of hill areas in the tourism development the physical factors are collated with the tourist factors (Figs. 26.1, 26.2, and 26.3). Raha et al. (2021) has considered three sustainable parameters to demarcate the Eco Tourism potential zones. In one of these parameters availability of scenic beauty and Infrastructure is used.

When the mean of the physical factors increases which implies the scenic beauty is more in the area the tourist factors also increase. Othman (2015) has mentioned hilly landform and architectural heritage have significant scenic values. It is found that there is a correlation between these two factors the physical which can be termed as the geographical factors and the tourist factors. Python software is used for the analysis. There is a strong correlation between physical factors and the

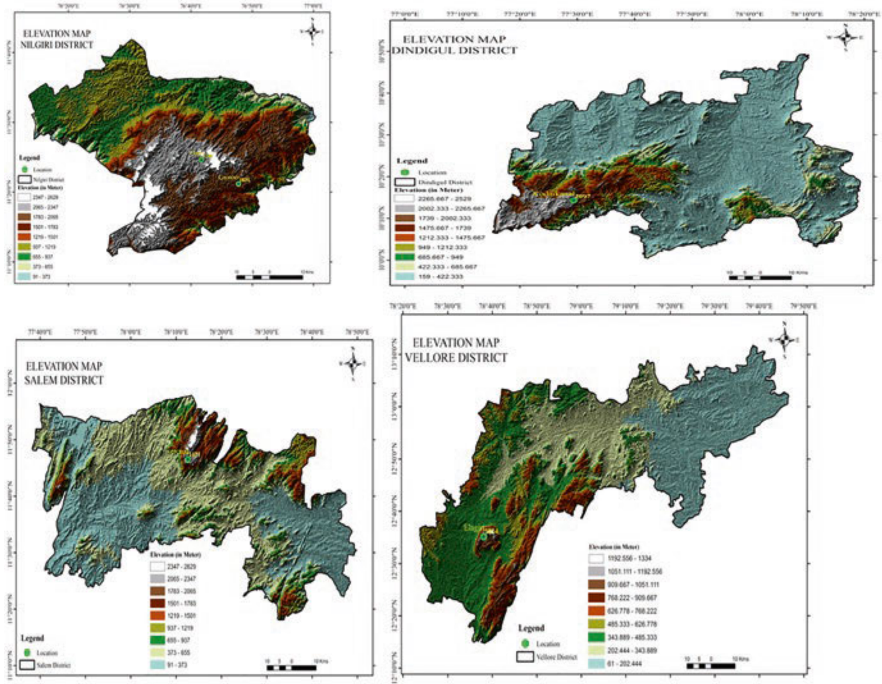

Fig. 26.3 Altitude of the hill areas

Table 26.1 Physical parameters for the evaluation

Name of the district	Area under moderate slope in percentage	Area under steep slope in percentage	Relative relief in meters	Altitude in meters
Nilgiris	32.54	25.91	1232.82	2637
Dindigul	13.85	16.96	1551.29	2505
Salem	12.67	15.44	1092.5	1586
Vellore	12.88	10.91	885.41	1034

Computed by the authors

Table 26.2 Transformation of measurement scale to value scale

Name of the district	Altitude measurement scale in meters	Value scale of altitude	Relative relief measurement scale in meters	Value scale of relative relief	Slope average	Value scale of slope
Nilgiris	2637	100	1232.82	52.17	29.22	100
Dindigul	2505	91.76	1551.29	100	15.40	20.21
Salem	1586	34.43	1092.5	31.10	14.05	12.44
Vellore	1034	0	885.41	0	11.89	0

Computed by the authors

Table 26.3 Index of scenic evaluation

Name of the district	Value scale of altitude	Value scale of relative relief	Value scale of slope	Index of scenic evaluation	Hierarchy order
Nilgiris	100	52.17	100	84.05	I
Dindigul	91.76	100	20.21	70.65	I
Salem	34.43	31.10	12.44	25.99	III
Vellore	0	0	0	0	IV

Computed by the authors

Table 26.4 Physical factors and tourist factors

Name of the district	Hill station	No. of tourist spots	Tourist flow (2019)[a]	Index of scenic evaluation
Nilgiris	Udagamandalam	43	17,391,085	84.05
	Coonoor	17	3,212,242	84.05
Dindigul	Kodaikanal	35	15,917,715	70.65
Salem	Yercaud	20	8,621,124	25.99
Vellore	Elagiri	25	3,159,403	0

[a]Source: Tamilnadu Tourism Development Corporation

tourist arrivals and a very strong correlation between tourist arrivals and the number of tourist spots in the hill stations (Table 26.4).

26.5 Conclusions

With the help of the above calculation, it is evident that when the physical factors increase the tourist factors also increases. There are also other hill areas with high tourism potential in Tamilnadu. If these resources are turned into attractions the tourism industry will develop there by paving a way to the economic development of the nation. A project can be carried out to find the suitable areas high in scenic beauty and then turning the area into tourist spot by including man made features like infrastructural facilities. When carrying out the development activities, conservation of these hill areas also must be taken up. NBA National Biodiversity authority with the support of Ministry of Environment and forest has initiated several special projects and programs to effectively implement in the hill areas. The best way to conserve these hill areas is by community participation and practicing Responsible tourism, where the tourists are educated to use the resources without spoiling the environment.

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Chapter 27
Influence of Groundnut Shell Ash and Waste Plaster of Paris on Clayey Soil for Sustainable Construction

Abhishek Kanoungo, Vishal Dhiman, Shubham Sharma, Jagdeep Singh, and Akhilesh Kumar

Abstract Groundnut shell ash (GSA) is an agricultural dissipates whereas Waste Plaster of Paris (WPOP) is a powdered material obtained from gypsum. In order to attain better efficiency of composites, which can be used on roads, the present research is an attempt to investigate how WPOP and GSA along with soils that are available locally are efficiently used. The investigation explores the testing of the soil characteristics when combined with WPOP and GSA to improve UCS and CBR strength. Present work shows that maximum value of UCS was found at – 79% Soil + 18% of WPOP + 3% of GSA and CBR will be highest for 79% Soil + 18% of POP + 6% of GSA. Thus, when both WPOP and GSA are collectively added in soil it leads to an effective reduction in the thickness of pavement by using waste POP and groundnut shell ash thereby reducing environmental hazard while improving the strength.

Keywords Groundnut shell ash (GSA) · Plaster of Paris (POP) · Optimum moisture content (OMC) · UCS · CBR · Clayey soil

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27.1 Introduction

The soil needs to be solid in every base of a building. Soil life is an extremely important thing to consider when any project starts (Benemann et al. 2018). The quality and features of the soil are needed for which industrial commodities are added in soils for improving the soils strength (Lwin et al. 2018) Particular additives include bitumen emulsifiers, lime and graph-enhanced asphalt, but they tend to exceed the cost limits however these substances provide better quality, durability, solidity (Lavin 2003). Few materials that can be groundnut nutshell, fly ash, bagasse etc can be used to manage the prices as they are economical. Mixing such materials can produce better engineering results than the usually used engineering materials (Sharma and Akhai 2019a, b). Soil stabilization involves mixing materials with soil that can reinforce the features of soil according to the desired requirements. This is done to achieve a stronger structure, cost-efficiency, and to achieve safety protocols. There are waste materials and by-products which are obtained from industries that can be used in soil stabilization techniques. These materials can enhance the characteristics of the soil plus keep a check on costs. The purpose of soil stabilization and adjustment is to obtain good stability soil and expanding protection (Chittaranjan et al. 2011).

27.2 Materials

This work aims to study the incorporation of WPOP and GSA and its effect on the durability of soil used in road construction. GSA is an agricultural waste produced by burning groundnut shells after obtaining the groundnut seeds. Increased groundnut production leads to an increase in groundnut shell ash production. Groundnut shell is usually buried or burnt. Burying them will require space and burning it causes air pollution (Reddy et al. 2017). POP stands for plaster of Paris and its name comes from the fact that it is found in large quantities in Paris. Gypsum ($CaSO_4.2H_2O$) is suitable for commercial purposes and in making fertilizers. It is a mineral that exists in white or grey colour (Figs. 27.1 and 27.2).

It is obtained after heating gypsum or calcium sulphate dehydrate to about 1400–1800 °C. There are certain benefits of using POP such as it does not shrink and avoids cracks. It provides a hard surface and it, therefore, becomes a favourable option in the road. It has less mass and is a bad conductor of heat making it a good insulation material (Singh and Singh 2021).

Additives reinforce the geotechnical properties of soil. They increase soil particle cohesion, work as a substitute for cement, and are non-permeable (Arif 2017). In this review paper, the author has highlighted the aspects of using POP and groundnut shell ash as additives in the soil for enhancing its properties.

Fig. 27.1 Transformation from groundnut shell to groundnut shell ash

Fig. 27.2 Plaster of Paris (POP)

27.3 Experimentation

In this section, the results of California Bearing Ratio and Unconfined Compression tests on soil samples including and omitting the specified admixtures in planned compositions are displayed.

The changes in the maximum dry density and optimum moisture content containing WPOP and GSA contents in the clay soil are shown in Table 27.1.

Figure 27.3 showing a gradual drop in the MDD, as the percentage of WPOP rises, and the OMC value increases accordingly. According to Fig. 27.3 and Table 27.1, the values decremented for MDD are due to inclusion of soil replacement by WPOP in the mixture. The WPOP can be associated to the soil coating, which leads to larger pieces/fragments forming and therefore decreases the value of MDD. The increased value of OMC can be linked to the usage of WPOP in filling soil gaps, which increases soil weight. It may also be supposed that the decrease in MDD could be due to WPOP as WPOP not able to engross the voids across the soil matrix in addition to the flocculation and agglomeration of the clay particles. The

Table 27.1 Variations of MDD and OMC of the clayey soil with WPOP and GSA content

S. No.	Soil specimen (%)	POP specimen (%)	GSA specimen (%)	Max dry density (gm/cc)	Optimum moisture content (%)
1	100	0	0	1.6	19
2	79	18	3	1.58	20.5
3	76	18	6	1.57	21.5
4	73	18	9	1.55	23
5	70	18	12	1.53	24.5
6	67	18	15	1.52	26
7	64	18	18	1.52	27.5

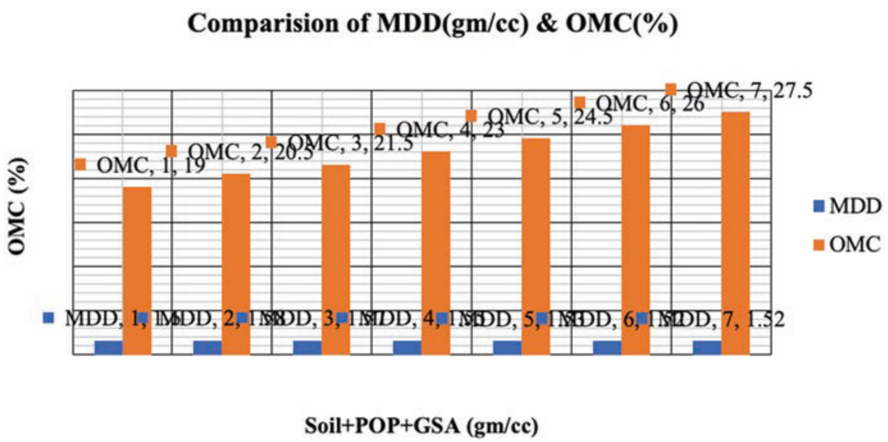

Fig. 27.3 Relationship between the MDD&OMCfor 18% of WPOP & different types of GSA mix with clayey Soil

OMC enhanced perpetually with increased WPOP contents. This trend was interpreted in line with the increasing demand for water, which corresponds to the higher volume of WPOP needed for the cation exchange reaction and dissociation.

Table 27.2 shows that the value of UCS increases initially as the percentage of GSA increases up to 6%, but then gradually decreases as the percentage of GSA increases along with 18% of WPOP in comparison to the 100% clayey soil, which may be due to ion replacement at the surface of clay particles as the Ca^{2+} responded to lower valence metallic ions of the soil interface.

This caused soil particle aggregation and stacking, which raises UCS but decreases UCS after a certain amount because the soil particles are unable to form a strong bond. If we also consider CBR value of processed soil including GSA and WPOP, it increased up to 10.51% in the presence of 6% GSA and 18% WPOP and after that the valuation of CBR declines, which could be because of the quality of calcium silicate hydrate, which leads to bonding, yet after certain evaluation, the quality of CBR departs which could be due to the quality of calcium silicate hydrate bond as it is dependable of making liberation. The Figs. 27.4 and 27.5 depict all of

Table 27.2 Strength characteristics of experimental compounds

Compound composition	UCS kg/cm^2	CBR %
Soil (S)	0.5	4.3
79% S + 18% WPOP + 3% GSA	2.42	9.45
76% S + 18%WPOP + 6% GSA	2.1	10.51
73% S + 18% WPOP + 9% GSA	1.95	10.21
70% S + 18% WPOP + 12% GSA	1.86	9.81
67% S + 18%WPOP + 15% GSA	1.74	8.95
64% S + 18%WPOP + 18% GSA	1.52	8

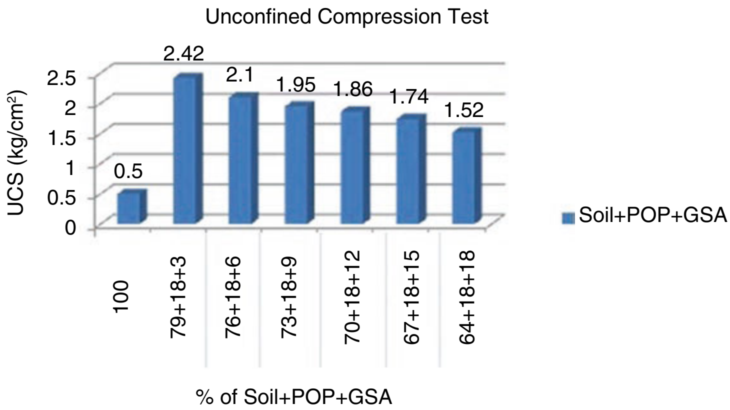

Fig. 27.4 Chart of UCS for different % of GSA, 18% of POP mixed with clayey soil

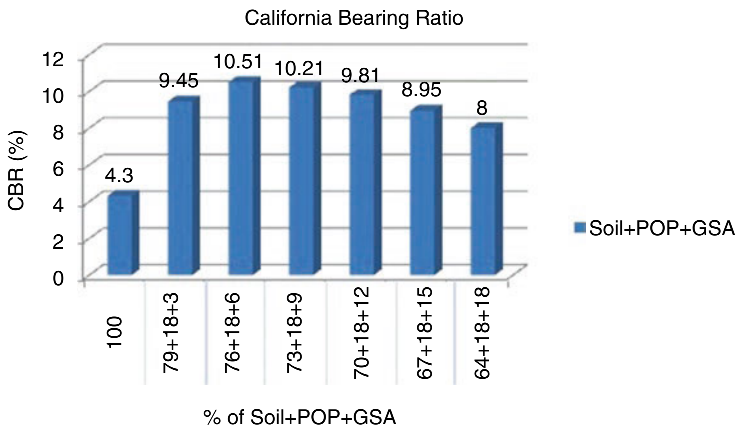

Fig. 27.5 Chart of CBR for different % of GSA, 18% of POP mixed with clayey soil

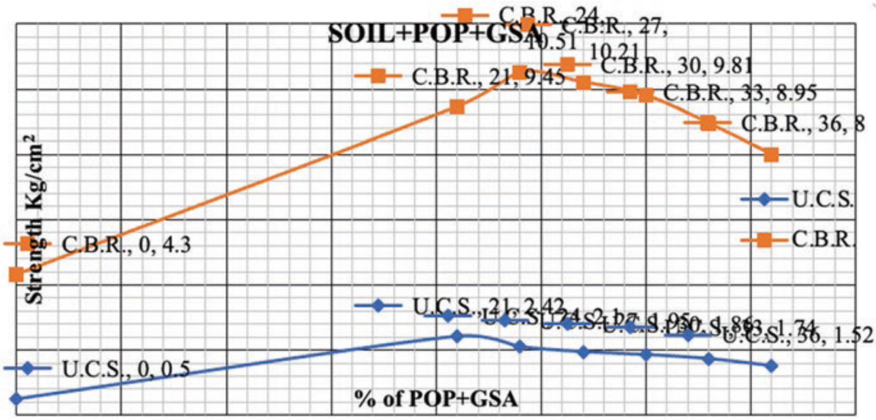

Fig. 27.6 Comparison between UCS & CBR for different % of GSA, 18% of POP mixed with clayey soil

the intricacies of UCS and CBR test findings after certain evaluation. Figure 27.6 presents the combined results obtained for UCS and CBR strengths for different % of GSA, when mixed with 18% of POP collectively.

27.4 Conclusion

The effects of adding WPOP and GSA in clayey soil sample are presented in this study. WPOP and GSA were introduced in the soil in various ratios. The following conclusions were drawn based on the outcomes of the experiments conducted:

- Strength results of 18% WPOP mixed with soil gave better result so 18% WPOP content was fixed with GSA and soil admixture.
- The OMC increased and MDD decreased when we mixed 18% WPOP with varying compositions of GSA in soil.
- 79% Soil + 18% of POP + 3% of GSA composition showed maximum value of UCS.
- 76% Soil + 18% of POP + 6% of GSA composition showed maximum value of CBR as compared to results of 100% soil content, so this composition can be used in construction projects.

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Chapter 28
Influence of Metakaolin and Steel Fiber on Strength of Concrete – A Critical Review

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Abstract Metakaolin (MK) is a pozzolanic amorphous powder substance derived by the calcination of pure kaolinite clay, while fiber reinforcement is the minor pieces of reinforcing material that possesses certain characteristics properties. To attain better efficiency of composites that can be used as a material of concrete the present research is an endeavor to investigate how composite fiber-reinforced concrete with metakaolin as an admixture is efficiently used. The current investigation explores the testing of the concrete cube characteristics when combining with steel fiber and metakaolin to improve the compressive strength and split tensile strength of concrete. This current examination reveals that the optimum value of compression strength and split tensile strength of concrete is achieved by using metakaolin in a proportion of around 15% to 20% along with 1.5% of steel by the weight of cement. Both the findings promote the use of metakaolin and the addition of additives such as hooked steel fibers to provide a concrete of greater strength than ordinary concrete.

Keywords Metakaolin (MK) · Steel fiber · Kaolinite clay

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28.1 Introduction

In various construction projects worldwide, concrete is being used as a building material (Mehta and Monteiro 2014). Even though nowadays when COVID-19 has an influence on construction sites, but absolutely no shutdowns in the construction industry have been reported as air filtrations are being introduced (Akhai et al. 2021). Having 7.2% MK, the compressive strength (CS) of elite high-performance concrete is 13% higher than the strength of ordinary concrete. The CS of concrete increments with time and certain specific percentages/levels of metakaoline incorporation increase the concrete's frangibility. Performance in concrete reinforced with steel fibers (SF) of an alkaline activated slag has been analyzed for the mechanical and permeability properties of steel-reinforced alkaline-activated slack concrete (Menhosh et al. 2018). Almost two billion tons of concrete are used all over the world in one year (Barbhuiya et al. 2015). The previous studies shows that the incorporation of stainless-steel fiber removed the buckling, gave extra transverse strengthening and that the overall efficiency was similar to that of standard concrete beams so a model for study can be prepared further by incorporation of other materials like fly ash (FA) also (Ghugal et al. 2017). The application of concrete is wide-ranging from the construction of bridges to buildings and many more. With such a wide application of this material, every single application of concrete requires some special properties (Jang et al. 2018). Nowadays, cement concrete is generally used. As the use of concrete is rising day by day, the use of cement is also growing rapidly (Liu et al. 2020). According to research given by Central Pollution Control Board, the cement sector in India is one of the most polluting industries in the world. A huge number of polluting substances like dust, carbon dioxide, nitrogen oxide, sulphur oxide pollutes the environment (Mehdipour et al. 2020). Not only outdoor pollution, the building indoor environment is also of prime importance as most of the people spend their time inside such built-in dwellings (Meng et al. 2016).

28.2 Materials

The goal of this work is to investigate the integration in the concrete of MK and SF. The analysis shows the effect on the CS and split tensile strength (STS) of concrete by the inclusion of MK and SF. Metakaolin is an amorphous pozzolanic powder that is obtained by unstained or superior kaolinite clay calcination, while fiber reinforcement has some characteristic features in a small part of the reinforcing content.

Research is underway to minimize the use of cement in concrete and use materials which aim towards green buildings (Akhai et al. 2021). We are trying to use a waste product that can be used to replace cement in making concrete and can give better results than cement concrete are harmful materials present in the atmosphere that are unconstrained from industries (Akhai et al. 2020).

Fig. 28.1 Metakaolin

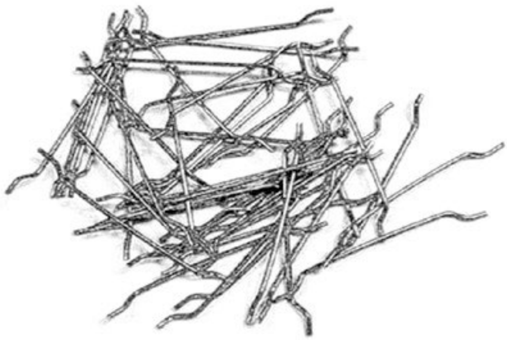

Fig. 28.2 Steel fiber

Research is going on in various materials such as fly ash, groundnut shell ash, sugarcane husk ash (Sharma and Akhai 2019a, b). "Use of steel fibers as crosswise reinforcement in slantwise reinforced coupling beams with normal concrete – and high-strength concrete" presented research utilizing steel fiber as an admixture material where the test results show that in the connector beam the shear strength increases with the increase in compressive strength while the energy degeneracy ability for the normal and elevated strength reinforced concrete coupling beam (Mohanta and Samantaray 2019) (Figs. 28.1 and 28.2).

28.3 Experimentation

Compressive Strength of different samples -The CS was obtained for cubes in accordance with the BS. 1881: part 116: 1989 (Muduli and Mukharjee 2019). Three cubes were tested for each mix with the dimensions of 100 × 100 × 100 in mm using a hydraulically powered 2000KN compression apparatus. The test-examinations were performed at the age of 7 days and 28 days. The CS test findings for specimens are seen in Table 28.1 and Fig. 28.3. The seven-day CS varied from 46.2 to 53.4 MPa and the strength for 28 days ranged from 61 to 70.4 MPa. Figures 28.3 and 28.4

Table 28.1 Compressive strength in (MPA)

% of Metakaolin (MK)	Compressive strength (MPA)		% Increase
	7 days	28 days	
0% MK	46.2	60.9	
5% MK	51.3	64.8	6.4
10% MK	53.4	70.4	15.6
15% MK	52.3	68.3	12.15
20% MK	50.2	67.2	10.34

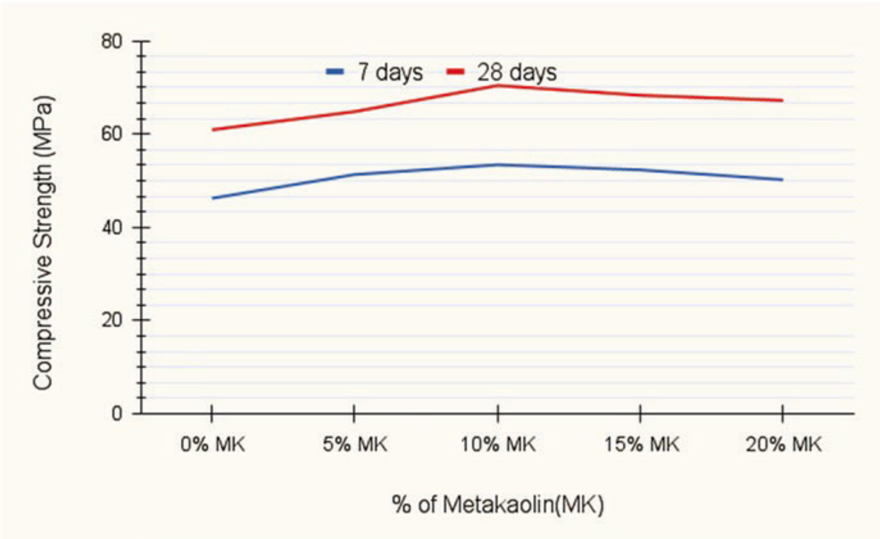

Fig. 28.3 Variation in compressive strength

shows the alliance between CS and MK ratios for 7 to 28 days. The maximum strength was observed for MK10 mixtures which reached 70.4 MPa over 28 days. This clearly explicates that the substitution ratio of 10% is optimum in regards to CS. The compressive strength for MK 5% increases in 6.4% after 28 days, when compared to control specimen. For 10%, 15% and 20% the compressive strength increases in 15.6%, 12.15% and 10.34% respectively. When compared to all other mixes MK 10% increases in higher strength. But when we compare MK 10% to MK 20%, decreases in strength is 5.26%. So, the percentage of MK 10% is the best proportion for adding cement.

Split Tensile Strength of different samples – At MK 10% mixture the results of Split Tensile Strength exhibited the highest strength. The mixture with MK 5% enhances the STS by 8.33% and for MK 10% increases in 16.7%. The mixture with MK 10% increases in higher strength, when related to all other mixes. But when we compare MK 20% mixture with MK 10%, the strength decreases are 11.9%. So, we may determine that MK 10% must be considered as the best fraction for the addition in cement. Figures 28.5 and 28.6 demonstrates alterations in STS of various concrete mix samples, and their magnitudes are shown in Table 28.2.

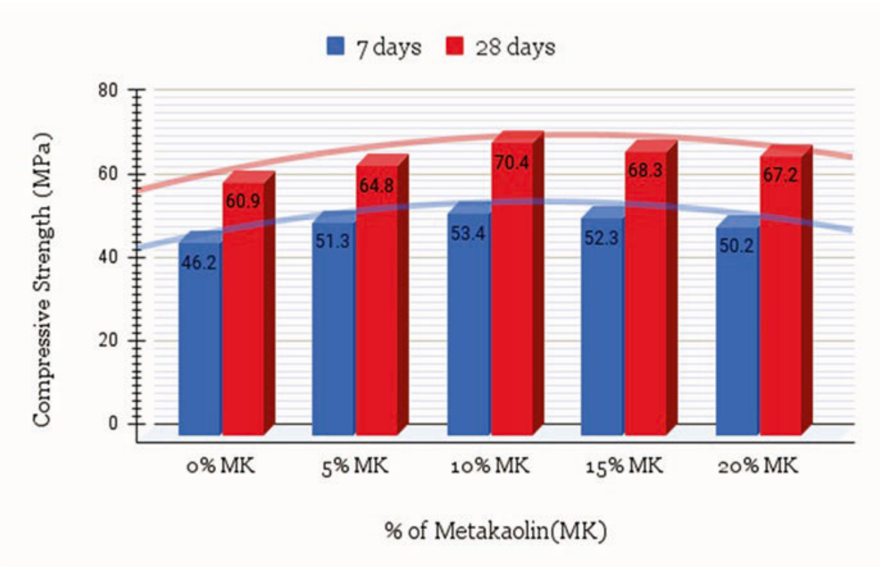

Fig. 28.4 Comparison of compressive strength

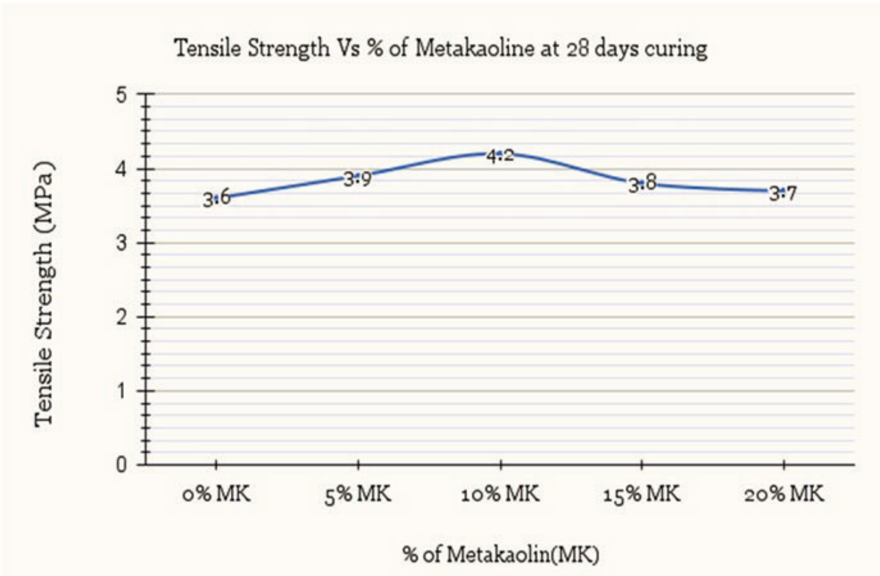

Fig. 28.5 Tensile strength of concrete mixed with Metakaolin at 28 days

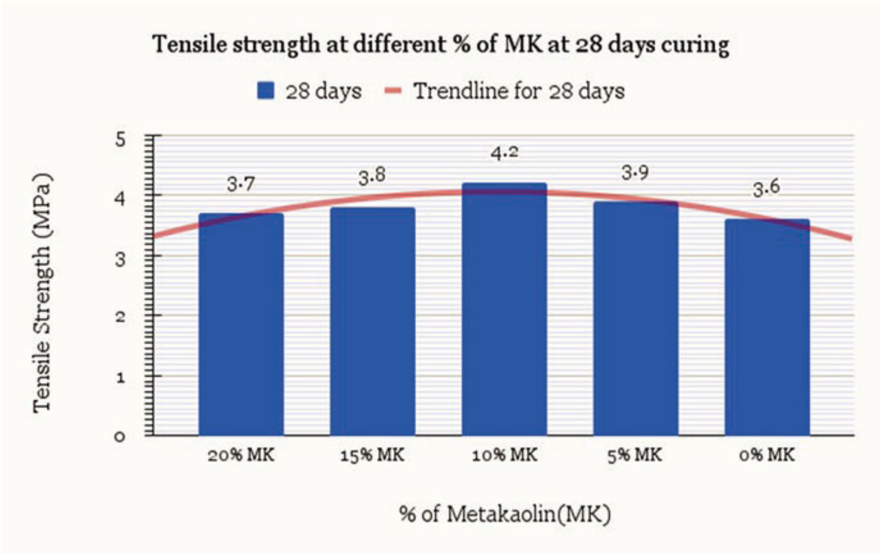

Fig. 28.6 Variation of split tensile strength for Metakaolin concrete

Table 28.2 Split tensile strength in (MPA)

% of Metakaolin (MK)	Tensile strength (MPA) 28 days	% Increase
0% MK	3.6	
5% MK	3.9	8.33
10% MK	4.2	16.7
15% MK	3.8	5.6
20% MK	3.7	2.8

28.4 Conclusion

- After analyzing previous studies being carried out by researchers it is observed that steel fiber can be used and this has shown a positive effect on the properties such as splitting tensile strength that can increase by 34.23%.
- It has been proved that metakaolin which was used as an admixture material in the concrete showcases better results in RAC which clues to a decrease in the water absorption and volume of voids.
- Metakaolin can be used in a proportion of around 15–20% and steel fiber can also be substituted by almost 1%. But it is highly dependent on the material used, volume, climatic condition, etc.
- Metakaolin can be used to enhance properties. Steel fibers can also be used for enhancing properties. It can be used in different aspect ratios in different percentages. One can replace cement with these materials and prepare a concrete that will be much better than the ordinary one.

28.5 Future scope

There are still some possibilities which can be explored through further research:

- The authors who conducted this review paper have analyzed extensively on the present topic at hand. Some ratios are yet to be analyzed by mixing the metakaolin and steel fiber. Maybe the results and conclusions show that better properties can be achieved.
- More and more studies can be done with different cement grade, for achieving better properties (strength, compressive strength, etc.).
- Different types of waste material can be used for different concrete so that the properties can be improved and analyzed as to which material leads to enhancing and improving the property. Some waste material such as sugarcane husk ash, etc can be very suitable. They are generated in large amounts by factories and are evidently of no much use and application. Adding to that is the fact that they can be potentially dangerous for both the environment and humans.
- 76% Soil + 18% of POP + 6% of GSA composition showed maximum value of CBR as compared to results of 100% soil content, so this composition can be used in construction projects.

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Chapter 29
Decadal Monitoring of Coastline Shifts and Recommendation of Non-structural Protection Measures Along the Coast of Rameshwaram, Tamil Nadu, India

C. Prakasam, R. Aravinth, S. Sanjeevi Prasad, and J. Murugesan

Abstract The shoreline is more dynamic and complex in nature. Shoreline change is induced by many factors like Littoral current, wave and riverine activities and even some times tides. Construction of coastal hard structures disrupts natural deposition and erosion taking place along the coast. The way they are affected depends upon the type of structure and longshore transport. The current research focuses on evaluating long term Shoreline change analysis and providing Non-structural stabilization measures of coastal areas along the coast of Rameshwaram Taluk, Tamilnadu. India. Shoreline was extracted between the year 1992 to 2015 using the LANDSAT series of satellite imageries (LANDSAT 5,7,8). Transects were created every 100 mts using the oldest shoreline data as a base reference through DSAS plugin. Net Shoreline deposition and erosion were calculated through the End Point Rate (EPR) and Weighted Linear Regression (WLR) model. Results reveal that erosional features dominant during 1995 to 2000 with the highest rate of erosion at −11.1 mts, 2005 to 2011 with the highest rate of erosion at −10.1 mts near the Ollakuda village. Weighted linear regression was estimated for the year (1992–2015), it extends between (−8.0 to 6.8 m/year). Most of the coast falls under (− 1.1 to 0.5 m/year). In order to mitigate the coastal erosion, use of Non-structural Protection measures can be of advantage in Rameshwaram Taluk. Revegetation of pant species with particular capacity of widened and deep root system would provide to be useful in arresting the soil erosion and stabilizing the beach and coastal environment. Species such as Palm trees, Coconut and Eucalyptus trees can be preferred in the

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current study as a Non-structural mitigation measure to promote a stable coastal environment.

Keywords End point rate · Shoreline change · Non-structural protection · DSAS · Weighted linear regression

29.1 Introduction

Coastal areas are ecologically more dynamic and changes rapidly due natural as well as anthropogenic causes (Marzouk et al. 2021; Matin and Hasan 2021; Seenipandi et al. 2021). More than 40% of the world's population lives nearby coastal areas due to their natural scenic beauty and also their role as an important economic aspect in terms of coastal produce such as varieties of fisheries and also tourism hotspot (Vrinda and Mohammed-Aslam 2021; Ferreira et al. 2021). Shoreline can be defined as a boundary where land and ocean interacts (Natesan et al. 2015; Saxena et al. 2013). It is unique and fragile ecosystem that continuously changes due to dynamic conditions. Over the course of millions of years' various geologic actions, sea level rise and extreme climatic events such as cyclones and torrential rain have changed the Earth's coastlines (Dwarakish & Nithyapriya, 2016; Hegde and Akshaya, 2015; Jayanth et al. 2016; Lakshmi et al. 2016). In recent years' rapid urbanization, population explosion and increased seal level due to global warming and climate change has put severe stress on the coastal areas there by changing the shoreline process of deposition and erosional activities (Kaliraj et al. 2017; Ramachandra et al., 2016; Sreenivasulu et al., 2016). The Shorelines are modified by both natural and anthropogenic causes (Raj et al. 2019; Sahani et al., 2019; Vivek et al. 2019). The natural factors include waves, currents, tides and construction harbours, jetties and artificial structures are the result of anthropogenic factors (Natesan et al. 2015). Due to these rapid change in environment protection of coastal areas and its related ecosystem is not only of utmost importance at regional level but also all over the world as they play a dominant role in the social as well as economic aspects of the human life (Abou & Ali, 2020; Kanga et al. 2020).

Shoreline changes is temporal process can be both long-term and short-term (Addo et.al. 2012). As in many other maritime countries, change in coastal ecosystem is also a serious concern in India. The study area Rameshwaram taluk is located along the southern part of the west coast of India experiences high wave energy and strong sediment transport (Rajawat et al. 2015). Nearly 23% of the coastal are is affected by various degrees of erosion leading to loss of beaches and threatening coastal communities (Sanil et al. 2006). Accurate delineation of shoreline changes is necessary for understanding the various coastal processes. Advancement in the area of remote sensing and various sensors helps in providing more information about shoreline changes in a short span of time. Remote sensing and Geospatial platform provides a greater advantage in shoreline delineation and assessment in rapid time at a cost effective manner. Many researchers have studied the shoreline dynamics in the past. Balasaraswathi et al. (2016) studied the change detection of shoreline along the Cuddalore district, India. Chandrasekar (2013) estimated coastal vulnerability and shoreline for the southern tip India. Mahapatra et al. (2013) studied shoreline changes along the coast of south Gujarat. Various other researchers (Mageswaran et al. 2015; Aravind et al. 2014; Prabakaran and Anbarasu 2010; Sundaresh et al. 2014; Murali and Shrivastava 2005; Paula et al. 2001) etc.

The research is focused on evaluating the evaluating the net shoreline changes along the coast of Rameshwaram taluk, Tamilnadu and to suggest suitable remedial measures in areas that are prone to severe erosion. The study focuses on estimating the End Point Rate, Weighted Linear Regression along the coast of Rameshwaram for the year 1992–2015.

29.1.1 Objectives of the Research

1. Demarcation of shoreline for various years through LANDSAT imageries (1992–2015).
2. Deriving erosion and accretion output for EPR and WLR.
3. Mapping of Highest deposition and erosion through EPR method for long term analysis.

29.2 Study Area

Rameshwaram is an island Taluk located at Tamilnadu district, India. The taluk is situated between SriLanka in the east, Gulf of Mannar in the south and Palk bay in the north. The study area extends from 9°08′55″ to 9°20′18″ N and the longitude of 79°18′40″ to 79°27′04″ E with an average elevation of 10 mts above mean sea level (MSL). According to 2011 census, Rameshwaram had a population of 44,856. The total geographical extent of the study area is 61.8 sq.km. Rameshwaram Taluk receives most of the rainfall during the Northeast monsoon season with an average monthly rainfall of 29.77 mm (Fig. 29.1). The Taluk experiences dry tropical climate with low humidity. Fisheries and tourism industry are the economic backbones of the study area. Most of the local people rely on deep sea fishing activities for day to day economic activities. The study area is located in a linear pattern and experiences drastic variation in shoreline changes along the south and northern part of the study area due to changes in littoral currents leading to variation in sediment deposition. Construction of small scale jetties and boat docks alters the shoreline sedimentary process leading to increased sediment deposit in the eastern part and erosion in the western part of the study area.

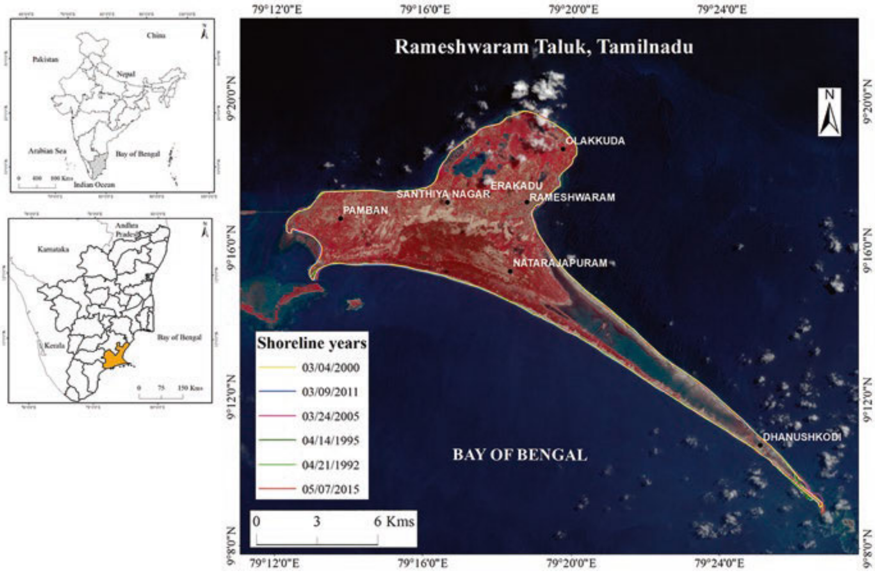

Fig. 29.1 Study area. (Rameshwaram Taluk)

29.3 Data Used & Methodology

To analyse the long – term change in shoreline multi – temporal data from [Landsat 5, 7, 8] for the years (1988, 1992, 1995, 2000, 2005, 2010 and 2015) were used at five-year interval. Band 5 in Landsat 5&7 and Band 6 in Landsat 8 uses short wave infra-red that clearly distinguish between land and water. This band was used to demarcate the shoreline in the satellite imageries. The digitized shorelines were then assigned respective dates [mm/dd/year]. The shorelines were then exported into personal database in ARCGIS environment. The entire coastline was divided into 100 meter transect to calculate shoreline change. Digital shoreline analysis system (DSAS) is an ARCGIS extension created by USGS was used to analyse shoreline change rate. End point rate, Net shoreline movement and weighted linear regression were calculated and the results were then exported as a table (Fig. 29.4). These tables were then used to create maps to identify erosional and depositional areas throughout the study area (Sowmya et al. 2019; Sreenivasulu et al. 2016; Vivek et al. 2019) (Table 29.1).

This methodology uses satellite imageries such USGS LANDSAT 5, LANDAST (7 ETM, ETM+) and LANDSAT 8. The total number of years taken for the study period 1998 to 2015 with 5 years' interval (Sowmya et al. 2019). The study is carried out for the summer season period. The High Tidal line is demarcated from the satellite imagery. Band 6 is used to demarcate boundary between Land and Shore. The digitized shoreline was then incorporated into GIS environment and the erosion and deposition rates were calculated using DSAS software an extension of GIS software.

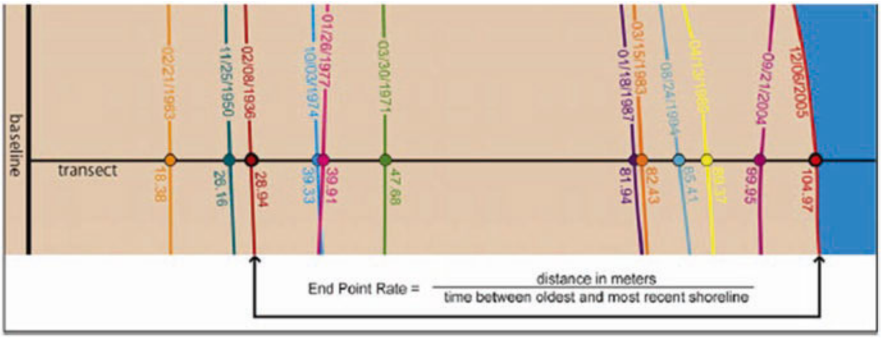

Fig. 29.2 End point rate. (Source: DSAS manual, USGS website)

Table 29.1 Data used for Shoreline change analysis

S.no	Data Type	Source	Date	Resolution
1	"LANDSAT 8 (OLI)"	"Earth Explorer (USGS)"	07/05/2017	30 m
2	"LANDSAT 7"	"Earth Explorer (USGS)"	09/03/2011	30 m
3	"LANDSAT 7"	"Earth Explorer (USGS)"	24/03/2005	30 m
4	"LANDSAT 7"	"Earth Explorer (USGS)"	09/02/2001	30 m
5	"LANDSAT 7"	"Earth Explorer (USGS)"	03/04/2000	30 m
6	"LANDSAT 5"	"Earth Explorer (USGS)"	14/04/1995	30 m
7	"LANDSAT 5"	"Earth Explorer (USGS)"	21/04/1992	30 m

End Point Rate

End point rate denotes the ratio of net change in shoreline. It is calculated by dividing the distance between the oldest and youngest shoreline (Fig. 29.2). End point rate has advantages of minimal computation and output. The disadvantages are that in the case of existence more number of datasets rest of the years are ignored. For ex when the data is collected between 1990 to 2020 the years present in between are ignored and only the oldest and youngest shoreline are take into account.

$$\textbf{EPR} = \left(\begin{array}{l} \textbf{Distance between the shorelines /} \\ \textbf{time between youngest and oldest shorelines} \end{array} \right)$$

Weighted Linear Regression

The disadvantage of the EPR method is overcome by the Weighted Linear Regression model (WLR). In these datasets, higher amount accuracy have been given more importance rather than considering the timeline of the datasets (Fig. 29.3). That way the uncertainty in the datasets have been kept at minimum level to reduce the error (Fig. 29.4).

$$w = 1/(e2)$$

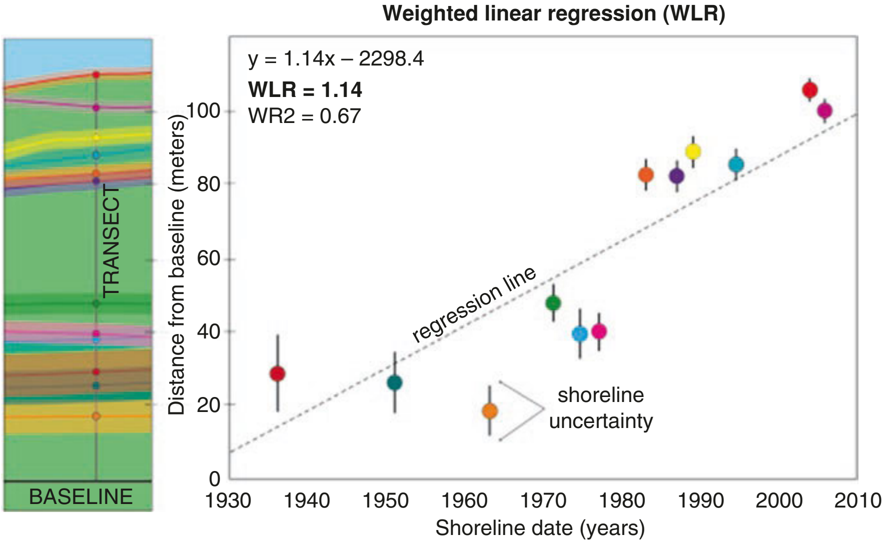

Fig. 29.3 End point rate. (Source: DSAS manual, USGS website)

W = Weight of the shoreline
e = Shoreline uncertainty value

29.4 Results and Discussion

The Long-term Shoreline change was estimated for Rameshwaram coast in Ramanathapuram district through visual image interpretation and shoreline delineation for the year (1988–2015) of summer season (Fig. 29.5). The shorelines were then processed through DSAS software an extension of ARCGIS. Weighted linear regression and End point rate were calculated and saved in a table. These table were then used to interpret erosion and accretion prone zones (Table 29.2).

Throughout the study period the erosion and depositional features were observed all along the Rameshwaram. During the year 1992 to 2015 (Fig. 29.6) highest amount of erosion and accretion were observed near northern side of Pamban village (−10.1 m) and eastern side of Santhiya nagar (11.1 m). For, the year 1995–2000 (Fig. 29.7) highest amount of erosion and accretion were observed near south of Ollakuda village (−11.3 m) and north eastern side of Santhiya nagar (11.2 m). For, the year 2000–2005 (Fig. 29.8) highest amount of erosion and accretion were observed near southern tip of Dhanushkodi (10.7 m) and northern side of Ollakuda village (−10.1 m). For, the year 2005–2011 (Fig. 29.9) highest amount of erosion and accretion were observed near Pamban bridge (−12.6 m) and (10.06 m). For, the year 2011–2015 (Fig. 29.10) highest amount of erosion and accretion were observed near north western side of Ollakuda village (−10.7 m) and southern side of Pamban

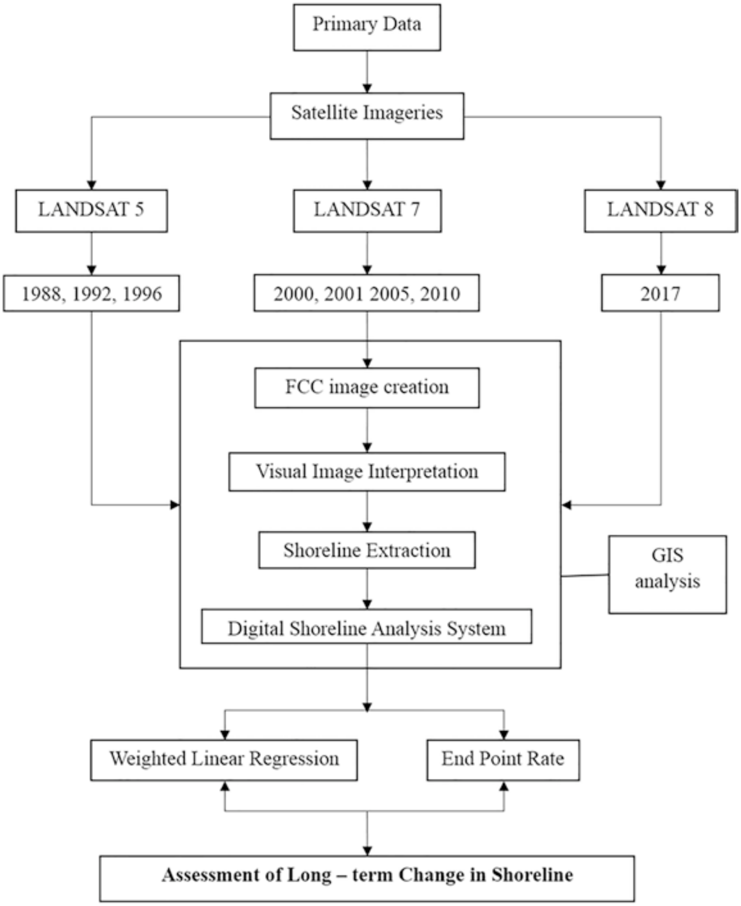

Fig. 29.4 Research methodology

bridge (9.45 m). Erosional features dominant during (1995–2000, 2005–2011). Weighted linear regression was estimated for the year (1992–2015), it extends between (−8.0 to 6.8 m/year) (Fig. 29.11). Most of the coast falls under (− 1.1 to 0.5 m/year).

29.5 Conclusion

The research conducted provides a detailed understanding of the costal shoreline changes through DSAS, High resolution satellite imageries and Geospatial techniques. Both deposition and erosion features were present equally along the coast of Rameshwaram. Depositional were prominent along the upper part of the southern

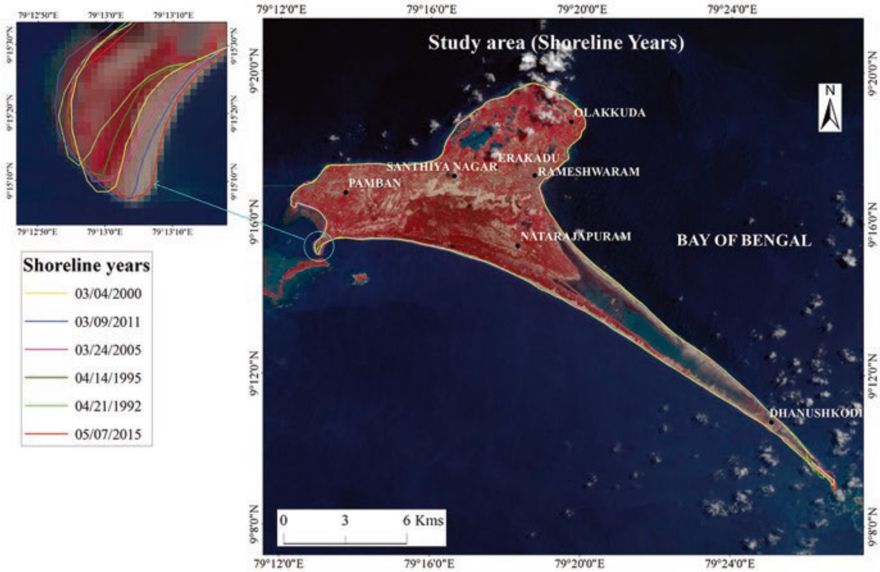

Fig. 29.5 Shoreline years (1992–2015)

Table 29.2 Highest erosion and deposition

S.no	Year	Deposition (mts)	Erosion (mts)
1	1992–1995	11.1	−10.1
2	1995–2000	11.2	−11.3
3	2000–2005	10.7	−10.1
4	2005–2011	10.06	−12.6
5	2011–2015	9.45	−10.7

Source: Author calculation

coastline and erosional features were prominent along the downside of the southern coastline. Both highest deposition and erosion along Dhanushkodi upto 11.2 m for the year 1995 to 2000 and − 12.6 m for the year 2005 to 2011. In order to mitigate the coastal erosion and protection of coastal areas is of utmost important. Non-structural Protection measures can be of advantage in Rameshwaram Taluk. These Non-structural protections suggested are of two main types namely artificial nourishment of beaches and vegetation plantation. In areas with greater degree of erosion artificial beaches can be constructed by dumping sands from over sediment deposited areas. Revegetation of plant species with particular capacity of widened and deep root system would provide to be useful in arresting the soil erosion and stabilizing the beach and coastal environment. Species such as Palm trees, Coconut and Eucalyptus trees can be preferred in the current study as a Non-structural mitigation measure to promote a stable coastal environment.

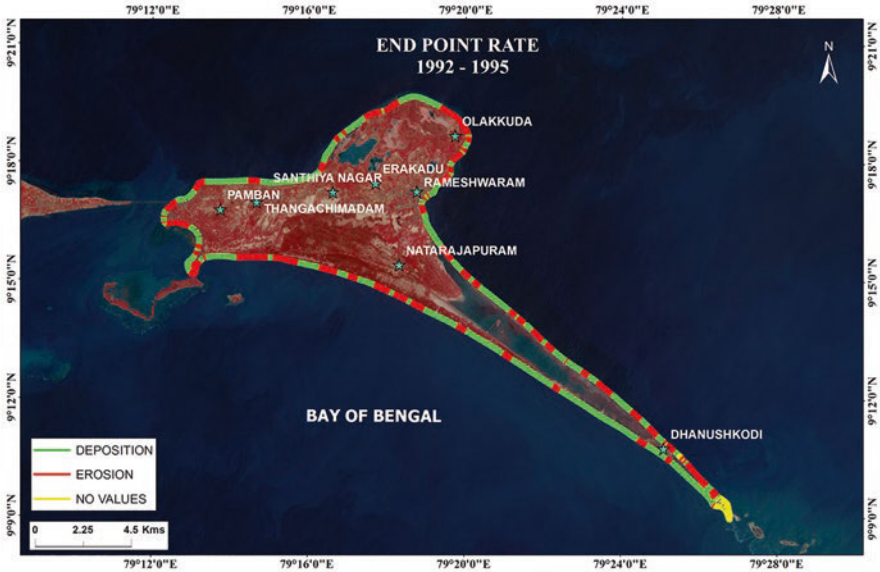

Fig. 29.6 End point rate (1992–1995)

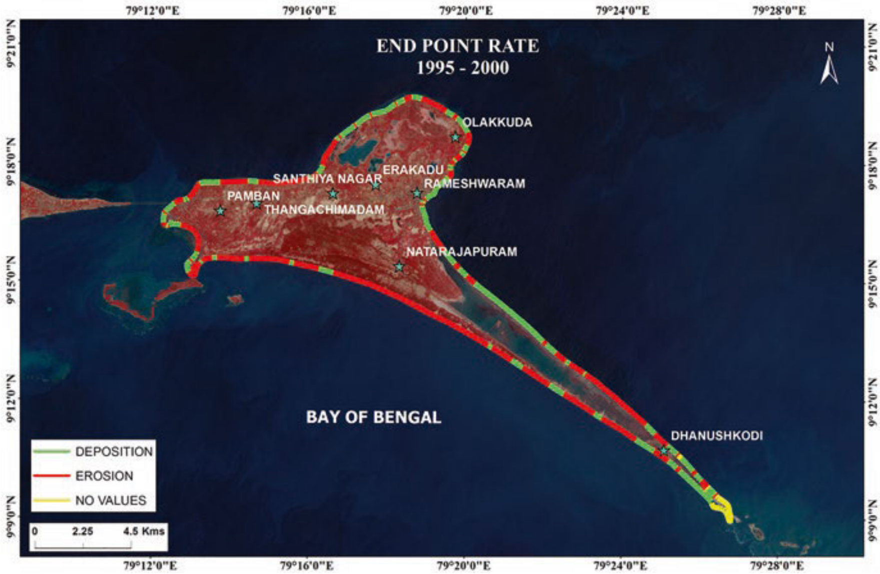

Fig. 29.7 End point rate (1995–2000)

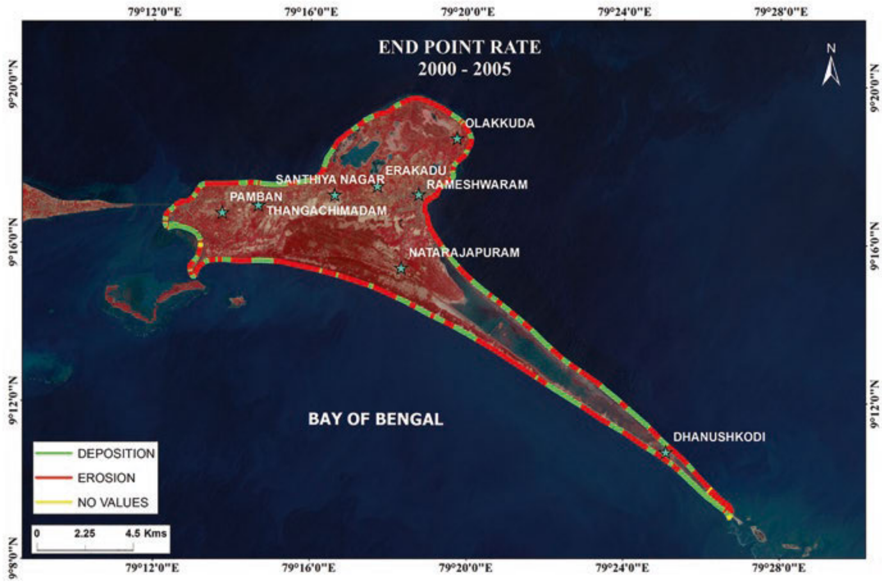

Fig. 29.8 End point rate (2000–2005)

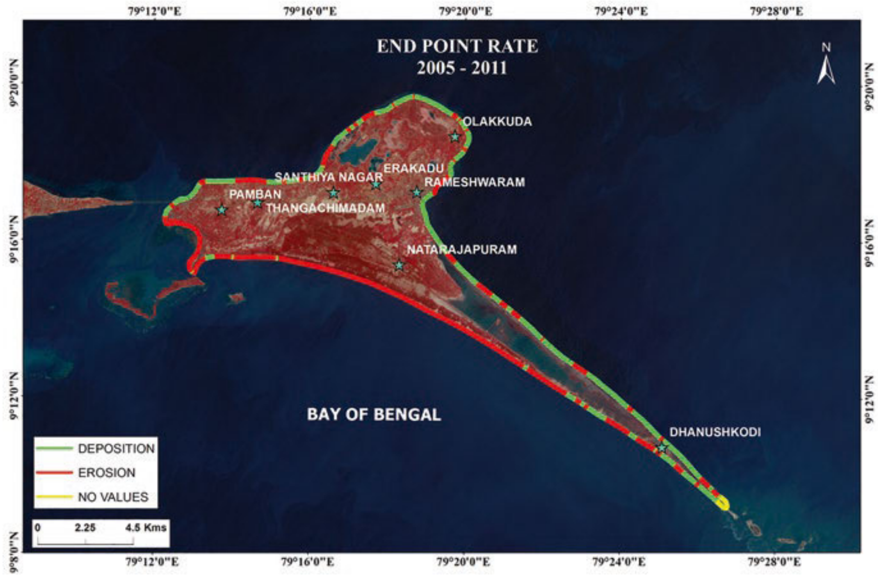

Fig. 29.9 End point rate (2005–2011)

Fig. 29.10 End point rate (2011–2015)

Fig. 29.11 Weighted linear regression (1992–1995)

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Chapter 30
Development of Sustainable Concrete Using Slag and Calcined Clay

Ankur Gupta and Arun Kumar Parashar

Abstract Geopolymer are a unique type of polymer formed when aluminosilicates are combined with sodium/potassium silicate and their hydroxide solutions. Ground granulated blast furnace slag (GGBS) is an excellent alumino-silicate material because of rich silicon dioxide and aluminum oxide content, both of which are required for the reaction of geo-polymerization to occur. In this paper a sustainable concrete has been developed using GGBS and calcined clay (CC) and the same has been investigated for its strength and durability characteristics. Three ratios of GGBS and calcined clay (i.e. 80:20, 50:50, and 20:80) were used in this investigation. As an alkaline activator, a 12 M concentration of NaOH with Na_2SiO_3 has been used. The geopolymer specimens were cured in the open air for practical reasons. Split tensile, three-point loading and compression tests were conducted to investigate the mechanical characteristics and ultrasonic pulse velocity testing was done for the estimation of durability characteristics of the developed concrete. Results indicate that as the content of GGBS in the developed concrete is increased its mechanical properties as well as the durability properties got improved.

Keywords GGBS · Calcined clay · Alkaline activator · Strength · UPV

30.1 Introduction

Portland cement serves as the binding agent in normal concrete (Sharma and Sharma 2021). Cement manufacture is a high-energy and resource-intensive operation. About 1.5 tons of raw materials are estimated to produce 1 ton of cement, while the manufacture of 1 ton of this binder produces almost equivalent extent of CO_2 in the environment. The generation of this greenhouse gas is an important concern in terms of sustainability (Naqi and Jang 2019). Numerous researches have been performed with the goal of decreasing cement usage by substituting waste materials

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(Gupta et al. 2020; Kumar Tiwari et al. 2020; Parashar and Gupta 2021; Sharma et al. 2021). Many studies have been conducted with the aim of decreasing porosity and permeability in concrete [6–8]. In this regard, Davidovits' Geopolymer technology provides an approach to replace cement in concrete (Davidovits 1994). Geopolymer are inorganic alumino-silicate polymers made by alkali activation of alumina and silica-rich minerals (Singh et al. 2016). The use of geopolymer materials improve the environment and the economy by allowing waste materials from many areas to be recycled and reused (Parthiban and Saravana Raja Mohan 2017). Geopolymer concrete is strengthened through polymerization, whereas nominal concrete is strengthened by the hydration of cement (Ramujee and Potharaju 2017). Many investigations have been done in the past to study the characteristics of geopolymer composites (Naskar and Chakraborty 2016; Albitar et al. 2017; Okoye et al. 2017). Geopolymer composites composed of fly ash pozzolan are proving to be a possible substitute to Portland cement-based concrete as they also exhibits similar strength and durability characteristics as that of Portland cement concrete (Fernandez-Jimenez et al. 2007; Pasupathy et al. 2017). GGBS, fly ash, calcined clay and other raw materials have been utilized in geo-polymerization reactions over the years, and previous research have demonstrated that geopolymer concrete have the ability to be used as a substitution to cement concrete (Ding et al. 2017; El-Hassan and Ismail 2018; Huseien et al. 2018; Cordoba et al. 2020; Zannerni et al. 2020). Geopolymer concrete also shows resistance against temperature and acid attack. Raw materials have a significant impact on the chemical processes that lead to the synthesis of geopolymer concrete. Because of the various types of raw materials used, variations in microstructure properties as well as variations in chemical and physical characteristics have been noticed, (Nazari et al. 2011; He et al. 2013; Prachasaree et al. 2014; Mo et al. 2016).

In the current study sustainable concrete has been developed using slag and Calcined clay in proportion of 80:20, 50:50 and 20:80. Alkaline activator consists of a mix of 12 M concentration NaOH and Na_2SiO_3 solutions. The developed composite has been investigated for its compressive, tensile and flexural strength. Additionally, UPV test has also been done to assess the durability characteristics.

30.2 Materials and Methods

30.2.1 Materials

GGBS and Calcined clay were originated from Krishna Techno Minerals, Ajmer, Rajasthan as shown in Fig. 30.1a, b. The alkaline activator was made using NaOH and sodium silicate solution. Figure 30.2a, b represents the NaOH flakes, used for making NaOH solution, and Na_2SiO_3 solution respectively. Silicate solution was made with a SiO_2 (silicon dioxide) to sodium oxide (Na_2O) mass ratio of 2 (Na_2O = 14.67%, SiO_2 = 29.33%) and 56% water. The 98–99% pure sodium

Fig. 30.1 (**a**) Calcined clay (**b**) GGBS

Fig. 30.2 (**a**) Flakes of NaOH (**b**) Solution of alkaline activator

hydroxide pellets were combined with water to form a mixture with a concentration of 12 M. IS 383–2016 was followed for selecting coarse and fine aggregates. This research was conducted with zone-III river sand. Fine aggregates had a specific gravity (SG) of 2.68 and a moisture level of around 1.40 percent. The present research employed coarse aggregate with a SG of 2.61 and of 20 mm downgrade size. The chemical composition of the alumino-silicates used in this research is shown in Table 30.1.

30.2.2 Methods

The alkaline activator solution was made by diluting Na_2SiO_3 with 12 M NaOH solution at silicate to hydroxide ratio of 2.5. The mixed solution was then left for 24 h before using it as a concrete activator. Cube moulds of size 15 cm × 15 cm × 15 cm, cylinder moulds of size (dia. x height) 15 cm × 30 cm and beam moulds of size 15 cm × 15 cm × 70 cm were used to cast the specimens required for compression

Table 30.1 Quantities of ingredients in the mixes per m^3

S.N	Oxide compound	GGBS in %	CC in %
1	Silicon dioxide	30.14	47.16
2	Calcium oxide	32.66	0.73
3	Magnesium oxide	7.78	0.0
4	Aluminum oxide	14.13	40.01
5	Ferric oxide	2.82	1.13
6	Sodium oxide	–	0.11
7	Titanium oxide	–	2.55

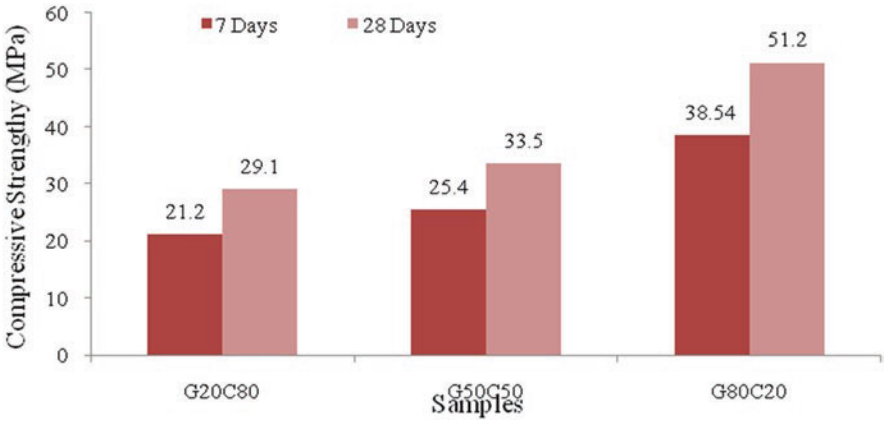

Fig. 30.3 Compression strength test results

test, tension test and flexure test respectively. All these testing have been performed at an age of 1 week and 4 weeks. Ultrasonic pulse velocity testing has been done on all the samples, after 4 weeks of curing, in order to acquire a sense of the structural integrity of the developed concrete.

30.3 Results and Discussion

30.3.1 Compression Strength

The compression strength testing was conducted for the determination of potential strength of developed geopolymer concrete samples. The load is applied at 90 degree to any side of samples with dimensions of 150 mm × 150 mm × 150 mm. Figure 30.3 shows the results of the compressive test on the specimens of various combinations of GGBS and CC.

From Fig. 30.3, it is clear that the geopolymer specimen G80C20 exhibited the greatest improvement in compressive strength. The strength, in MPa, of G20C80, G50C50 and G80C20 samples at 7 and 28 days were obtained as 21.2, 25.4, 38.54 and 29.1, 33.5, 51.2 respectively. In general, it can be seen that increase in the GGBS content is also increasing the strength in compression. The strength of the samples having 80% GGBS got increased by almost 76% at 28 days as compared to the samples containing 20% GGBS. This increase in strength could be because of the filling of voids by the GGBS and the formation of the CSH gel along with the geopolymeric gel. As a result of all this slag-based geopolymer concrete also possess greater early age strength (El-Hassan and Ismail 2018).

30.3.2 Splitting Tensile Strength

This test was performed to estimate the tensile rupture susceptibility of geopolymer concrete. The radial load was applied to cylinder samples of size 150 mm in diameter and 300 mm height. Figure 30.4 represents the results of the split tensile test.

Figure 30.4 shows that when the amount of GGBS in the mix was increased, the splitting tensile strength values also got enhanced in the same way as that for the compression strength. The split tensile strength, in MPa, of G20C80, G50C50 and G80C20 samples at 7 and 28 days were observed as 2.21, 2.46, 3.28 and 2.65, 2.92, 4.08 respectively. The maximum increase in strength is observed for samples containing 80% GGBS. This enhancement in the split tensile strength is also because of the same reason as that of the compressive strength. This filling of voids ultimately leads to the formation of a high density interfacial region between the geopolymer paste and aggregates (Singh et al. 2015).

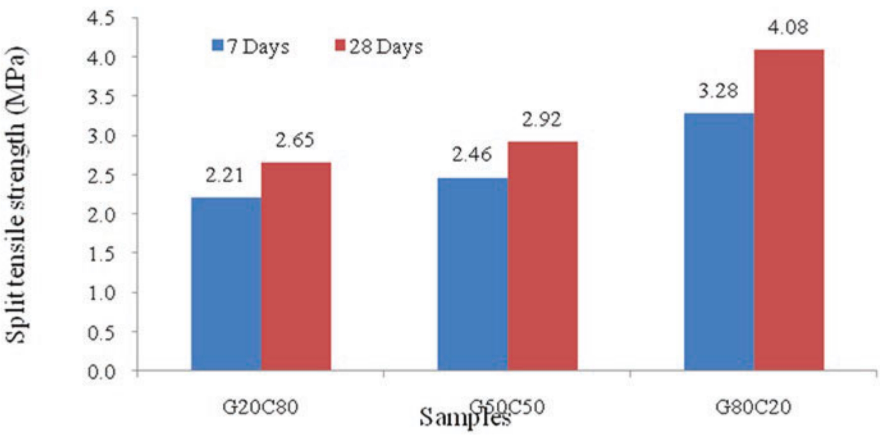

Fig. 30.4 Split tensile strength test results

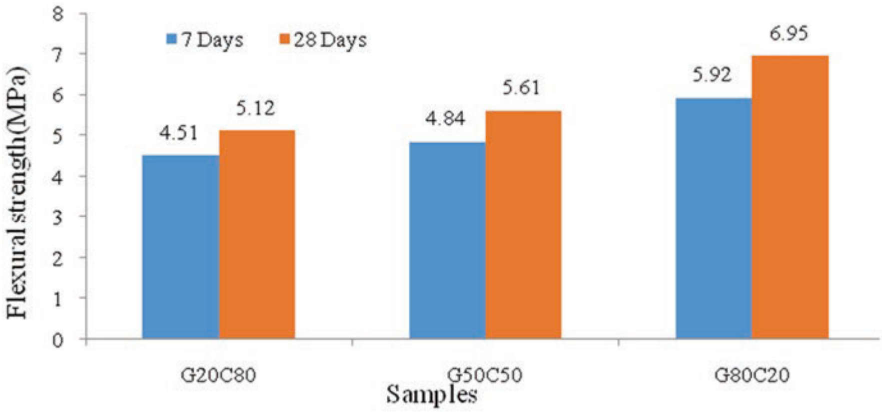

Fig. 30.5 Flexural strength test results

30.3.3 Flexural Strength

The flexural strength of developed samples was determined after 1 and 4 weeks of curing using a universal testing machine. The three-point load method, in accordance with IS: 516-1959 has been used for the test. The testing results of strength in flexure are represented in Fig. 30.5.

Figure 30.5 indicates that when the proportion of calcined was decreased, the value of flexural strength got improved. The strength in MPa, of G20C80, G50C50 and G80C20 samples at 7 and 28 days were observed as 4.51, 4.84, 5.92 and 5.12, 5.61, 6.95 respectively. Since there is a direct relation among the compression strength, tension strength and the flexure strength, the strength here also increased in the same way as that for compression and tension. The reason again is the increase in the density of the mix as a result of the filling of the voids by the fine particles of the GGBS.

30.3.4 Durability Test (UPV)

This test was conducted to analyze the uniformity and integrity of the developed geopolymer concrete at various proportions. The testing was done after 28-day of on cubical specimens of size 150 mm × 150 mm × 150 mm. Figure 30.6 shows the results of the ultrasonic pulse velocity test.

From Fig. 30.6, it is clear that the ultrasonic pulse velocity values have increased with the increasing GGBS content. The pulse velocities in km/s for G20C80, G50C50 and G80C20 samples were obtained as 4.91, 4.95 and 4.99 respectively. The pulse velocities travel faster in the denser medium as compared to the light medium. At 80% GGBS content the density of the developed geopolymer concrete

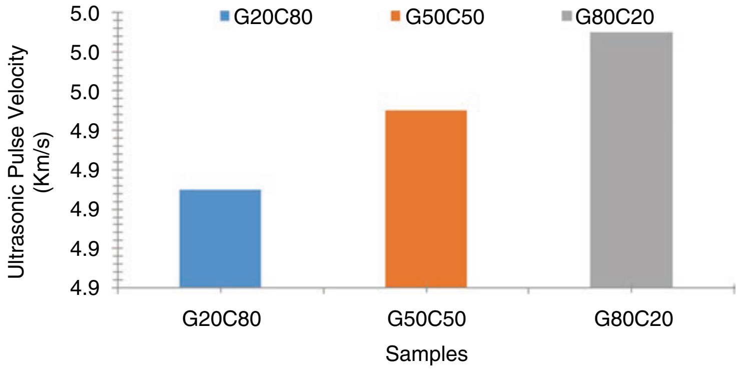

Fig. 30.6 Ultrasonic pulse velocity test results

was maximum due to the filling of the voids therefore the velocity of the ultrasonic pulse was maximum for G80C20 samples. It can be concluded that G80C20 samples possess highest integrity and homogeneity among all the samples (Celik et al. 2018).

30.4 Conclusions

The impact of variation of GGBS and calcined clay in geopolymer concrete was the focus of this research. There was a considerable enhancement in splitting tensile, flexure and compression strength when the amount of GGBS in the geopolymer mix was increased. This is due to the development of sufficient reaction products when the slag concentration is higher. Following are the conclusions that could be drawn from the present investigations:

- Presence of GGBS tends to increase the mechanical strength of the geopolymer concrete with time.
- Maximum compression strength of 51.2 MPa was obtained for G80C20 (80% GGBS and 20% Calcined clay) sample which shows an increase of almost 76% as compared to G20C80 samples.
- The tensile strength and flexural strength also showed the same trend as that of the compressive strength. Tensile strength increased by around 53.7% and flexural strength increased by 35.7% respectively after 4 weeks for G80C20 samples as compared to G20C80 samples.
- UPV values were also observed highest for G80C20 samples which are due to the increased density of the mix and filling of the voids.

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Chapter 31
Assessment of the Impact of Bacillus Cereus Bacteria on Strength and Water Absorption Capacity of Sustainable Concrete

Arun Kumar Parashar and Ankur Gupta

Abstract This paper shows the impact of incorporating bacteria (bacillus cereus) on strength in compression and water absorbing capacity of developed sustainable concrete. The study was conducted in two parts. In the first part cement is substituted with fly ash at the rate of 5%, 10%, 15% and 20% and in the second part bacteria cereus was added to the concrete along with the fly ash replacement by using a solution of bacteria, at a rate of 10%, in place of the mixing water. The compressive strength of the conventional cement concrete got enhanced on substituting cement with fly ash. The maximum improvement was observed at 10% fly ash replacement. The bacteria incorporated samples showed further improvement in the strength as well as water absorbing capacity after 1, 2 and 4 weeks. Adding bacteria increased the 7 days strength by around 19.24%. The water absorption capacity of the fly ash replaced samples reduced considerably due to bacteria cereus and a maximum reduction of around 20.35% in the water absorption value was observed at 20% fly ash replacement. Therefore, bacillus cereus bacteria could be efficiently used to enhance the strength and impermeability characteristics of conventional cement concrete.

Keywords Compressive strength · Water absorption · Bacillus cereus bacteria · Fly ash

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31.1 Introduction

Concrete is the world's most consumed product in the building sector used to create human-made structures (Tziviloglou et al. 2016). Concrete is generally used for the construction of bridges, road pavement and buildings etc. (Shukla et al. 2020a). Concrete is highly compressive and has poor ductility and tensile strength, because of which concrete is susceptible to develop cracks (Chahal and Siddique 2013; Nagarajan et al. 2017; Nain et al. 2019; Siddique and Chahal 2011). The development of cracks provide a passage for the ingress of harmful material inside the concrete and thereby decreases the strength of concrete (Kishore and Gupta 2019; Sharma et al. n.d.; Shukla et al. 2020b; Tariq and Bhargava 2020). To overcome this problem, many researchers have studied the application of pozzolanic materials and fibers in the concrete (Gupta et al. 2020a; Kumar Tiwari et al. 2020; Parashar and Gupta 2020; Siddique et al. 2016). Alumino-silicate pozzolanic material was used to replace cement in concrete for studying the characteristics of concrete at fresh and hardened stage. Test results show enhancement in the hardened stage properties of the alumino-silicate based concrete (Zhang and Malhotra 1995). Bagasse ash was utilized as a partial substitution of cement in concrete and resulted in enhanced strength in compression when compared to standard concrete (Chusilp et al. 2009). Stone dust and waste ceramic aggregates when used as a partial replacement of sand and aggregate respectively resulted in improved mechanical properties (Gupta et al. 2020b). Many researchers have studied the application of bacteria in the concrete (Hosseini Balam et al. 2017; Nagar et al. 2020; Parashar et al. 2020; Pei et al. 2013). R. Sribhavana et al. used fly as a replacement of cement along with bacillus subtilis bacterial solution and found that the properties of concrete at 10% FA content enhanced relative to the standard cement concrete (Sri Bhavana et al. 2017). Ganesh Babu et al. used calcium lactate as a partial substitute material with cement in the proportion of 5% and 10% and found that strength was reduced with the use of calcium lactate but the use of bacterial concentration in calcium lactate concrete increased the mechanical properties of composite as compared to controlled concrete. Bacteria filled the voids of concrete and hence improved the density and strength of concrete (Babu and Siddiraju 2016). Bai et al. used bacillus subtilis bacterial solution and fly ash as a partial substitute material with cement in the concrete and found that mechanical characteristics of fly ash concrete was improved up to 10% use of fly ash and at higher replacement proportions properties tend to decrease. Bacillus subtilis bacteria used in optimum fly ash concrete with different concentration and it has been observed that 105 cells/ml gave best results among all the used concentration (Bai and Varghese 2016). Nidhi Nian et al. used bacillus subtilis and bacillus megaterium with 108cells/ml bacterial concentration in the concrete and observed that bacterial concrete gave better result as compared concrete (Nain et al. 2019). N. Balam et al. used light weight aggregate and bacillus sporosarcina pasteurii in the concrete mix and found that improved the strength in compression and reduction the water absorption and chloride penetration (Hosseini Balam et al. 2017).

In this study, bacillus cereus bacterial solution was used as a partial substitute for the mixing water in concrete at a bacteria concentration of 10^8cells/ml. In various proportions, fly ash was used to substitute cement (e.g. 5%, 10%, 15% and 20%), and the strength and impermeability properties of the prepared concrete were investigated.

31.2 Experimental Work

Cube (150 mm × 150 mm × 150 mm) specimens were cast for testing the compression strength in accordance with IS 516-1959 (BUREAU OF INDIAN STANDARDS 2004). All the specimens were filled in three parts and then vibrated with a table vibrator until a water film appeared along the edges. The samples were then taken out of the moulds and were placed in the tank containing water until the time of test.

31.2.1 Materials

In this work, primary binding material used is OPC of grade 43 as per the requirements laid down in IS: 8112-2013 (BIS 8112 2013). The specific gravity (SG) and soundness were found as 3.14 and 2.2 mm respectively. The setting time of cement at initial and final stage were recorded as 56 and 471 min respectively. Class F ash was procured from Bathinda thermal power plant. Fineness and density of fly ash were 3.48cm^2/g and 2.20 g/cm^3. Fine and coarse aggregate were used in accordance with IS 383-2016 (IS383 2016). Zone 3 river sand were used in this experimental work. The SG and moisture content of the fine aggregates used were determined as 2.64 and 1.38% respectively. The SG of coarse aggregates used was found to be 2.65. Coarse aggregates of 20 mm downgrade size were used. Bacillus cereus bacteria were used at a concentration of 10^8cells/ml.

31.2.2 Bacteria Cultivation

Powder form of the frozen bacillus cereus bacteria were brought from institute of microbial technology (MTCC) Chandigarh. The cereus bacteria were mixed in the concrete by converting it into liquid form. The nutrient broth media culturing was carried out in a cone shaped bottle. NaCl, peptone and beef extract were used in calculated quantities of 500 mg, 500 mg and 300mgrespectively. The pH range of 7–7.4 was maintained for the cultured nutrient broth media. The bacillus cereus bacteria grow by feeding the cultured broth media solution. Strips of the powdered form of bacteria were made on agar plate using inoculation on Petri dishes to

Fig. 31.1 Growth of bacillus cereus bacteria on agar plate

develop a solution of the cereus bacteria as shown in Fig. 31.1. After 1 day the plates were nurtured at a temperature of around 37 °C. The adulteration due to environmental agencies and the decay of the bacillus cereus bacteria was prevented. Proper sanitization of the equipment used was also done carefully to prevent any loss. For developing the bacteria groups, the protected liquid solution was shifted to the orbital shaker from the conical flask and the shaker was allowed to rotate at 150 rotations per minute for 24 h.

31.2.3 Preparation of Specimens

M30 grade of concrete mix was cast by using conventional cement of 43 grade, zone-3 natural sand, bacillus cereus bacteria, having concentration of 10^8 cells/ml and locally available aggregate. The casting of specimens has been done in accordance with IS-1199-1959 (Standards 1959). The concrete has been cast in three layers by tamping each layer twenty-five times. Vibrating table was used to vibrate the concrete moulds in order to remove air voids from concrete mix. All the specimen moulds were retained unharmed for 24 h after compaction and then the specimens were demolded for curing. The water curing of the specimen was done till the testing day. The water absorbing capacity and the compression strength of the specimens were determined after 1, 2 and 4 weeks. All the necessary precautions were observed while preparing mix and casting samples.

31.2.4 Testing

A total of 45 cube moulds for compressive strength and 54 cube moulds for water absorption were cast. The testing was done in a 2000KN digitally operated compression testing machine in accordance with IS 516: 1959 (BUREAU OF INDIAN STANDARDS 2004). The loading was done at a rate of 5.15kN/sec. The values of the load at which the samples got distressed were noted. The water absorbing capacity of the samples was determined in accordance with (Bureau of Indian Standards 1974) after 2 and 4 weeks of curing. For measuring the water absorption, the specimens were removed from the curing tank and were fed in the automatic oven for 1 day at a temperature of 105 degrees Celsius for the purpose of drying. The weights of the oven dried samples (W1) were noted. After that the samples were again put in the curing tank for a period of 1 day so as to allow them to absorb water. The specimens were again taken out of the curing tank after 24 h of water absorption. The weights of these samples were noted (W_2). The weighing of the samples wascarried out using a 30 kg digitally operated weighing machine. The water absorbing values of the specimens were determined with the help of Eq. 31.1 as mentioned below.

$$\text{Water Absorption} = \frac{W2 - W1}{W1} x100 \tag{31.1}$$

31.3 Results and Discussion

The complete study has been done in two parts. In the first part, the replacement of fly ash with cement from 0 to 20% and bacterial solution was used in optimum fly ash concrete at second part. Mechanical and durability characteristics were determined in terms of the compression strength and water absorption capacity.

31.3.1 Compressive Strength

The prepared cubical samples were assessed after 1, 2 and 4 weeks of curing. The compression strength of the conventional concrete sample, fly ash replaced samples (5%, 10%, 15% and 20% replacements) and bacteria incorporated samples was determined using digital CTM. The test results of fly ash alone used in concrete and fly ash used with bacterial solution have been shown in Fig. 31.2.

From Fig. 31.2, it is clear that the compression strength of fly ash concrete at 5%, 10%, 15% and 20% replacements have enhanced relative to the conventional concrete by 4.56%, 9.36%, 7.59% and 4.63% after 7 days of curing, 4.23%, 11.18%, 6.72% and 5.18% after 14 days of curing, 4.64%, 9.59%, 6.78% and 5.10% after

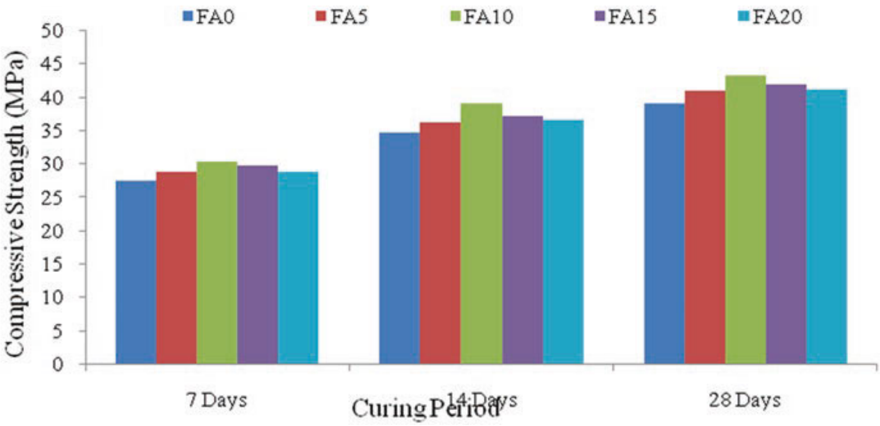

Fig. 31.2 Compression strength test results of fly ash concrete

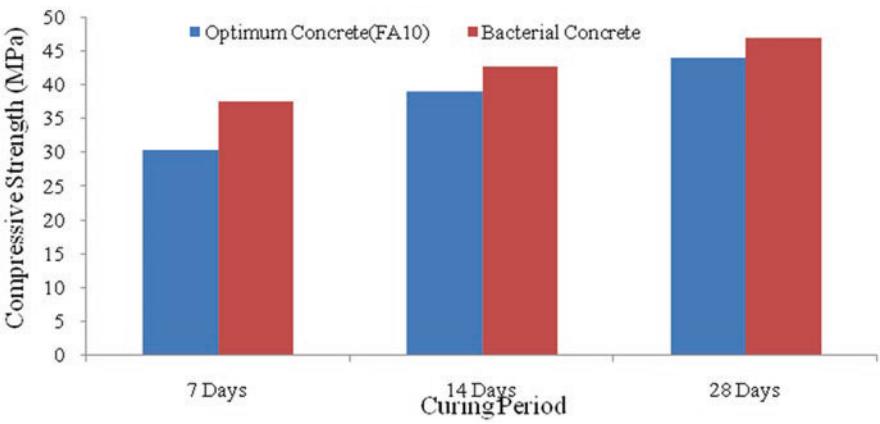

Fig. 31.3 Compression strength test result of bacterial and optimum fly ash concrete

28 days of curing respectively. The maximum gain in strength was achieved for FA10 (10% fly ash replacement) samples. At 28 days, when the fly ash content was enhanced above 10%, the compressive capacity began to decline in comparison to the nominal concrete. Since fly ash is a slow reactive pozzolan, the hydration process is delayed. The reduction in compressive strength may be attributed to a slow hydration process (Bai and Varghese 2016).

Figure 31.3 delineates the strength in compression of the bacteria incorporated fly ash-based concrete at 10% replacement. The compression strength for the samples containing bacteria increased relative to the samples without bacteria by 19.24%, 8.76% and 7.75% at 7, 14 and 28 days. This enhancement in compression strength might be becauseofthe calcite precipitation in concrete. The calcite layer formed on the exterior face of the cubical samples tends to fill the voids in the concrete and concrete become more dense and durable (Vijay et al. 2017).

31.3.2 Water Absorption

Water absorbing capacity of all the 54 samples were determined as per the standard method given in IS: 1124-1974 (Bureau of Indian Standards 1974). The water absorption of the conventional concrete sample, fly ash replaced samples (5%, 10%, 15% and 20% replacements) and bacteria incorporated samples was determined using the method as stated in the testing section above. Figure 31.4 represents the test results of water absorption.

Figure 31.4 show that 5% fly ash replacement recorded 6.35% and 7.07% reduction in water absorbing capacity after 2 and 4 weeks relative to the standard samples. Similarly, substitution of fly ash at 10%, 15% and 20% levels showed a reduction in water absorption values. The reduction in WA at 10% replacement was found to be 9.60% and 10.87% at 15% replacement 12.36% and 13.90, at 20% replacement 16.58% and 17.19% at 14 and 28 days respectively.

It is also observed that the bacteria (bacillus cereus) containing concrete observed a decrease in the water absorbing capacity relative to conventional concrete. The absorbing capacity of bacillus cereus bacterial concrete at 5% replacement of fly ash with cement has reduced by 10.09% and 11.37% at 14 and 28 days respectively. Similarly, 10%, 15% and 20% fly ash replacement with cement and addition of bacterial concentration show reduction in water absorption values. The reduction in WA at 10% replacement was found to be 12.46% and 13.40%, at 15% replacement 15.83% and 16.56%, at 20% replacement 19.57% and 20.35% after 2 and 4 weeks respectively relative to the conventional concrete. In comparison to standard concrete, crystals of the calcite get accumulated close to the surface of the bacteria incorporated concrete and this might have resulted in a reduced water absorption values (Kadapure et al. 2019).

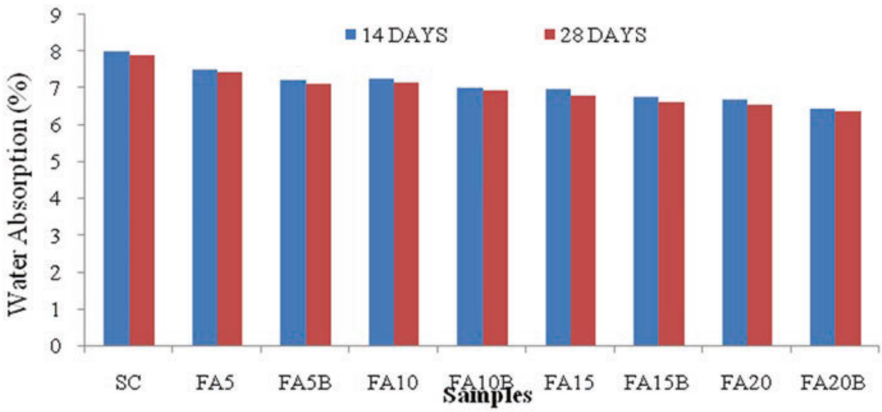

Fig. 31.4 Water absorption test results

31.4 Conclusion

The present study aims at assessing the strength and water absorption capacity of the conventional concrete, fly ash replaced concrete and bacteria incorporated concrete. The fly ash has been used in partial replacement with cement in proportion of 5%, 10%, 15% and 20% and bacterial solution has been used as a partial substitution of mixing water at 10% proportion. The overall conclusions out of the current study can be stated as follows:

- The optimum level for OPC substitution by FA for compression strength has been obtained at 10 percent replacement. At 7, 14 and 28 days the increase in compression strength at the optimal level of substitution was 9.36%, 11.17% and 8.20% respectively.
- Compression strength of the bacteria added concrete at optimum fly ash concrete gets enhanced by 19.24%, 8.76% and 7.75% at 7, 14 and 28 days respectively. Bacillus cereus bacteria were found effective in filling the voids of the concrete (Nain et al. 2019).
- In comparison to normal concrete and fly ash concrete, bacteria in fly ash concrete have lower water absorption potential.
- Bacillus cereus bacteria can be efficiently used to enhance the strength and water absorption characteristics of the conventional as well as fly ash-based concrete.

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Chapter 32
Design and Development of COVID-19 Pandemic Situation-Based Remote Voting System

P. Sivaram, Md Abdul Wassay, and S. M. Nandhagopal

Abstract The electronic voting machine (EVM), a device within the voting system in India, provided a digital mechanism in the overall voting process of various elections. Remote voting is the process of a unified and globally unrestricted voter's system, as any voter can provide their selection of vote to the particular candidate of their local from remote/distance, i.e., within in India or out of India. The voter is not forced to visit their unique polling station to vote. In such a case, the achievement of 100% vote in entire national elections is highly possible. The proposed COVID-19 Pandemic - Remote Voting System (C19P-RVS) further provides the social distancing (SD) in the means of a remote voting scheme to ensure the hygiene culture of the society with care and precautions. In addition, the work provides novelty by validating the voter at the initial stage of the voting process as they initiate the remote voting. It collects the geo-coordinates of the voter location and verifies the address data with the validation server. If the validation passes, the voter is permitted to enter further to do the remote voting process, and if not, the voter is restricted from the voting process. Even the voter's address validation passes, the duplication verification for votes is done in the next stage to identify the voter have already voted or not? The reliability, integrity, authenticity, and completeness with confidentiality of operations within the remote access and accomplishment of tasks of intended purpose are focused in the C19P-RVS.

Keywords Aadhaar authentication · C19P-RVS · Conventional Indian voting system · E-democracy · EVM

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32.1 Introduction

In India, the government official operations shaped many smart applications with the beginning of the digital era in Indian Governance. It might not be explained with smartness and the crisp and time-reduced procedures possible with the digitalized processes. For example, the EPFO activities and operations are systematically available online with confidentiality and smartness (Source: https://www.epfindia.gov.in/site_en/For_Employees.php). The EPFO shaped with their ethics as "Providing online service for EPFO benefits through the state-of-the-art technology following best service delivery practices and ethics" (Source: https://www.epfindia.gov.in/site_docs/PDFs/MiscPDFs/Resolution_Ethics_1.pdf). The EPFO completely shifted its operations from manual to online digitalized mode and functioning perfectly and efficiently with the listed details. Many EPFO beneficiaries utilize the digital service and enjoy operational completeness within their home by avoiding official physical visits. This example is provided in the introduction section of this article to emphasize the importance and clarity/certainty of digital operations of Indian e-governance. The new era of e-democracy is begun, and the decision-making process of every Indian citizen is in digital form (Patricia et al. 2021).

The EPFO, as for the employees, serves their betterment with the help of integrating the data of various digital subsystems of Aadhaar (UIDAI) Authentication (Source: https://uidai.gov.in/my-aadhaar/get-aadhaar.html), PAN data, and Banking data of the beneficiary. The data integrity from necessary subsystems is essential to perform the operations with completeness. There is no need to create a database of beneficiaries newly to form the entire operations. The processes are Aadhaar Authentication as the first data integration, the PAN data verification, and the critical banking server's interaction to confirm the beneficiary bank account for the transactions. Even though the manual mode of operations is possible in EPFO, now the beneficiaries' can operate their expected services from EPFO remotely. The fair on remote operations and stress-free task accomplishments in official operations proves the importance of e-governance with remote operations. The conventional democracy's decision-making power with the Indian nationals is provided with e-democracy and e-voting, where the society is now equipped with internet-enabled activities. Their decision-making in elections also provided with them remotely/distantly.

The modular-based proposed system design and development carries the validation and verification in the initial stage of the remote voting process to reduce the overall overhead of the entire system. Without validating and verifying the voter at the initial stage, if the voter is allowed to enter the remote voting process leads to heterogeneity in the dishonesty of the voter behaviour. In the initial stage, voters' address verification and validation with the geo-coordinates, such as latitude and longitude of the voters' home/house premises, extends the perfectness of the entire remote voting system. The validation of the voters' address is the main operational feature in the proposed system, where the further stages of the remote voting process can be avoided with dishonesty. By the confirmation on the validating the voters' address and fail assurance on the voted information acknowledgement of the specific voter, the remote voting process lets the new voters enter the further process and confirms its authenticity, confidentiality and consistency in operational goals.

32.1.1 Election Process

The election process in India has its unique operations, and the functions are divided into three stages. The detailed representation is given in Fig. 32.1. This process begins with the Prior election stage, where the preparation activities of elections are held, and the voter's identification is the primary activity of this stage. The second stage is the conducting election, in which the voter communicates with the polling station officials to ensure their cast of voting is held. The third stage is the post-election stage. The results were announced after counting the recorded votes from various regions.

There are six processes available in the election process. The announcement process is in the prior election stage, where the ECI announces the date of nomination for the candidates, duration of voters' registration, and date voting. This act is the primary stage where the nomination candidates and voters must ensure their active participation in the election process. The registration process applies to the nomination candidates for election as well as to the voters. The nomination registration is essential for the voters to elect the candidate using the voting process. To select the nominated candidates of an individual voters' interest to register as a voter is also significant.

The day of election operations by voters and voting station officials is the second stage of the election process. The voter is verified with the identity of the specific polling station by the officials. The voters are allowed to cast the vote of their choice with high confidentiality. This stage has two processes, authentication and voting

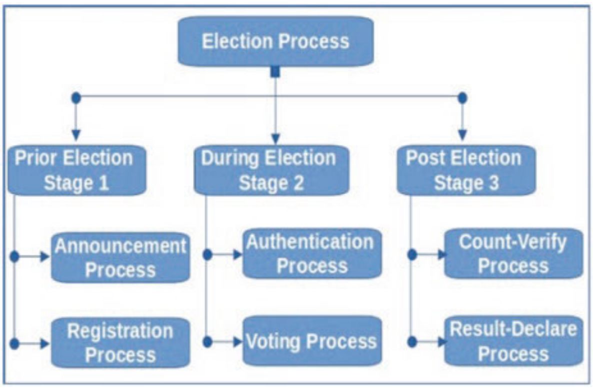

Fig. 32.1 Election process with three stages and six processes of operations

processes. The third stage is the post-election process, where the ECI takes the polled votes for counting, verification, and final announcement of results.

32.2 Existing System

32.2.1 EVM Based Voting System by Election Commission of India

Since 1982, the EVM is being utilized in various elections in India (Source: https://eci.gov.in/files/file/11411-evm-broucher-for-electors/). The EVM is designed with several advanced technologies with adaptive quality controls in manufacturing and equipped with optimum administrative safety measures during its utilization in elections. The same EVM techniques are utilized worldwide by various countries, which provides credibility to India in conducting elections (Source: https://eci.gov.in/files/file/11411-evm-broucher-for-electors/). As for the EVM-based Voting System (EVM-VS), the existing practice is maintained and administrated by the Election Commission of India (ECI). During the elections, the voting system's end-user points are called polling stations, where the voters do the actual voting with the help of polling station officials. The EVM is based on the integration of three units. The first is the control unit (CU), the second is the ballot unit (BU), and the third one is the voter-verifiable paper audit trail (VVPAT) and are connected through physical cables by way of BU is connected with VVPAT and VVPAT is associated with CU. Figure 32.2 details the basic units of components in the EVM-VS, which ECI prescribes (Source: https://eci.gov.in/files/file/11409-broucher-for-presiding-officer-on-use-of-evm-vvpat/).

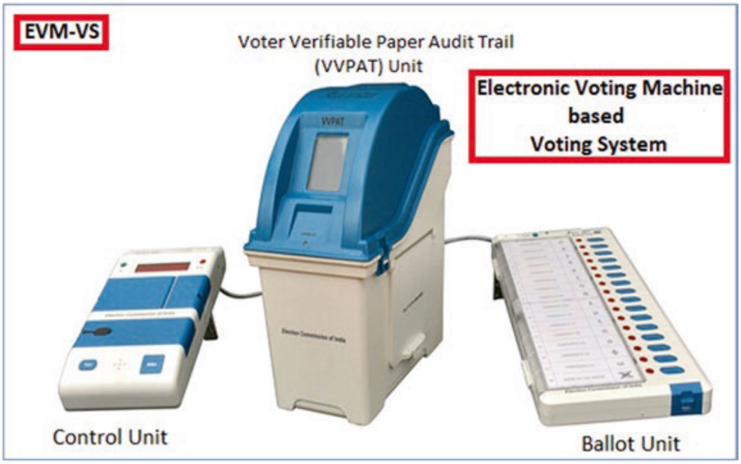

Fig. 32.2 EVM-based voting system with its operational three units

The CU by the name itself is a controlling entity of the election, where a voter before providing his vote, with the help of this unit a polling station official is letting the voter with proper verification and making the voting system get ready to collect the specific voter's choice of vote. This unit is always present with the presiding officer to make the control activities of the voting. The BU is the actual voting unit where the details of candidates and their symbols are displayed. The BU and the VVPAT both units are placed in the voting compartment of the polling station, where the voter provides his vote and perceives the information as for their certainty on the completed voting process (Source: https://eci.gov.in/files/file/11411-evm-broucher-for-electors/). The role of VVPAT is that, when a voter casts their vote with BU, an information slip gets printed and gets collected automatically in the sealed box of the VVPAT for based on need cross-checking and, at the same time, voted information such as candidate and his symbol will be displayed on the VVPAT Status Display Unit (VSDU) for 7 s. The collected slips in the VVPAT are sealed and are available for audit by the courts (Sources: https://eci.gov.in/files/file/11411-evm-broucher-for-electors/; https://eci.gov.in/files/file/11409-broucher-for-presiding-officer-on-use-of-evm-vvpat/).The current system of voting process lets the voters' can register in multiple geo-locations. The multiple locations registered voters are provided with the choice of selection of voting station, without the knowledge of the ECI, and the dishonesty of the voter is encouraged in the hidden mode. The proposed remote voting system provides the novelty in avoiding the dishonesty of the voters to ensure the one vote per voter.

32.2.2 Electoral Roll System

As for conducting elections, the ECI prepares the voters list every time, before the elections, and the process is called electoral roll (ER) preparation. The existing voters' list is verified during this process. The new voters are provided with awareness and information to enroll themselves in the electoral roll system to become active in the election process with manual or online modes. Invariably, the ECI focuses on high-fidelity electoral roll preparation. There are three stages of ER preparations. The first stage is the Pre-revision activities, the second stage is the revision processes, and the third stage is the continuous updation. The preparation and updation of ER are done by ECI throughout the year before the election is announced. This act is not done between the duration from the last date of making nominations of an election in a constituency to the date of declaration of result of that election. Figure 32.3 describes the electoral roll cycle (Source: https://eci.gov.in/files/file/6917-manual-on-electoral-roll-2016/).

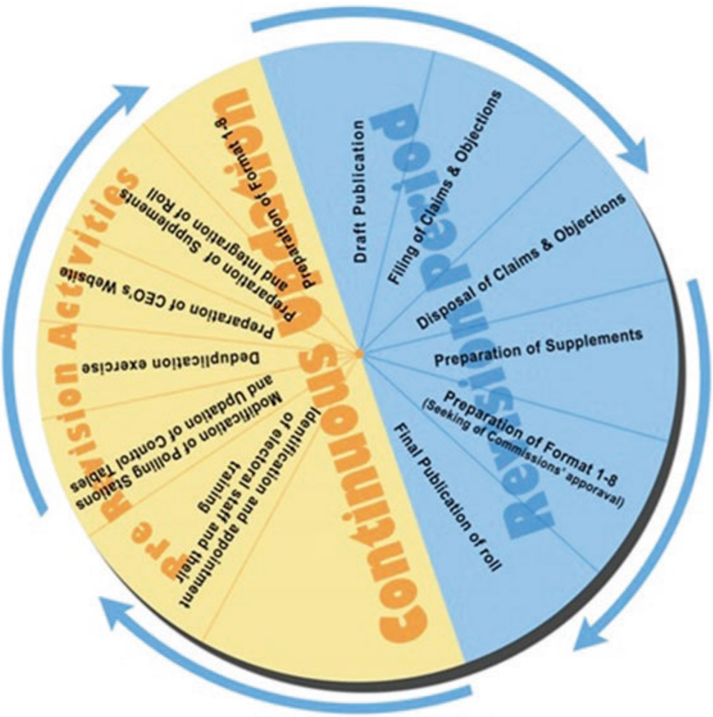

Fig. 32.3 Electoral roll cycle

32.2.3 UIDAI's Aadhaar Number System

The C19P-RVS relies upon its necessary subsystems for remote operational completeness. The Unique Identification Authority of India (UIDAI) – Aadhaar Number Sub System is the repository of unique data set of Indian nationals with no redundancy. That is, the duplication of the data set is highly not possible (Source: https://uidai.gov.in/images/FrontPageUpdates/aadhaar_authentication_api_2_0.pdf) To all Indian residents, a unique identifier (Aadhaar) is provided by the Unique Identification Authority of India (UIDAI), and it provides the authentication to the Aadhaar holders for verification of their identity claims. The primary subsystem of the proposed C19P-RVS is the UIDAI's Aadhaar Number System (ANS), which is the 12 digits the random number of identifications named as Aadhaar Number (AN), which is issued by the UIDAI authority to the residents of India, with proper verification and validation on the individuals' information. The Indian nationals are now strictly enrolling themselves to get the Aadhaar Number because all Indian government officials are running based on this number. The Indian individuals' demographic information and biometric information are collected to provide Aadhaar Number by the UIDAI (Source: https://uidai.gov.in/what-is-aadhaar.html).

The demographic information such as name, date of birth, gender, address, mobile number, and Email ID, and the biometric data such as ten fingerprints, two IRIS scans, and facial photograph in digital mode of the applicant are collected by the UIDAI to provide Aadhaar Number. The UIDAI is not fixing any constraint in the age to enroll with the Aadhaar Number, i.e., a child within the age group of 5 onwards and up to the senior citizen above 60 can also enroll in the Aadhaar number system. The child is mandatorily enrolled with the supporting Aadhaar number of any parents, either father or mother (Source: https://uidai.gov.in/what-is-aadhaar.html).

32.3 Literature Survey

The Xuechao Yang et al. presented their work, the online/e-voting system with a publicly verifiable, self-tallying concept-based secure distributed system with Intel Software Guard Extensions hardware components. This hardware is the unit, which functions with CPU-based cybersecurity technology. The Distributed SGX network system (DSGXNS) is connected with the board of the election. They contributed to their online voting process by designing a safe, verifiable, and self-tallying e-voting protocol based on DSGXNS, and culminated with secure and private online voting (Xuechao et al. 2021a, b). Adrien et al. (2021) describes the e-voting system, which facilitates voting by reducing participation time and effort. The system turns out with increased voters with active participation in the election process. The authors did their work on Bayesian multi-level models, tested in Geneva, Switzerland, and concluded that offering e-voting has increased turnout among abstainers and occasional voters. Cristina et al. (2021) presented their work with a secure option for electoral processes, proposed a Secure Internet Voting Protocol, and presented the concept of fraud-free elections using blind signatures and public-key cryptography, concluding the system with eligibility, democracy, privacy, verifiability, accuracy, fairness, robustness, receipt-freeness, and coercion-resistant.

Rathee et al. (2021) described in their blockchain-enabled, e-voting application within IoT-oriented smart cities, as with the incorporation of 5G technology in a detailed manner and concluded with the security and privacy enhancement e-voting system. Qureshi et al. (2019) projected a secure and verifiable electronic polling system, with well-known cryptographic primitives to provide vote and voter's privacy, and poll integrity, confirms the identity of voters through a multifactor authentication scheme, enables multiple voting within the allowed polling period, prevents double voting, and achieves verifiability in the presence of an untrusted voting device. By considering electoral fraud in the e-voting system, securing voting systems with blockchain solutions is presented by Patricia et al. (2021) and introduced the term e-democracy in work and validated the significance of distance voting with such e-voting systems. The security in cyberspace with the detailed discussion on vulnerabilities and defenses for the e-voting systems is presented in the work of Feng et al. (2010).

Md Shihab UA et al. (2021) presented a low cost biometric equipped EVM with fixed infrastructure-based polling station, hardware design and focused on security, and delivering government services with the available latest technologies for Bangladesh and detailed a low-cost solution for the EVM with the authentication of active voters with a central database using a biometric identification process with confidentiality of voters' all sort of information on voting processes. Khoury et al. (2018) projected a decentralized, trustless voting platform relies on blockchain technology, in which, focused on their work with integrity and transparency of the voting data, and con-firming one vote per mobile phone number with assured privacy. Coercive behavior of the systems in the remote e-voting process is presented by Krips and Willemson (2019) and discussed the academic-based proposed protocols of the e-voting processes with coercion-resistance properties in the developer point of view. Bernhard et al. (2017) described the KTV-Helios voting scheme and narrated the voters' proofs for verification, receipt-freeness on the voting process, and ballot privacy. The non-addressed security issues are addressed with their proposed work. An advanced Aadhaar based e-Voting system with an RIFD tag as a new method was introduced to the existing process and ensured the quality-based system (Yogesh 2019).

The challenges and issues in the mobile standalone and mobile browser-based e-Voting scheme were discussed by Heiberg et al. (2021). The integrity, privacy, and available voting channel are presented, which are very helpful for the C19P-RVS. Michał and Poniszewska-Marańda (2021) presented various challenges faced by the e-Voting scheme. They introduced blockchain technologies in the system modeling with a survey on the blockchain-based methods, benefits, and challenges. Not only with blockchain, with the cloud server-based e-Voting scheme was presented by Somnath and Bimal (2021) and provided the prevention for the ballot stuffing attack. Seyed-Hosein et al. (2021) described a cyber-physical system design with automated parallel simulation flow to accomplish the task faster. The same idea can be utilized for C19P-RVS work, and parallel processing can be incorporated to achieve the system's reliability.

Shubhani and Neeraj (2021) detailed the voting system with blockchain technology concluded with the privacy on the vote provided by the voters. Peng Li et al. (2021) described an application system of event-based linking and tracing anonymous authentication by the voters and made their casting traceable and linkable for the verification. This work highly supports the proposed RVS. Xuechao et al. (2021a, b) presented a distributed voting system with a publically verifiable online voting scheme with a self-tallying concept and sup-ported the C19P-RVS design and development. Tania et al. (2021) described the change and fear in the voting process by the voter due to the C19P situation of the world, and this supports the proposed C19P-RVS with contactless (CL) operations on the e-Voting system with social distancing (SD). The questions raised by Laurent et al. (2021) are also a major key factor to drive the e-Voting system into the CL-SD-based C19P-RVS and are presented by our proposed work. Micha Germann (2021) presented an excellent job of turning non-voters into active participation in the election process with an increase in votes, which is the crucial work of our C19P-RVS with the achievement focused on 100% of the vote in the election process.

32.4 Proposed System

32.4.1 C19P-RVS Frameworks

The C19P-RVS frameworks are divided into two for the voters' registration with the system and the voting process. Each framework has six layers of operations to accomplish its system objectives. The first is treated as the C19P-RVS Voters Registration Framework (RVRF). The voters with the application were provided with their handheld device and fingerprint sensor, applying for the authentication, if the verification of an Indian individual from the UIDAI based Aadhaar identifies that individual. The demographic data present in the Aadhaar data as date of birth is verified for registration eligibility. The voter has to complete 18 years old at the time of election conduction year. The voter is now passing the eligibility criteria. The voter is registered as a successive voter for the current election process. Figure 32.4a is the pictorial representation of the C19P-RVS Voters' Registration Framework.

The second framework is the C19P-RVS Voting process Framework (RVPF), where the registered voters are eligible to participate in the current election conducted by ECI. ECI provides physical application-specific hardware infrastructure-based polling stations for C19P-RVS, and the individual voter, with his handheld device equipped with a biometric sensor, is involving in the RVPF operations. The voter is permitted to authenticate with UIDAI based Aadhaar authentication through the application and with the biometric sensor, and his record on the e-Electoral roll is verified. The location of the voter is collected for localization support. With localization details, the specific constituency and the details of candidates are identified by the C19P-RVS, which will be presented on the voter's device for providing his

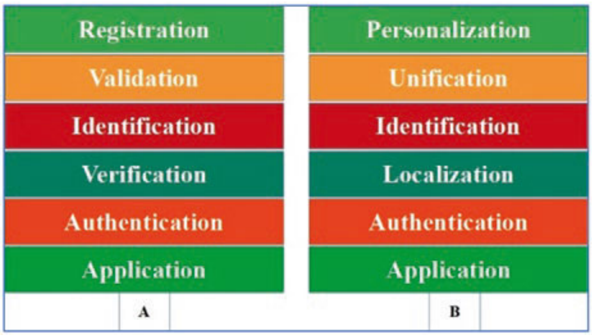

Fig. 32.4 (**a**) The C19P-RVS voters registration framework (**b**) The C19P-RVS voting process framework

decision with this election process as casting a vote. The unified polling station details will be projected on the current voter's device's display by opting to cast their vote. After the voting, the voting persons' choice is recorded by the corresponding localization-based polling station database for the counting process. The voting process success acknowledgement is displayed with the voter device and terminates the connection with the voting person C19P-RVS. Figure 32.4b is the pictorial representation of the C19P-RVS Voting Process Framework.

32.4.2 Unification: Novelty of Operations

Figure 32.4b is the voting process framework. The application of the remote voting process allows the voter to initiate their voting process on a specific day of the voting process. The geo-locations coordinate such as latitude and longitude of the voters' home/house premises pair with the voters' address are made as a separate database for this unification process on the voting process of the proposed system. With the help of the remote voting process application with smart devices, voters enter with their authentication credentials. In the following operational framework, the voters are categorized and enabled with localization access to navigate their location-based polling station data details to provide their vote of interest. In the operational framework of identification, the voters' address database is verified for the current geo-coordinates with the registered geo-coordinates to ensure the voter's address is correct. In parallel, the voters' pre-vote status is also verified in the very initial stage of the voting process to overcome the dishonesty and duplicate voting on the same day. If the verification is passed, the voter is unified in the proposed work and allowed further to vote through the remote voting process. The enabled localization access is provided with complete details of the polling station at the operational framework called the personalization. Suppose the verification suffers, and validation is not passed during the operational framework stages identification and unification: The voter is restricted from the progressive process to proceed further in the remote voting process. The reason for not allowing the voter is recorded on the database for future reference. An acknowledgement of the same is forwarded to the registered voter with the details. The consistency, confidentiality, and reliability are maintained with a unique approach in this proposed work.

32.4.3 C19P-RVS Work Flow

The workflow of C19P-RVS begins with the voters' registration, where an Indian individual is enrolling their candidature in making eligible to vote in the forthcoming election process. Figure 32.5a represents the voter's registration workflow. An Indian Individual who wants to enroll in ECI's electoral roll reaches the ECI enrollment center or remotely with the help of his handheld device with a fingerprint

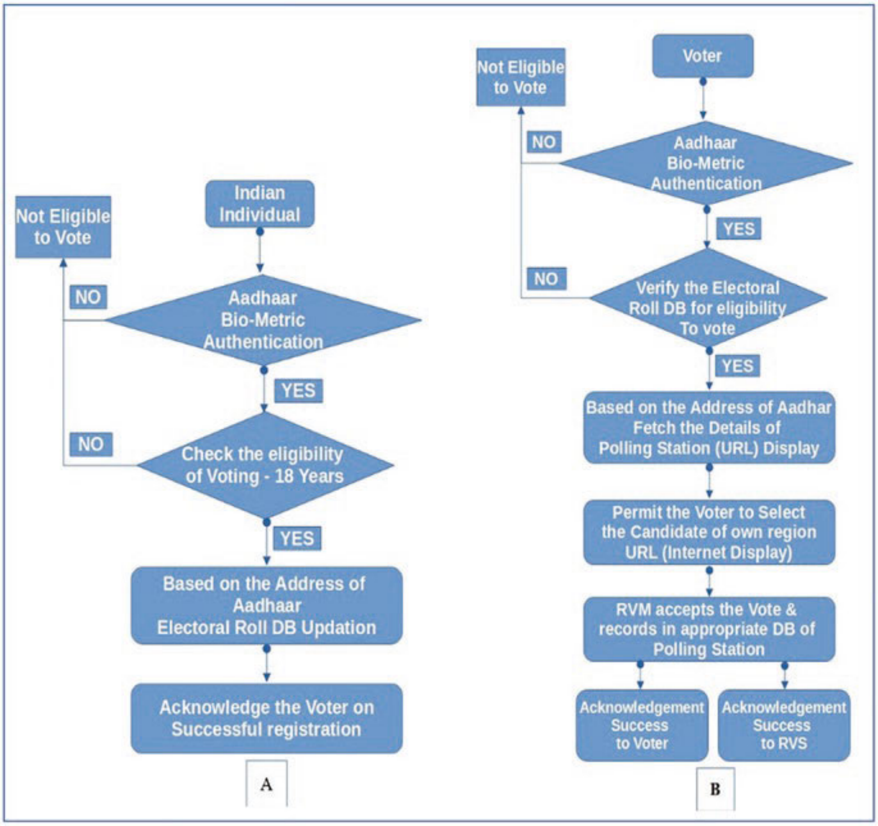

Fig. 32.5 (**a**) The flow of C19P-RVS voter's registration (**b**) The flow of C19P-RVS voting process

sensor attached application. The application further verifies the Aadhaar authentication. On successful verification from the Aadhaar, from the date of the birth data field, the age is confirmed as an active voter as the voter has completed 18 years of old on the year of election. After verifying eligibility, the voter is enrolled on the ECI's electoral roll with the localization as per the address available on the Aadhaar data. The corresponding constituency and the polling station database are updated with the current voter information. In between any of the verification fails, the voter is not registered in the database. On successful registration, the acknowledgement to the voter is provided successfully, and a flag of a registered voter in the database is fixed positive, as he is eligible for the current election to provide their vote to support e-democracy.

The second workflow is on the date of the voting process. Figure 32.5b describes the details of the voting process workflow. The registered voter in the electoral roll is entering the system with the handheld device or with the polling station C19P-RVS infrastructure provided by ECI, and the Aadhaar based authentication is the primary verification of the system to ensure the voter is Indian national or not. After the Aadhaar authentication success, the electoral roll verification is held. On successful verification, the voter is provided with their decision-making process to cast a vote. Their Aadhaar address-based polling station details are displayed with input options to vote. In between, any of the verification fails, the voter is not permitted to cast a vote with the C19P-RVS. On the successful voting accomplishment of the voter, an acknowledgement is sent through SMS/e-mail by ensuring their participation in the current election process, as well as the flag on the electoral roll, is set positive to ensure C19P-RVS not to allow the same voter to cast a vote once again on the same day of the election.

32.4.4 C19P-RVS Overall Architecture

The system architecture has two flows: the infrastructure or voter premises-based, and the second is the C19P-RVS software architecture. In the first flow of architecture, ECI based fixed infrastructure doesn't destroy the concept of the proposed C19P-RVS but supports the voters to cast their vote from their present locality. i.e., Suppose a voter belongs to another polling station but is willing to cast their vote from the current ECI provided C19P-RVS infrastructure, which is not his exact polling station. In that case, the voter is provided with the opportunity to cast a vote remotely.

The voter is not subjected to being physically present on the election day at their polling station. The second flow is the software architecture of C19P-RVS, where the user interface, relational databases, security mechanisms, and technology are provided with it. The infrastructure of this system is of two types, and the first is polling station-based. The ECI offers such infrastructure for the voters in the prescribed locations to make voters cast their votes. The overall architecture and the flow of operations in the system are described in Fig. 32.6. As the first phase of this work, the ECI based polling stations are preferred to complete the election process in the form of C19P-RVS. The contactless C19P-RVS operations are achieved through a mobile or web application-based interface provided by the user devices. The possibilities to the voters are provided in such a manner. They can choose any polling station to give the vote of their choice, i.e., to their Aadhaar address-based constituency polling station, with the details of nominated candidates information of the specific polling station display.

The C19P-RVS Software Architecture is the application layer activity of the system. The voter is provided with a mobile app and web-based application software to enable their vote casting through this architecture's provided application user interface (AUI). The C19P-RVS-AUI is the complete human interaction entity that collects user input into various extensive data analyses of the C19P-RVS. The voting process identifies the GPS coordinates as latitude and longitude of the voter's device, whether mobile or PC. The voting application (VA) at the initialization phase of the process sends the GPS values to the ECI electoral database, and verification of the address is held. The voter details are fetched with the VA. The

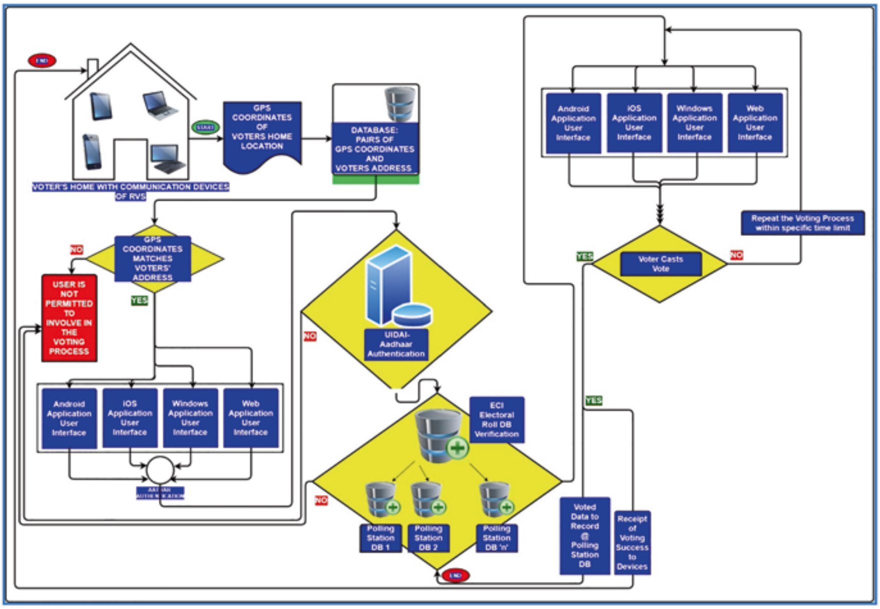

Fig. 32.6 The overall architecture of the C19P-RVS

predefined data on the voters' VA again provides the authentication as the voter is the confirmed individual and verifies for the voting completeness. In the operations, on completing the casting vote, a log is recorded as a data entity. Detailed log data will be verified at the beginning stage of the voting process to avoid the repetition of casting a vote by the same voter. If the log is filled with the voting task performed, at this stage itself, the voter is reported as the casting of the vote is over and repeated chance will not be provided, and time of casted vote completion will be registered with the VA. Thus, the duplication of casting a vote by the voter is eliminated. The VA identity value is provided to every user during the registration process on the electoral roll as a voter.

The available support officials for this system-based election process are provided with the global VA (G-VA) mobile and the PC on the polling station premises. The member who is not equipped with such a device-based VA can approach the polling station by providing any of the ECI based identity data. G-VA is designed by collecting the data parameter prescribed by the system to identify the voter. This approaching at polling station happens with the strict following of SD. The overseas voters are provided with the voter-specific VA, and the Indian embassy-based polling station will be arranged to cast their vote with the help of C19P-RVS. The Indian embassies of all countries are equipped with the C19P-RVS subsystem elements to collect the votes of India's NRI voters.

32.5 Advantages of C19P-RVS

- The duplication of voting cannot be done due to the biometric data of Aadhaar. Once the voter has completed their decision-making in the election process, their vote is processed, and they cannot vote for the second time on the same day. The high consistency is achievable. One vote for the one Aadhaar authentication is ensured in the system, which is the crucial factor of C19P-RVS, to avoid duplication of the voting process with the same voter.
- The existing voters' communication is highly possible by ECI, with the Aadhaar enrolled mobile number and email. The awareness of the election process is energized with the help of the e-election process. The Aadhaar holders are insisted through SMS and email to verify their presence on the electoral roll before the election. It happens on the initial election state 1, where ECI's announcement is over on the current election. The reliability of the election process is achievable.
- The ECI has the privileges to identify the eligible voters with the help of Aadhaar data present in UIDAI and can communicate the existing above 18+ aged Aadhaar holders to ensure their presence on their specific electoral roll. The integrity of the election process is achievable.
- The ECI can provide continuous awareness messages to the enrolled voters, in terms of SMS and email messages of UIDAI, to make 100% vote, which is every election slogan but is not achieved up to now. The completeness of the election process is achievable.
- After election completion, the non-voted voters can be again provided with the awareness communication, with which from the next elections the voters can cast their vote without fail. The authenticity of the election process is achievable.
- ECI now has complete control over the registered voters to advise them to participate in the election decision-making process. Their efforts in the election will result in certainty. The confidentiality of the election process is achievable.
- A voter is not to be present on the day of the election with his specific polling station, which is the major drawback. The deficiency can be eliminated with the Aadhaar based identification of localization of the voter and providing support in RVS to cast a vote remotely. The voters within India/abroad, provided with any polling station by ECI or the RVS software application, equipped any smartphone/PC with a biometric sensor. The voters can cast their votes remotely.
- The contactless operations provide the SD, which is highly needed to maintain hygiene while focusing on the pandemic situation-based e-Elections.

32.6 Future Enhancement

This proposed work opens the door for big data analytics, data mining, and AI-based further optimizations. The further development on handling big data with novel algorithms provides new research that can be incorporated with this work as a successor. The data mining to provide the match with the accurate data for the fast processing of C19P-RVS creates another domain of novelty in optimization. The innovation is further extended with the proposed system with AI-based machine learning, provides the insertion of AI concepts with the design, and brings the system into automation. The exploration of the future enhancements is not restricted with this and can be explored furthermore.

32.7 Conclusion

The design and development with the framework of operations and optimized architecture are provided in this work. The more extended explorations on the same system functionalities based on the localization needs of any region can be made as a concept of optimization. The GPS coordinates-based identification of the voter from his home location device brings novelty and completeness in the election process. The voting process is initialized with the individual identification of the voter. It relies on the system's application software, where the duplication is further eliminated at the Aadhaar data verification, and the entire system operations are reliable. With the voter end's voting process step by step, the whole system is integrated towards the intended purpose. The voter is provided with the remote operations on the voting process with his automatic authorization and the validated system conformity all the process offers the authenticity. The casted votes by the voter are recorded in the system with confidentiality. The human presence at the polling booth is eradicated with the available system modifications with existing technologies during the election process.

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Chapter 33
Waste Pozzolanic Material as a Substitute of Geopolymer Mortar

Akshay Dhawan, Nakul Gupta, and Rajesh Goyal

Abstract The research objective is to examine about the Engineering Characteristics and Mixture Design of the Geopolymer Mortar using FA (Class F) and naturally available Zeolite and a combination of Na_2SiO_3 and NaOH as an antacid activators. Sodium Hydroxide of 12 M obsession has been used and Na_2SiO_3 to NaOH ratio is varied from 1, 2 and 3. The geopolymer mortar's compressive strength improves by the high concentration of NaOH and Na_2SiO_3 as an activator. The compressive strength was most prominent when theNa_2SiO_3 to NaOH content ratio was kept at 1:3. The water retention is likewise less at higher soluble base substance because of the presence of lower void spaces. There are various climate and financial advantages of utilizing Fly Ash and Zeolite in the Geopolymer Mortar creation.

Keywords Geopolymer mortar · Zeolite · Natural zeolite · Pozzolans · Fly Ash · Waste Pozzolanic Material · Waste Pozzolans

33.1 Introduction

The largely consumed material in construction is concrete and its demand is expected to continue deep into the future. The vital constituent of concrete is cement and cement is not environment friendly. Cement emits in the atmosphere approximately 8% of the total greenhouse emissions (Okoye et al. 2017). A considerable amount of fossil fuel, 1.5 T of limestone and electrical energy is required to produce about 1 T of cement (Barker 1963). We need to find an alternative binder of the Portland cement which is more environmentally friendly and Sustainable. One of such effort is through development of Alumina-Silica polymer called as Geopolymer, which uses synthetic geopolymer material available as a byproduct material. The

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word "Geopolymer" was given by Davidovits for the first time in 1970 to describe alkali activated alumino silicate binders. Alumino-Silicate oxides react with Alkali Polysilicates in a chemical reaction to produce SI-O-AL bonds (Lloyd 2009). Geopolymer binders has the potential of partial and full replacement of Portland cement and is environmental friendly apart from its other technical benefits. It majorly contributes by substantially reducing the CO_2 emissions and sodium Silicate solution has been used as a chemical activator. Mineral Admixtures offers ecological benefits and also reduces the cost of construction and helps in energy saving by using waste pozzolanic materials like Fly Ash and Micro Silica. The information regarding the use of naturally available Zeolite for producing Geopolymer Mortar and Geopolymer Concrete is very finite. In this study, we aim to produce geopolymer mortar which can be relieved at room temperature by industries Waste Pozzolanic Materials like Naturally available Zeolite and Fly Ash (Class F).

33.2 Environmental Methods

33.2.1 Raw Materials

In this examination, we are utilizing Fly Ash and Naturally accessible Zeolite, the two of which are wealthy in silica and alumina and has a capability of delivering Geopolymer Mortar, that can supplanted by either half or 100% low calcium fly ash (Class F) (Wallah and Rangan 2006). It was secured from Jharli, Jhajjar, India and was utilized as base material. Characteristic Zeolites was secured from Gujarat, India. Reviewed Silica sand of zone III was utilized in the creation of Geopolymer mortar. The synthetic organizing and actual qualities of Fly Ash and Naturally accessible Zeolite are appeared in Tables 33.1 and 33.2, respectively (Palomo et al. 1999). A blend of *Na_2SiO_3 and NaOH* was utilized as a basic activator. NaOH with 98% immaculateness and Sodium silicate arrangement (27% SiO_2, 8% Na_2O, and 65% H2O) was secured from a neighborhood merchant. The NaOH drops of 12 M fixation was broken down in refined water (Wallah and Rangan 2006). Various proportions of Na_2SiO_3 arrangement/NaOH arrangement were utilized as soluble activator. The proportions are 1, 2 and 3 separately. Na_2SiO_3 in fluid structure and NaOH of 12 M focus was consolidated and kept at a temperature of 28–32 °C for around 24 h prior to utilizing it.

Table 33.1 Chemical structuring of source materials

Structuring of chemicals (%)	Fly ash	Naturally available zeolite
Silicon oxide	52.95	68.3
Al_2O_3	23.50	10.97
Fe_2O_3	8.70	1.02
CaO	4.75	3.24
MgO	3.10	1.01
Na_2O	0.40	0.17
K_2O	2.01	2.39
SO_3	2.84	–
Cl^-	0.019	–
Calcium oxide	0.879	–
Reactive silicon oxide	34.01	54.92
CaO	0.65	–
LOI	0.54	12.91

Table 33.2 Physical characteristics of source materials

Physical characteristics	Fly ash	Naturally available zeolite
Retained on 45 lm (%)	28	23
Specific gravity (g/cm^3)	2.89	2.79
Blaine surface area ($m^2\ kg^{-1}$)	376	125
Strength index (%)		
7 days	66	87
28 days	73	85

33.2.2 Sample Testing and Their Different Conditions for Curing

The geopolymer mortar's design mixture used are mentioned below in Table 33.3. The weight batching and mixing was done by a baby mixture of FA, NZ, both FA NZ and sand as its constituents. The sand to binder ratio as per the mass was fixed at 3.0. Some more water was added to enhance the utility of geopolymer mortar. Water to be added was determined by standard flow table as per the ASTM C230 by a flow diameter of 110 ± 5 mm (Rangan 2009). The fresh water was subsequently transferred into 50 mm cube moulds.

We have kept the curing under room temperature to explore the geopolymer mortar suitability in normal atmospheric temperature i.e. about 30 °C. The humidity level was around 60–64%. The samples were completely covered in the room temperature for about 24 h, thereafter the moulds were removed and cubes were left in the testing laboratory until the date of the test.

Table 33.3 Geopolymer mortar's design mixture

Mixture	Naturally available Zeolite (%)	Naturally available Zeolite KG/CUM	Fly ash (%)	Fly ash KG/CUM	Coarse sand KG/CUM	Water KG/CUM	Sodium silicate solution KG/CUM	NaOH KG/CUM	Mass ratio of NaOH–to-Na_2SiO_3
NZ	100	512	–	–	1529	80.02	127.49	127.49	1:1
FA	–	–	100	512	1529	40.01	127.49	127.49	1:1
NZ + FA	50	256	50	256	1529	40.01	127.49	127.49	1:1
NZ	100	512	–	–	1529	90.02	170	85	1:2
FA	–	–	100	512	1529	40.01	170	85	1:2
NZ + FA	50	256	50	256	1529	40.01	170	85	1:2
NZ	100	512	–	–	1529	90.02	191.24	63.74	1:3
FA	–	–	100	512	1529	40.01	191.24	63.74	1:3
NZ + FA	50	256	50	256	1529	20	191.24	63.74	1:3

33.2.3 Test Results

The compressive strength testing was done by universal testing machine (UTM) of a 500 Kilo Newton (KN) capacity on a 50 mm × 50 mm × 50 mm cube samples. The requisite sample's compressive strengths were checked in a set of three samples, for each mixture after 3, 7, 14, 21 and 28 days. The water absorption tests on each mixture was performed in an oven at a temperature of about 78–80 °C for 24 h and then, it is cooled at a room temperature. The high temperature of 80 °C was chosen to possibly test the microstructure disturbances in the mortar samples. It was then completely submerged in water and then the saturated dry weight was recorded. Water absorption was reported based on the percentage increase in the weight. The unit weight of each of the sets of the cube samples was determined and averaged to find the geopolymer mortar's unit weight.

33.3 Test Findings

33.3.1 Type of Binder's Effect on the Geopolymer Mortar's Compressive Strength

The compressive strength testing outcomes are obtained after a time frame of 3, 7, 14, 21 and 28 days and are clearly pictured in the Fig. 33.1. As is clearly depicted from the figure, the highest 28 days characteristic compressive strength was accomplished by fly ash mixes which contained 100% fly ash (23 MPa). On the contrary, the lowest level of compressive strength was achieved by 100% naturally available zeolite (7 MPa). The addition of 50% Fly Ash to Naturally available Zeolite based mixture enhanced the compressive strength from 7 MPa to 16 MPa and the same has

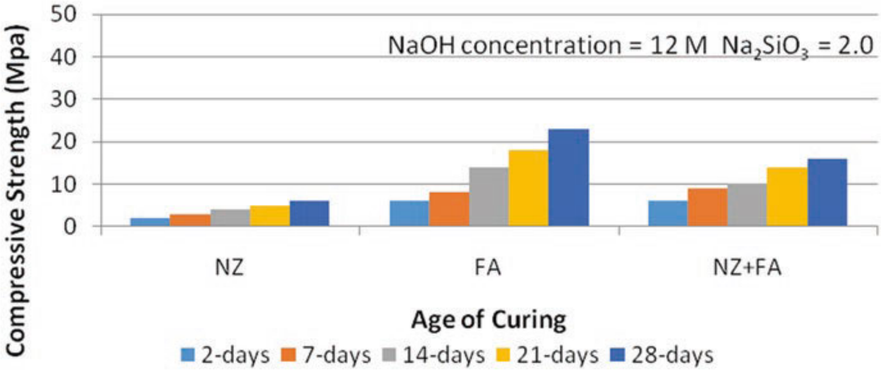

Fig. 33.1 Geopolymer mortar's Compressive Strength at various ages with diversified binder ratio of content

been depicted in the figure. This clearly indicates that adding 50% of Fly Ash to NZ would lead to increase in compressive strength by more than 2 times. Both FA and NZ has less of Ca content and Ca has a huge impact on improving the mechanical strength (Barbhuiya et al. 2009). The effect of FA (Class F) on characteristics of Compressive Strength is comparatively better and more significant than NZ. This also indicates that the pozzolanic activity in FA (Class F) is more than that of naturally available Zeolite.

The findings plotted in Fig. 33.1. Shows that the geopolymer mortar's compressive strength cured ambiently is improved with its age but elevated temperatures are more convenient for geopolymerisation. This is a fruitful finding for cast-in situ construction.

33.3.2 Effects of Ratio of Na_2SiO_3 to NaOH on the Geopolymer Mortar's Compressive Strength

The Na_2SiO_3 to NaOH mass ratio on the Geopolymer mortar's compressive strength can be observed in Fig. 33.2. The NaOH's concentration is kept at 12 M. The ratios are ranged from 1, 2 and 3 and the diverse geopolymer mortar's compressive strength are evaluated in 2, 7, 14, 21 and 28 days. When the ratio was 3, compressive strength achieved had been the highest. This unmistakably demonstrates that the strength of geopolymer increments with the expansion in Na_2SiO_3 solution (Lloyd 2009). The conceivable justification of this finding might be credited to sodium silicate having more silica gel and consequently, adds to the higher strength. Notwithstanding, if the Na_2SiO_3/NaOH proportion is expanded from 3.0, the compressive strength will in general diminish in view of unnecessary soluble base substance, which recently hinders the geopolymerisation interaction. This implies that the presence of more Si gives more mechanical strength and favors the

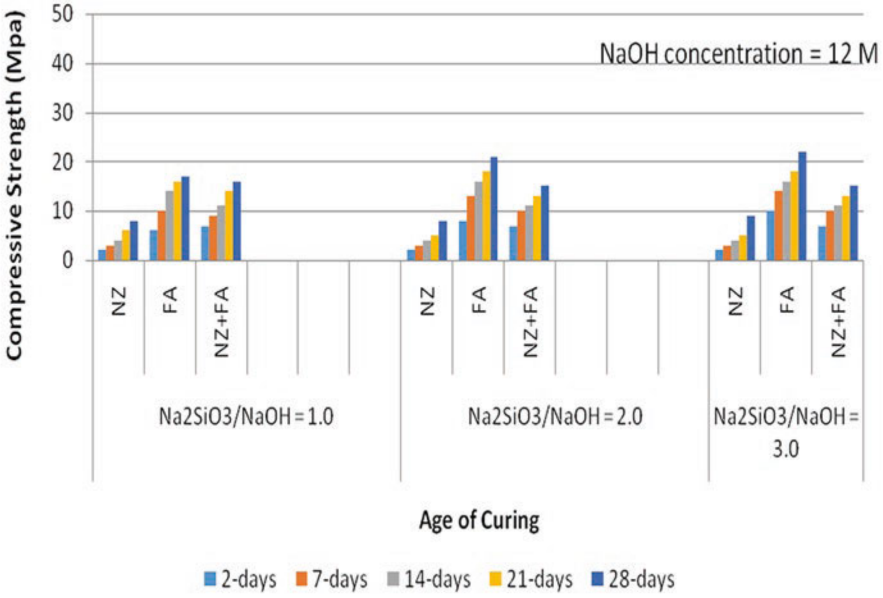

Fig. 33.2 Effects of Ratio of Na_2SiO_3 to NaOH on the Geopolymer mortar's compressive strength

geopolymerisation interaction. In this manner the discovering shows that the compressive strength of geopolymer mortar which is based on normally available zeolite (NZ) increments with the expansion in the substance of Na_2SiO_3 up to the proportion of 3, from there on the strength begins getting accordingly diminished.

33.3.3 *Effect on Geopolymer Mortar's Compressive Strength That Gained Compressive Strength from H2O-to-Geopolymer Solids Ratio*

It is perhaps the most eminent feature and the water mass in the solution is the addition of water mass present in the Na_2SiO_3, the water used in the making NaOH, and any more water contained inside the design mix(Standards 1940). The geopolymer mixture is an aggregate of Fly Ash or Naturally available Zeolite, sodium hydroxide solids, sodium silicate solids for instance mass of solid substance from a specific perspective. As it is unquestionably found in the Table 33.4, the water ratio of geopolymer ranged from 0.3 to 0.5 while the sodium hydroxide concentration has been maintained constant at 12 molar. The result shows that geopolymer mortar's compressive strength decreases with the increment in water to geopolymer solid degree. The Geopolymer mortar containing naturally available Zeolite has a low compressive strength than FA based geopolymer mortar. The existence of Na_2SiO_3 activator gives better compressive strength results with lower water to geopolymer solid ratio.

Table 33.4 H2O-to-Geopolymer solids ratio's effect on compressive strength

Concentration of NaOH	Ratio of Na_2SiO_3 to NaOH	Mix ID	Ratio of H_2O to Geopolymer solids	Compressive strength-28 day (MPa)
12 M	1	NZ	0.46	5.82
		FA	0.42	15.06
		NZ + FA	0.38	12.88
	2	NZ	0.45	5.96
		FA	0.37	20.58
		NZ + FA	0.35	13.01
	3	NZ	0.45	8.40
		FA	0.35	21.78
		NZ + FA	0.29	13.68

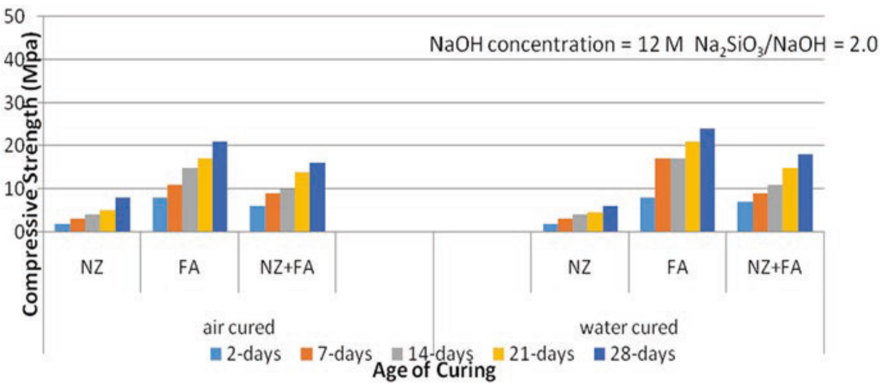

Fig. 33.3 Geopolymer's compressive strength mortar relieved in water and air

This is basically same as the effect of H2O to ratio of cement on the Portland huge mortar's compressive strength.

33.3.4 Water Curing Effect on the Geopolymer Mortar's Compressive Strength

Water is a fundamental segment for antacid initiation and its response, yet water restoring is isn't required in geopolymer. The stickiness level during the restoring interaction can influence the mechanical and actual characteristics of geopolymer mortar(C. Aldeaa et al. 2000). The 70% of the strength is achieved during the initial 12 h of the restoring cycle and the equivalent is noticed for the mortars relieved in air and water as demonstrated in the Fig. 33.3. The water relieved of naturally available Zeolite based geopolymer mortar showed lower compressive strength than the

Table 33.5 Water retention and geopolymer mortar's unit weight

Concentration of NaOH	Ratio of Na_2SiO_3 to NaOH	Mixture	Unit weight kg/m^3	Absorption of water (%)
12 M	1	NZ	1752	10
		FA	2010	8
		NZ + FA	1920	9.5
	2	NZ	1970	7
		FA	2150	6
		NZ + FA	2125	5.5
	3	NZ	1995	6
		FA	2380	4
		NZ + FA	2060	4

air restored of normally available Zeolite based mortar, this might be because of the great void spaces. For any remaining cases, the water relieved of geopolymer mortar showed preferred compressive strength results over restored in air.

33.3.5 Absorption of Water in Geopolymer Mortar

The rates of water retention for each of the example as portrayed in Table 33.5 are in the scope of 1–10%. The Naturally accessible Zeolite based geopolymer mortar showed most elevated water retention of 10% for soluble base proportion of 1. This result boiled down to 6% for the salt proportion of 2 and 3. This can be assigned to the high void substance in the geopolymer mortar in contrast with alternate blends. It is likewise seen that water absorption diminishes with the expansion of the proportion of Na_2SiO_3/NaOH in the geopolymer mortar. The water assimilation is less at the high soluble base substance because of lower void spaces.

33.3.6 Geopolymer Mortar's Unit Weight

The thickness of geopolymer mortar changes from 1750 kg/m^3 to 2400 kg/m^3. Tests with 100% normally accessible Zeolite created most minimal thickness because of higher void substance. The thickness of geopolymer mortar increments with the use of higher salt arrangement proportion.

33.4 Conclusion

The conclusion on the geopolymer mortar's compressive strength testing containing FA and Naturally accessible Zeolite (NZ) are as per the following:

1. The proportions of Na_2SiO_3 -to-NaOH, its relieving conditions and the restoring time assumes a crucial part regarding the geopolymer mortar's compressive strength.
2. The compressive strength of Geopolymer Mortar increases with the fly ash content and Molarity of the salt arrangement.
3. Naturally available Zeolite based Geopolymer Mortar had least compressive strength at all stages tested.
4. The Geopolymer Mortar compressive strength increases with the concentration of Sodium Hydroxide.
5. There is increase in the geopolymer mortar's compressive strength when the ratio of Na_2SiO_3 to NaOH proportion increases up to 3.
6. The increase of ratio of water-to-geopolymer solid content proportion detrimentally affects the geopolymer mortar's compressive strength.
7. The density of geopolymer mortar fluctuates between 1750 kg/m^3 to 2400 kg/m^3 depending on the materials being utilized. The utilization of high alkali arrangement proportion enhance the density.
8. Naturally available Zeolite based geopolymer mortar cured in water produced detrimental results than naturally available Zeolite based geopolymer mortar cured in air.
9. A microstructural analysis research will enhance the composition of the soluble activating agent.

This demonstrates that geopolymer mortar can be created without class F Fly Ash by utilizing modern side-effects, for example, Fly Ash (FA) and Naturally accessible Zeolite (NZ) and as binder materials. Each of these materials are locally accessible and help in diminishing the CO_2 emission and accordingly saving a great deal of carbon impression. The only natural effect can be related with the utilization of sodium silicate arrangement as an activator. Further examination should be possible for setting up the basic enacting arrangement and correlation of their ecological effects.

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Chapter 34
Study of the Carbon Emissions from Construction of a House in Plain Region Using Standard Construction Material and Eco-Friendly/Alternative Materials

Ankur Gupta, Shubham Kumar, and Nakul Gupta

Abstract Construction industry together with fossil fuel consumption accounts for more than 75% increase in atmospheric CO_2. Study of carbon emissions is essential so that greenhouse gas emissions can be monitored and controlled. In a country like India, still old traditional construction techniques and conventional building materials are used commonly. This research work aims at identifying the carbon emissions of those materials which are frequently used in India and to compare their emissions with the eco-friendly materials. A physical model affordable house has been constructed to study the carbon emissions of various materials. The conventional bricks have been replaced by burnt clay fly ash bricks and the cement plaster with the non-erodible mud plaster. Additionally, mud phuska has been used as an insulating medium in place of bitumen. The primary energy or embodied energy used up in construction of model house was found to be 230.7 GJ. The carbon footprint for model house was found out to be 17.5 tonnes of CO_2. When compared with carbon footprint generated using alternative materials, a reduction of around 44% in carbon footprint is observed. Therefore these alternative materials can be utilized for the construction of affordable housings with reduced carbon footprint.

Keywords Carbon footprint · CO_2 emission · Eco-friendly material · Energy efficiency

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34.1 Introduction

The rapidly changing climate has globally become a matter of great concern that needs to be focused upon before it gets too late. The amount of greenhouse gases (GHG) in the atmosphere has raised to an alarming level and the chief contributor among these gases is carbon dioxide whose volume has increased for the most part (Azevedo et al. 2018). The concept of 'Carbon Footprint' was introduced somewhere around 1999–2000 but the exact definition of carbon footprint was not clear. The carbon 'footprint' doesn't refer to an area of land, but it refers to the value that represents emissions of carbon dioxide or the group of GHGs (Wright et al. 2011). Wackernagel and Rees in 1998 have coined carbon footprints as a subgroup of ecological footprint and Manfred Lenzen and Shauna A. Murray in 2001 proposed modified ecological footprints (Bazan 1997; Lenzen and Murray 2001). Carbon footprint can be defined as the net volume of CO_2 and other GHGs, discharged during the entire life cycle of the process/ product. It can be represented in terms of gm of CO_2 equivalent/KWH of production (gCO_2eq/kWh) (Solís-Guzmán et al. 2018). IPCC has been formed as a result of the global concern related to the roots and magnitudes of the changing climate (Skoglund and Jensen 2013). The carbon footprint calculations aids in identifying the diminution measures for managing and controlling the GHG emissions (Larsen and Hertwich 2010). This CF calculation in terms of the emissions helps in identifying the primary. Embodied carbon and embodied energy calculations for residential houses using life cycle assessment have been reported in a number of research works (Almeida et al. 2018; Monahan and Powell 2011; Rossi et al. 2012; Surahman et al. 2015). Many studies are primarily focused at determining the general value of the EC and EE (i.e. carbon footprint) in units of GJ/m^2 and $KgCO_2/m^2$ respectively (Dixit et al. 2012; Mohd et al. 2014; Moncaster and Song 2012). Greenhouse gas emissions from various building materials commonly used for construction such as concrete, steel, wood etc. have also been analyzed and examined by the researchers (Bolin and Smith 2011; Huntzinger and Eatmon 2009). It has been reported that the energy requirement for new construction using conventional materials is 25–50% more than the energy required by alternative materials (Milford et al. 2013; Shukla et al. 2009). Hacker et al. performed an analysis by considering the weight of the timber used in the frames. It was concluded that the heavy weight timber have around 15% more carbon emissions as compared to the light weight timber frames (Hacker et al. 2008). During a study in Hong Kong, focusing the emissions from the houses and the construction activities, it was reported that around 6–9% of GHG emissions resulted from the equipments used in construction activities, around 6–9% from the transportation and 82–87% is in the form of embodied carbon of the building materials (Wiedmann et al. 2010). Very few studies have been conducted in India that focuses on the calculation of carbon footprint of a model houses (Pandey et al. 2011; Ramachandra et al. 2014).

The Present work is aimed at calculating the carbon footprints of a low energy economical dwelling constructed at CBRI, Roorkee India in 2015. The total CF value for this economical house is assessed by determining the embodied carbon and embodied energy of all the materials used in the construction. The CF values were then calculated for the same dwelling by using alternative materials and a comparison has been done between both the cases.

34.2 Methodology

The CF analysis of the frequently used construction materials and the eco-friendly construction materials has been done through the model of economical houses constructed at Central Building Research Institute, Roorkee India in 2015. Process analysis life cycle assessment (PA-LCA) technique has been adopted for calculating the carbon footprints for the model houses. The carbon emissions for various materials used in the study have been calculated using the carbon factors and embodied energy factor of the Inventory of Carbon & Energy (ICE) (Geoff et al. 2011).

34.2.1 Affordable Model House Using Conventional Materials

The economical dwelling is constructed with low cost techniques consisting of single bedroom with a loft on upper floor, bathroom, toilet and kitchen. Figure 34.1 represents the ground floor plan of the model house which has a total inside floor area of 23.4 m^2. Materials used are lime, concrete, bricks, cement, aggregates, bitumen etc. Foundation of the model house is laid using bricks over the PCC. Superstructure walls are made of bricks. Tiles and Joist, RC channels are used in floor and roof respectively. Kitchen and bathroom roofs consist of RC planks and roof of upper floor is constructed using brick panels. Figures 34.2 and 34.3 show the front view plan and actual constructed view of model house.

34.2.2 Affordable Model House Using Alternative Materials

The CF of house for plain area as calculated earlier consists mainly due to bricks, cement and concrete. If these materials can be replaced by such materials which are similar and good in strength and performance as compared to traditional methods as well as are eco-friendly can significantly reduce CF. The materials that are used for replacement are the burnt clay fly ash bricks in place of conventional bricks, mud mortar in place of cement mortar and mud phuska in place of bitumen.

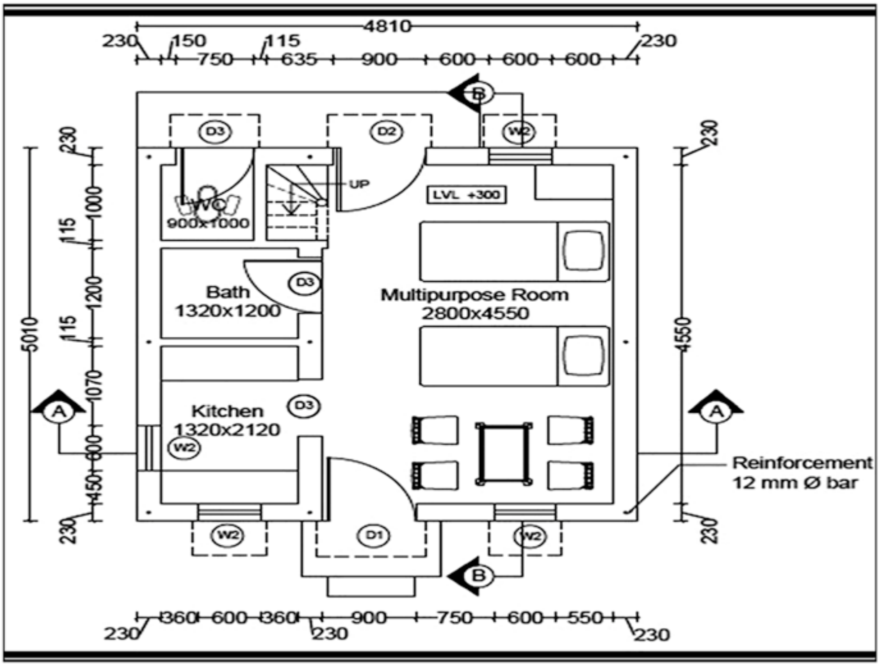

Fig. 34.1 Ground floor plan of model house

34.3 Result and Discussion

In the present study, the carbon footprints in the form of carbon dioxide emission, is measured for an affordable housing in plain region. In the first stage conventional bricks and cement mortar was used in the building and in the second stage, burnt clay fly ash bricks and non-erodible mud mortar was used. The affordable house is constructed using the conventional building materials such as lime, concrete, bricks, cement, aggregates, bitumen etc. The Foundation of the building is constructed using bricks above plain cement concrete. Figure 34.4, 34.5 and 34.6 shows the carbon emissions of various major materials used in the building construction in terms of the tonnes of CO_2 emitted per tonnes of the material used. Figure 34.7 shows the comparison of the total carbon emissions of conventional and Eco-friendly material.

Figure 34.4 represents the carbon emission of the conventional bricks and the eco-friendly burnt clay fly ash brick used in the affordable housing. It is evident from the Fig. 34.4 that there is a huge difference in the carbon emission of both the types of bricks. The burnt clay fly ash brick produces almost 57% less carbon as compared to the conventional clay bricks. The main reason responsible for this is the manufacturing process involved in both the types of bricks. The conventional bricks consume lot of energy during the burning process in the kiln (Rajarathnam

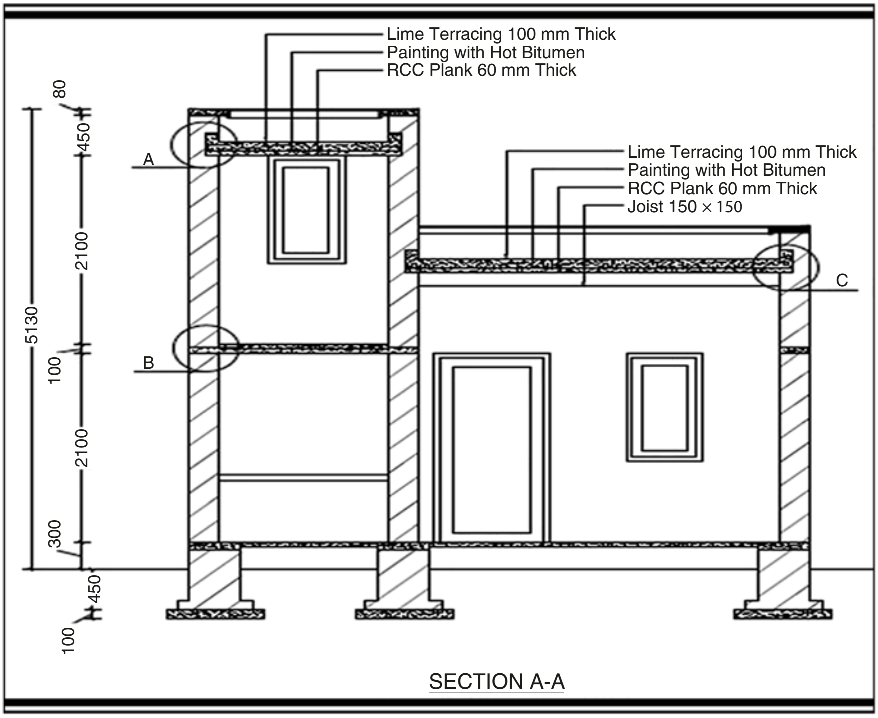

Fig. 34.2 Front elevation plan of model house

et al. 2014) whereas the fly ash bricks do not require any burning. Fly ash mixed with local soil is used to manufacturer burnt clay fly ash bricks. The fly ash content being 50% and having strength of around 9 N/mm^2 which is more than clay bricks and being weight of 3 kg usage of fly ash bricks helps in saving of coal, better thermal and insulation properties and usage of less energy as compared to burnt clay bricks (SHEE 2007).

Figure 34.5 shows the comparison of the carbon emitted by the conventional cement mortar and the eco-friendly mud mortar. The mud mortar is emitting 0.27 tonnes of CO_2 whereas the conventional cement mortar is emitting 0.61 tonnes of CO_2. The reason for this large difference in carbon emission is the presence of cement in conventional cement mortar. The cement is one of the major contributors of carbon dioxide in the atmosphere (Gale et al. 2003). As an estimate, more than 220 kg of C/t of cement is emitted by the cement industries globally (Worrell et al. 2001). This mud plaster is equally suitable to hot as well as arid region. It is used for plastering the walls in place of cement plaster. A mixture of hot bitumen and kerosene oil (SHEE 2007) has been used to make mud plaster non-erodible. The plaster increases the life of mud wall and serves best under all conditions. It also minimizes the maintenance cost.

Fig. 34.3 Actual view of model house

From Fig. 34.6, it is evident that mud phuska, being used as an eco-friendly material, is having slightly higher carbon emissions as compared to the bitumen. The CO_2 emission of mud phuska is almost 37% more as compared to the bitumen. The reason for this increased carbon emission from eco-friendly material is that the binder used in this mud phuska is bitumen which itself is having some carbon emissions.

Figure 34.7 shows the total carbon emissions of all the conventional materials and eco-friendly materials used for the construction of the affordable housing. Apart from the bricks, cement and bitumen, it also includes the carbon emissions from other materials. The total carbon emission from the affordable housing when constructed using eco-friendly construction materials is 9.7 tonnes which is almost 44% less as compared to the conventional materials.

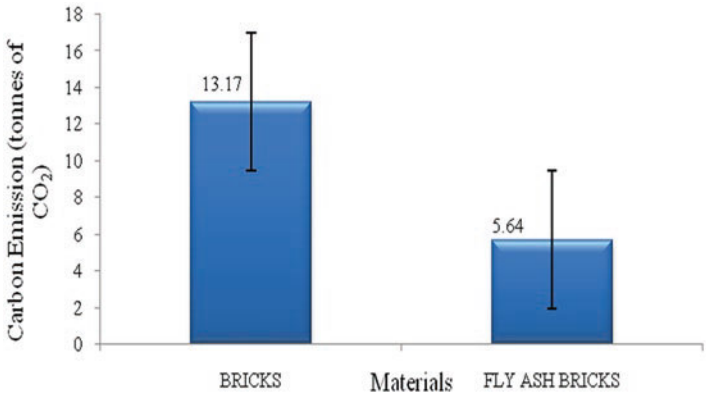

Fig. 34.4 Carbon emission of bricks and fly ash bricks

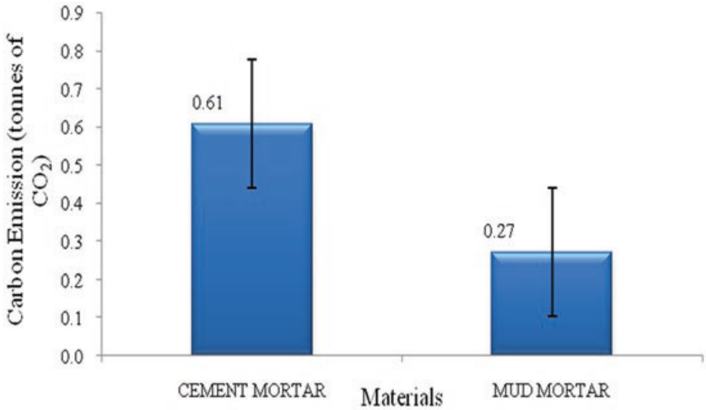

Fig. 34.5 Carbon emission of cement mortar and mud mortar

A total of 230.7 GJ of the energy has been consumed in the construction of the model house. The total inside floor area of 23.4m^2 accounts for approximately 9.86 GJ/m^2 of primary energy. Total CF value of the constructed model dwelling in terms of CO_2 is estimated to around to 17.5 tonnes which is equivalent to 748 Kg CO_2/m^2. Bricks are the major contributors to both EE and EC. Therefore, the use of the eco-friendly construction materials such as burnt clay fly ash bricks and non-erodible mud plaster can significantly reduce the carbon footprints. Additionally, if the binder in mud phuska is also replaced to some eco-friendly binder then it may also contribute to the reduction in carbon footprints.

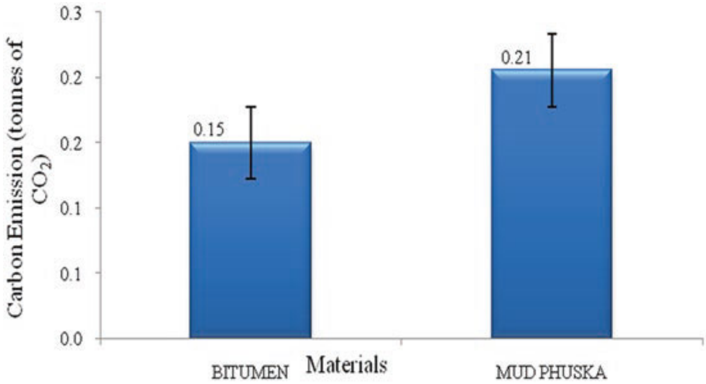

Fig. 34.6 Carbon emission of bitumen and mud phuska

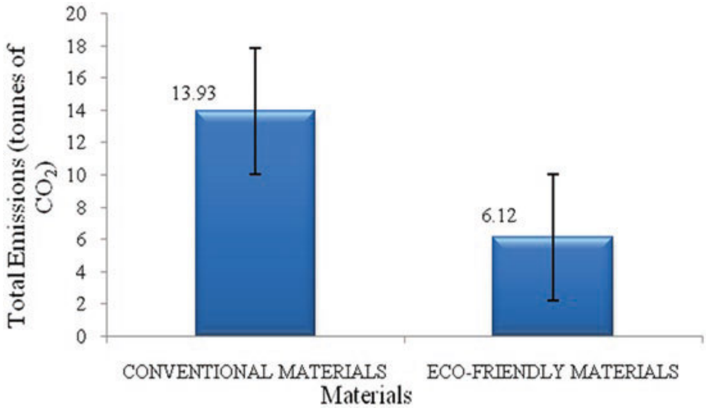

Fig. 34.7 Total carbon emission of conventional and eco-friendly materials

34.4 Conclusion

The present study aimed at analyzing and determining the energy consumption and carbon emissions from the building materials used for the construction of a model dwelling at CBRI Roorkee India. Following main conclusions that can be drawn from the study:

- The affordable house constructed for plain region has a high carbon footprint of 17.5 tonnes of CO_2 and requires 230.7 GJ of energy during its construction. The principal materials that contributed in huge amount of emissions are bricks and cement. Replacement of these materials is needed to control the carbon emissions.
- In case of affordable housing in plain region, bricks and cement together is contributing to an emission of 15.9 tonnes of CO_2 and hence both these materials need careful monitoring for controlling the emissions.

- Utilization of non-erodible mud mortar in place of cement mortar can significantly reduce the carbon footprints of the houses.
- Bitumen should not be used as a binder while using Mud Phuska as it leads to increased carbon emissions as compared to other materials.
- Therefore, for the construction of low energy buildings less polluting and low CF value materials should be considered. These materials serve dual purpose by providing required strength to the structure and minimizing the harmful effects on the environment as compared to the conventionally used construction materials.

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Chapter 35
Experimental Investigation of the Impacts of Partial Substitution of Cement with Rice Husk Ash (RHA) on the Characteristics of Cement Mortar

Nakul Gupta and Ankur Gupta

Abstract A major key factor that contributes to a great extent to the greenhouse gas (GHG) emissions and global warming is the manufacturing process of cement. The use of waste generated from industries and agriculture like ceramic waste, fly ash (FA), RHA and many others as a part substitution of cement may lead to a reduction in the GHG emissions. This paper is based on the utilization of ash, produced by burning rice husk, to partially replace standard cement in mortars. RHA is a pozzolanic material and therefore could be suitably used for the partial replacement of cement. The cement replacement with RHA was done in proportion of 4%, 8%, 12%, 16% and 20% by wt. of cement. The water/binder ratio of 0.38 was maintained in all prepared samples. Setting times, strength in compression, ultrasonic pulse velocity (UPV) and water absorbing capacity of the specimens at each replacement proportion has been investigated at specified days of curing. The times (initial and final) required for setting of pastes were increased as the proportion of RHA in the mix is increased and a maximum time of 151 min for initial setting and 306 min for final setting were obtained. The ultimate compression strength of 47.9 MPa was obtained at 56 days of testing and with 8% RHA content. The ultrasonic pulse velocity values indicate a sound mortar. The water absorbing capacity reduced with increase in the RHA content in the conventional mortar.

Keywords Rice husk ash · Setting time · Workability · Compression strength · UPV · Water absorbing capacity

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35.1 Introduction

The production of cement is causing environmental degradation not only because of the burning of the fuel but also because of the chemical process of calcinations which involves the liberation of almost equal proportions of carbon dioxide as is liberated during fuel combustion (Leung et al. 2014). Carbon dioxide, which contributes to around 80% of the Green House gases, is accountable for numerous disturbing phenomena triggering disproportioning on earth. The use of cement in India is increasing greatly due to the increasing construction activities and as an estimate it is around 0.2 tonnes per capita in 2019 (Gettu et al. 2019). The report submitted by Elias I. Saqan states that if 30% of the global usage of the cement was substituted with supplemental cementing materials (SCMs) then it may lead to the reversal in the increase in CO_2 emissions from cement production (Elias I. Saqan 2008). This increasing consumption of cement, of course, is an alarming condition and it can be controlled if the cement can be substituted by some other unconventional material. With the same thought of finding a compatible substitute of the cement, numerous researches have been initiated that utilizes various industrial and agricultural wastes possessing pozzolanic properties (Ashish 2018; Baeza et al. 2014; Gupta et al. 2020; Raheem and Ikotun 2020). The outside wrapper of the rice grains produces a residue during milling process which is known as the rice husk. Around 1000 lakh tons of rice husk residue is produced from 5000 lakh tons of paddy produced globally (Foo and Hameed 2009). RHA also owns binding capacity and could be utilized as a part replacement of cement (Ay and Ünal 2000; Heidari and Tavakoli 2013; Renato et al. 2015; Shukla and Gupta 2020; Vejmelková et al. 2012) in cement mortar. The pozzolanic activity of RHA is because of the large sp. surface area and the non-crystalline nature of silica units. The use of RHA to partially replace cement is also specified in the IS: 456–2000 (Bureau of Indian Standards 2007). The process of burning and the temperature at which the rice husk is burnt greatly affects the chemical composition of the RHA (Ai-khalaf and Yousift 1984). It has been reported in a study that preparation of RHA with larger specific surface area can be suitably carried out at temperature range of 600 °C to 650 °C in the muffle furnace. Whereas, improved pozzolanic activity of RHA can be achieved by extending the combustion time (Bie et al. 2015). Meticulous burning condition in industrial furnace produces ash containing highly cellular form of amorphous silica, with 50–1000 m^2/g of surface area (Pirtz n.d.). Partial substitution of cement with RHA leads to the improvement in workability and reduction in heat of evolution, thermal cracking and plastic shrinkage (Muthukrishnan et al. 2019). Controlled burning conditions for rice husk also improve the strength, durability and impermeability due to the strengthened transition zone, modified pore-structure and pozzolanic reaction. Few research works have reported that RHA at initial stage does not exhibit pozzolanic characteristics but reflected pozzolanic characteristics at later ages (Pokorný et al. 2014; Vejmelková et al. 2014). Pozzolans derived from industries and agriculture wastes, such as FA and RHA, are gaining popularity because their usage enhances the characteristics of blended cement concrete, lowers costs, and reduces deteriorating impacts on the environment (Shukla et al. 2020). Rice husks, also known as rice hulls, are the shells generated during the dehusking process of paddy rice and are one of the most common agricultural by-products. It accounts for 20% of the world's paddy production, which totals five hundred million tonnes. Rice-husk is not suitable for use as a feed for animals because of its low nutritional value. Furthermore, its siliceous nature resists natural degradation, posing a significant environmental burden. As a result, appropriate alternative disposal procedures must be established in order to minimize negative environmental consequences. Rice husk has been widely utilized as a fuel for rice mills and energy generating power plants in various countries as a cost-effective way to reduce rice husk quantity. Concrete manufactured by using rice husk ash in place of cement in proportion of 10% by wt. of cement, at water curing, depicted most promising results among all the proportions used and also developed more (or) less similar results as shown by the standard cement concrete. Hence the utilization of RHA seems both logical and economical (Dhrolwala et al. 2018).

In the current study, RHA had been used to replace conventional binder in various proportions (4%, 8%, 12%, 16% and 20%) by wt. of cement. The ratio of liquid to binding material was maintained constant at 0.38 in all mixes. The setting times at each replacement proportion was determined. The compressive strength test was carried out on all the specimens after a curing of 3, 7, 14, 28 and 56 days. The UPV values and water absorbing capacity of the specimens at each replacement proportion was determined after 28 and 56 days.

35.2 Experimental Program

35.2.1 Materials

OPC 43 cement meeting the requirements of IS 8112:2013 (Bureau of Indian Standards 2013) was utilized as conventional binder in the current study. The sp. gravity (SG) of the binder was 3.14. The consistency of the cement, found using Vicat apparatus as per IS: 4031 (Part 4) – 1988 (Bureau of Indian Standards 1988a) was obtained as 31%. Locally available sand confirming to IS: 383–1970 ((BIS), 1970) has been used. The fineness modulus (FM), SG and WA of the sand used were obtained as 2.61and 2.64 and 0.51% respectively and the sand lie in grading zone-II. Rice husk ash of average particle size 33.6 μm and SG 2.06 was used in the current study. RHA has been procured from Astra Chemicals, Chennai. Table 35.1 shows the chemical composition of RHA as delivered by the supplier.

Table 35.1 RHA chemical composition

Constituents	SiO_2	MgO	Al_2O_3	K_2O	CaO	Fe_2O_3	SO_3	LOI
Content (%)	89.06	1.86	1.26	1.01	0.81	0.61	0.56	5.89

35.2.2 Mix Preparation and Testing

A total of 75 cubical mortar specimens of surface area 50 cm2were cast. Both the standard and the RHA replaced mortar specimens were manufactured by using binder and sand in a ratio of 1:3. The cement was replaced with RHA in proportions of 4%, 8%, 12%, 16% and 20%. Vicat apparatus, compliant to IS: 5513–1976 was used to determine the time required for setting of the prepared samples in line with IS: 4031 (Part 5) – 1988 (Bureau of Indian Standard(BIS) 1988). The strengths of all the samples in compression were found after desired days of curing (3, 7, 14, 28 and 56 days) using digital CTM. The loading was continued till the failure of the specimen and the corresponding failure loads were recorded. The water absorption values and the UPV values were found at 28 and 56 days. The quantities of ingredients of the mixes per m^3 of the mortar are shown in Table 35.2.

35.3 Results and Discussion

35.3.1 Setting Times

The setting times of the conventional cement and RHA substituted cement at all proportions (i.e. at 4%, 8%, 12%, 16% and 20%) were determined using Vicat apparatus. The amount of water needed for making the paste was determined based on the standard consistency test. The initial setting time was considered as the time duration when water was first mixed to the binder and when the needle was unable to penetrate beyond 5 mm from the base of the mould. The readings were taken after every 5 min. The test results are shown in Fig. 35.1.

Figure 35.1 clearly shows that the setting times got increased as the proportion of the rice husk ash was increased. The initial setting time increased to 151 min from 84 min and final setting time increased to 306 min from 222 min for RHA-20 samples as compared to RHA-0 samples. Also, as the RHA proportion was increased from 4% to 20%, the paste became harsher. The delay in setting times with increasing rice husk ash proportions were 8 min and 6 min at 4%, 27 min and 26 min at 8%, 39 min and 37 min at 12%, 48 min and 50 min at 16% and 67 min and 84 min at

Table 35.2 Quantities of ingredients in the mixes per m^3

Sr. No.	Sample Id	Cement (kg)	RHA (kg)	Sand (kg)	Water (kg)
1	RHA-0	1044.1	0.0	2633.4	395.32
2	RHA-4	1002.3	41.8	2633.4	395.32
3	RHA-8	960.5	83.5	2633.4	395.32
4	RHA-12	918.8	125.3	2633.4	395.32
5	RHA-16	877.0	167.0	2633.4	395.32
6	RHA-20	835.2	208.8	2633.4	395.32

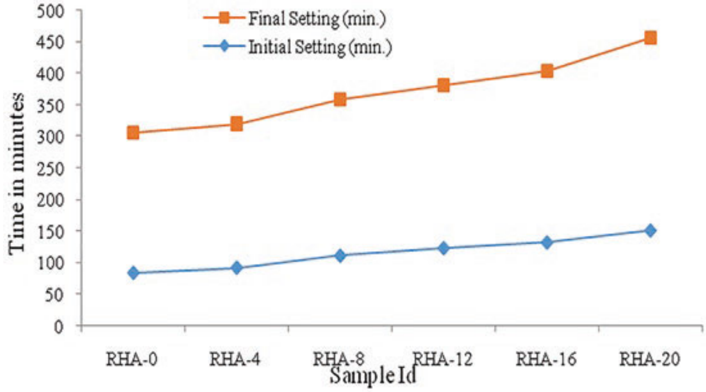

Fig. 35.1 Setting times of samples

20%. This trend of increase in the times required for setting might be due to the reduced hydration rate of the rice husk ash particles present in the samples (Marthong 2012). The cement with rice husk ash proportions possess finer particle size and therefore shows better setting behavior (El-Dakroury and Gasser 2008).

35.3.2 Compressive Strength

Cubical moulds of sides 70.6 mm each and having cement to sand ratio of 1:3 have been tested using compression testing machine (CTM) confirming to IS 4031 (PART 6): 1988 (Bureau of Indian Standards 1988b). Curing of the prepared cubical specimens has been done for 3 days, 7 days, 14 days, 28 days and 56 days. The water/binder ratio of 0.38 was maintained for all the specimens. The RHA was substituted in place of cement at 0, 4, 8, 12, 16 and 20% by weight of cement. The testing results are shown in Fig. 35.2.

It is obvious from Fig. 35.2 that the strength in compression at 3 days of testing decreased as the rice husk ash content was increased from 4% to 20%. At 7 days of testing the strength for 4% and 8% rice husk replacement were found as 31.9 MPa and 30.6 MPa which were more than conventional mortar strength of 29.4 MPa. The strength thereafter started decreasing on increasing the RHA content. The trend of variation in strength at 14, 28 and 56 days of testing were almost similar. The maximum strength was obtained at 8% rice husk replacement and then the compressive strength started decreasing at 12%, 16% and 20% replacements. The early strength of the mortar reduced as rice husk ash content was increased. This might be due to the slow hydration rate of the rice husk ash particles present in the samples. The compressive strength shows an improvement after 7 days of curing and upto 56 days of curing because of the onset of the hydration of the RHA particles. The RHA

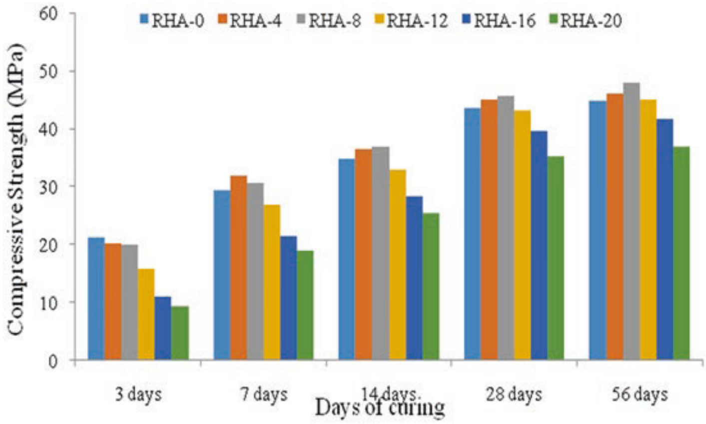

Fig. 35.2 Compression strength of samples

cement with a finer particle reveals higher compressive strength (El-Dakroury and Gasser 2008).

35.3.3 Ultrasonic Pulse Velocity (UPV) Test

Cubical specimens, at ages of 28 days and 56 days, have been tested using UPV testing machine. The testing has been conducted in accordance to the method as defined in Part-1 of IS 13311: 1992 (Bureau of Indian Standards 1992).

From Fig. 35.3 it is clear that the ultrasonic pulse velocities both at 28 days and 56 days are increasing up to rice husk substitution of 8% and thereafter started decreasing. The ultrasonic pulse velocities in km/sec of the samples at 0%, 4%, 8%, 12%, 16% and 20% rice husk proportions were found to be 4, 4.08, 4.15, 4.1, 3.93 and 3.71 respectively after 28 days of curing and 4.1, 4.22, 4.5, 4.27, 4.02 and 3.89 respectively after 56 days of curing. RHA presence in mortar tends to modify the physical and chemical structure of the pores due to its micro filling and pozzolanic effects and as a result of this the pores gets refined and porosity got reduced that leads to a dense pore structure thereby contributing to a greater ultrasonic pulse velocity values (Safiuddin et al. 2010).

35.3.4 Water Absorption Test

The testing was done for all the prepared samples at 28 and 56 days. The mortar samples were cured for specified number of days and then were removed from curing tank. These specimens were then kept in a temperature control device at 105 °C

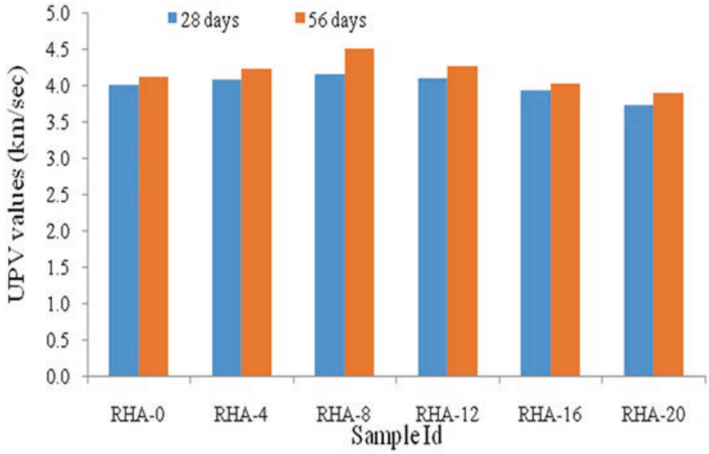

Fig. 35.3 Ultrasonic pulse velocity values of mortar samples

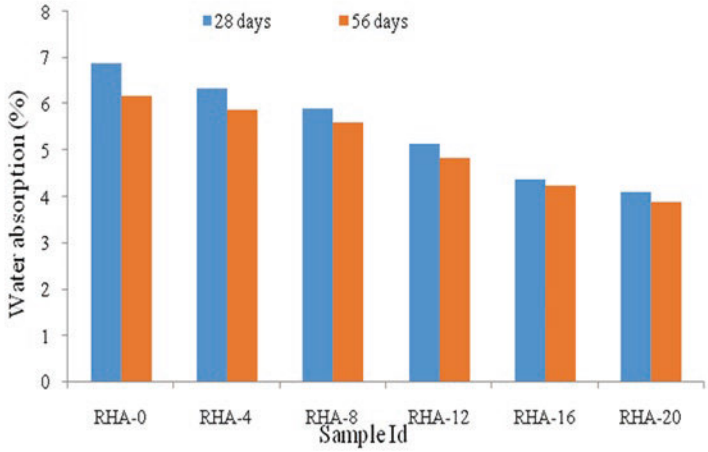

Fig. 35.4 Water absorption values of mortar samples

for 1 day. The weights of the dried samples (W_1) were measured with the help of a digitally operated weight machine. All the specimens were kept for curing again for a period of 1 day. The weights of the samples (W_2) after absorbing water for a period of 1 day were noted. The water absorbing capacity of the samples were determined as per the standard equation i.e. $[(W_2\text{-}W_1)/W_1] \times 100$. Figure 35.4 shows the representative absorption limits corresponding to the avg. of the absorption values of 3 samples.

It is evident from Fig. 35.4 that the capacities of absorbing water by the mortar specimens started decreasing as the RHA content was increased. The water absorption reduced from 6.89% to 4.09% at 28 days of testing when the rice husk content was increased from 0% to 20%. Similar results were observed after 56 days of testing. The water absorption percentages at 4%, 8%, 12%, 16% and 20% rice husk replacement were obtained as 5.88, 5.59, 4.83, 4.24 and 3.89 respectively after 56 days of curing. The reason for the decrease in the absorption capacities of the mortar specimen shaving rice husk ash proportion as compared to the standard cement mortar specimens may be attributed to the fact that the presence of rice husk ash particles reduces the internal pores in the mortar (Givi et al. 2010).

35.4 Conclusions

On the basis of the investigation of the effect of the addition of rice husk ash at different proportions (i.e. 4%, 8%, 12%, 16% and 20%) in conventional cement mortar, following conclusions can be drawn:

- The setting times increased with the increase in the RHA content and a maximum gain of 67 min in the initial setting time and 84 min in the final setting time was obtained at 20% RHA proportion.
- The early days compressive strength was less for RHA replaced mortars as compared to conventional mortar. However the strength started increased after 7 days for rice husk ash replaced mortar but the strength decreased as the RHA content increased beyond 8%.
- Ultrasonic pulse velocities both at 28 days and 56 days of testing increased upto 8% RHA content and then showed a decline at 12%, 16% and 20% content.
- The water absorption capacity of the mortar reduced as the rice husk ash proportion is increased. The water absorption reduced by 40.64% and 36.85% after 28 days and 56 days of testing respectively at 20% RHA proportion.

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Chapter 36
A Mini Review on Current Advancement in Application of Bacterial Cellulose in Pulp and Paper Industry

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Abstract Bacterial cellulose (BC) is a nano-biomaterial which is environment friendly and has gained attention in pulp and paper industry. The reason behind its popularity lies in its stout physical properties. BC has high water retention capacity, chemically and mechanically stable, biocompatible, crystalline, ultrafine network structure and has large surface area. The composition of BC consists of glucan molecules arranged linearly with hydrogen bonds. This structure seems indistinguishable from plant cellulose. Unlike other conventional, synthetic or natural cellulose, BC functions well in the field of biomedicine, paper making, nanofillers, water treatment etc. due to its above-mentioned properties. Pulp and Paper industry is one of the sectors where sustainable and environment friendly approach becomes the prime need. Potential application of BC in paper industry can include strengthening of paper, increase water holding capacity of paper, formation of electronic papers and in making of flame-resistant paper. In this review potential applications, current status and physicochemical properties of BC in pulp and paper technology are discussed.

Keywords Bacterial cellulose · Pulp and paper · Nano · Biomaterial · Plant cellulose · Biocompatible

36.1 Introduction

The environmental concern caused the research scientists to focus more on bio-based resources, which are imperishable in nature. The film forming properties of microbial polysaccharides such as Bacterial Cellulose (BC) makes them a potential source for several bio and non-bio based sectors of today's world. In contrast to

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plant cellulose the absence of lignin and hemicellulose makes it an inert and biocompatible material. Besides this, BC is biodegradable and safe polymer which is neutral for human consumption. Nanofibrillar structure of BC increases its surface area and makes it porous and a tough polymer at the same time. Because of its versatile nature BC can be modified and produce compounded materials with improved properties (Shah and Brown 2005; Klemm et al. 2006; Hong and Qiu 2008; Kurosumi et al. 2009; Zeng et al. 2011).

Traditional BC formation methods have proposed by various researchers and their facet of work based on lab-scale and large-scale production of bacterial cellulose. Recently, remarkable progress in production of BC has been observed and various research reports have also been published on use of BC in paper, pharmaceutical and cosmeceutical industries. There are various bacteria that produce cellulose out of which *Gluconobacter xylinus* is most common among them due to its high yield. (Nguyen et al. 2008).

BC is highly pure, thermostable, durable and consistent in nature (Yoshinaga et al. 1997; El-Saied et al. 2008). These features have led the scientist to focus the research towards the use of BC as a new alternative in paper forming and modulating process (Jonas and Farah 1998; El-Saied et al. 2004; Chawla et al. 2009; Cheng et al. 2011). Potential application of BC in paper industry include strengthening of paper, increase water holding capacity of paper, formation of electronic papers and in making of flame resistant paper. This review describes the potential use of BC in pulp and paper industry.

36.2 BC Based Modifications of Paper

The credit of stability and longevity of pulp when it is converted to paper goes to BC which can act as a binder in paper. The reason for this is its structure, which has tiny bundles of cellulose microfibrils (Brown 2004). The use of BC in paper making has been implemented by Ajinomoto Co. and Mitsubishi Paper Mills in Japan (Hioki et al. 1995). It was observed in a study that when fragmented BC is added to paper pulp, it gives good tensile strength to the paper which is formed out of it (Yamanake and Watanabe 1995).

36.2.1 BC for Enhancing Strength Properties of Paper

A study demonstrated that by mixing cationic starch or paper pulps to BC shown to improve film properties for enhance packaging strength. Addition of 30 wt.% pulp with short fibers to BC have shown improved mechanical strength, while 2% w/w cassava starch with BC have shown to improve burst, tensile strength, resistance to water vapor and permeability of Oxygen (Pradipasena et al. 2018). Surma-Ślusarska et al. (2008) reported the potential of modifying paper properties by addition of BC to fibrous paper pulps. For this, three different composition have made, in the first

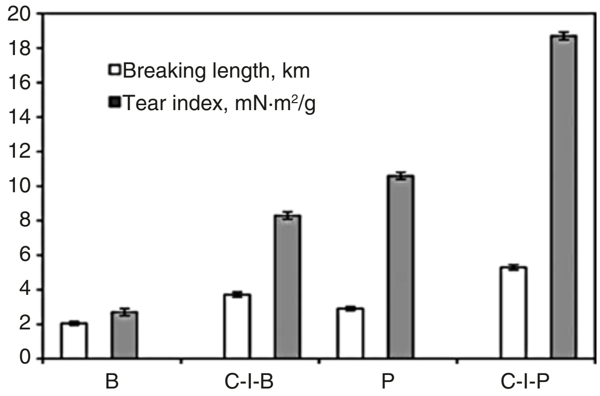

Fig. 36.1 Strength property comparison (Breaking Length and Tear Index) of B – Birch Pulp, C-I-B – Composite of BC and Birch Pulp, P – Pine Pulp, C-I-P – composite of BC with Pine Pulp. (Adapted from Ref: Surma-Ślusarska et al. 2008)

one BC synthesised by *Acetobacter xylinum* in medium containing fiber semi-products from papermaking process was used; in the second one suitably disintegrated bacterial cellulose film was added to the papermaking pulps; and the third one involves attaching semi-product paper sheets with bacterial cellulose film by placing them on a sheet of paper to let it dry drying using Rapid-Koethen method (Surma-Ślusarska et al. 2008). The comparison and determination of fibrous semi-products and their composites with bacterial cellulose was done on the basis of structure and strength. It was noticed, among others, that first two methods are good for the production of composites and these composites show more tensile and dynamic strength than other semi-products for composite preparation (Fig. 36.1). On comparing two-layered composite (i.e. fibrous semi-product and bacterial cellulose) with bacterial cellulose then the two layered shows higher tear resistance and peaked static strength in case of comparison with unbeaten pulp (Surma-Ślusarska et al. 2008). The semi product formed by joining the bacterial cellulose and pulp fibres has high mass per unit volume in natural state regardless of the joining method. Pure birch and pine pulps have lower breaking length as compared to the composites of BC, pine pulp, bleached birch and unbeaten pulp.

A study by Rattanawongkun et al. (2019) have made reinforced bagasse (BG) sheets by mixing it with BC. *Komagataeibacter nataicola* culture was used to produce BC, further the BC fibers were defibrillated by using microfluidizer. After studying the physical, tensile and morphology of the reinforced sheet, it was found that BC when mixed with BG has increased the overall density but decreased the porosity of the sheets. SEM images has clearly shown (Fig. 36.2) that BC fibers have bridged the gaps generally found in BG fibers which is the main cause of increasing strength of the mixed fibers (Fig. 36.3). There is 117% and 47% enhancement in elongation and tensile strength of the reinforced sheets after just mixing of just 5 wt% BC (Fig. 36.4) (Rattanawongkun et al. 2019).

Papers made up of recycled fibres can be strengthened using BC fibers. Xiang et al. (2019) in their study proved that carboxymethyl cellulose, xylan, cationized starch, glucomannan and polyethylene oxide were used to upgrade the diffusion of BC fibers. Paper made with the combination of BC fiber and recycled fiber showed an increase in dry tensile index of 4.2 N.m/g or 12.7%, obtained by addition of

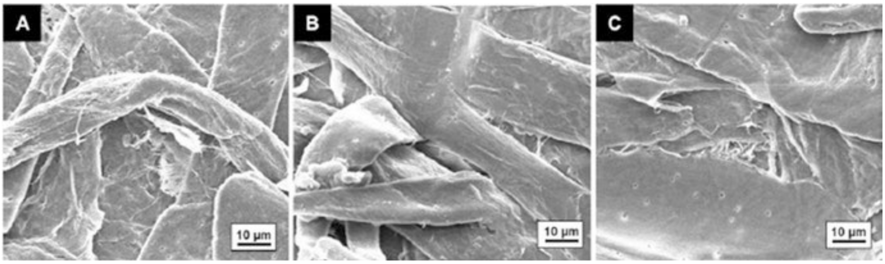

Fig. 36.2 SEM images of Bagasse sheet containing (**a**) 0%, (**b**) 0.5%, (**c**) 5% of Bacterial Cellulose. (Adapted from Ref: Rattanawongkun et al. 2019)

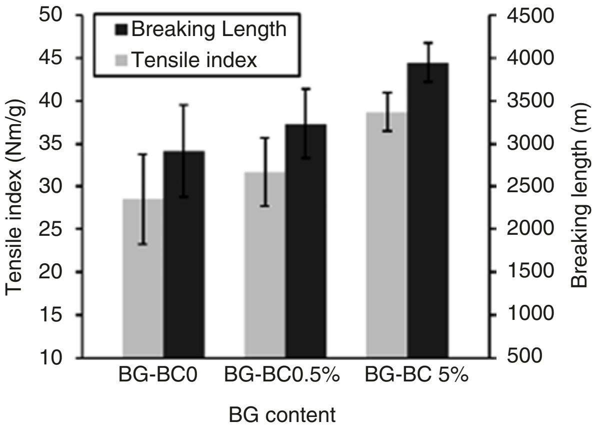

Fig. 36.3 Reinforcing effect (Breaking Length and Tear Index) of Bagasse sheet containing (**a**) 0%, (**b**) 0.5%, (**c**) 5% of Bacterial Cellulose. (Adapted from Ref: Rattanawongkun et al. 2019)

glucomannan. When glucomannan adsorption on BC fibers was studied, a high colloidal stability of BC fiber suspension with no signs of aggregation and enhanced wet tensile index was seen (Xiang et al. 2019).

In another study, an enhancement in tear and tensile index by 14.2% and 12.2% respectively was exhibited in papers that were produced with pulps that were cultivated in agitation process (Campano et al. 2018), thus the paper flexibility was increased as well. Whereas, in static culture enhanced pulps fail to improve the paper's tensile index while increasing the tear index by 12.4%. The mechanism of production of both types had been proposed. The primary fibers were coated by bacteria in agitated culture, thus improving their quality. Heterogeneous systems were found in static culture. This is because of the sedimentation of recycled fibers during the movement of bacteria to the culture broth's surface in the need of oxygen (Campano et al. 2018). Hence BC's production in situ with recycled fibers can hence be an alternative which replaces conventional paper strengthening agents. The results obtained indicate that upgraded pulps production in situ can be performed in paper mills that cultivate pulp streams which can be sterilized through non-exhaustive, low cost operations such as UV or ozone radiation (Campano et al. 2018).

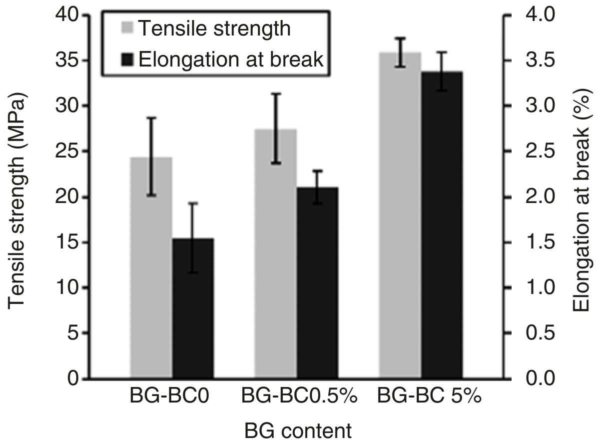

Fig. 36.4 Reinforcing effect (Tensile Strength and Elongation at Break) of Bagasse sheet containing (**a**) 0%, (**b**) 0.5%, (**c**) 5% of Bacterial Cellulose. (Adapted from Ref: Rattanawongkun et al. 2019)

Further a study was done to know the ability of bacterial cellulose on modifying pulp characteristics which was obtained from recycled waste papers (Kalyoncu and Peşman 2020). During Kombucha tea fermentation, bacterial cellulose was produced. The wet films of bacterial cellulose were dispersed and added at different rates of 5%, 10%, 15% to the waste papers that were recycled. The FTIR, SEM and thermogravimetric analyses were carried out whose values were used to determine the pulp sample characteristics. The tensile and burst index values were maintained constant whereas the value of tear index was partially decreased with increase in bacterial cellulose amount. After thermal aging, the papers that were reinforced with bacterial cellulose did not have any change in the values of brightness, whereas yellowness values have limited change. Higher rates of water absorption and lower values of air permeability were obtained from recycled paper sheets that were reinforced with bacterial cellulose. Considering physical and mechanical properties of bacterial cellulose reinforced paper, a promising alternative is represented by bacterial cellulose (Kalyoncu and Peşman 2020).

36.2.2 Fine Quality Papers

Some studies have shown that BC pellets taken from agitated culture were used to form fine quality paper. Bacterial cellulose can be added as a wet-end material during the papermaking process. A study to produce high quality biodegradable fiber was done by forming a composite of sugarcane bagasse and BC (Costa et al. 2020). For this process, the bagasse was first grinded, washed and further hydrolysed to separate cellulose fibers. Then the bagasse fiber was mixed with BC fiber and were further kept for drying. The final composite mixture was then characterised by TGA, DRX and FTIR, and it was found that the quality of the new composite is as good as a rigid and dense paper. This method not only reduces chemical load but also have totally reduced high water consumption to produce same type of material. Resulting pulp is eco-friendly produced from bio-waste from sugarcane industry and have shown high quality, biodegradable and high purity cellulose material (Costa et al. 2020).

36.2.3 Degraded Paper Restoration

One of the significant challenges in today's world is to preserve the documentary heritage. Boosting the strength of paper is an important characteristic of bacterial cellulose (BC) which can be exploited to rebuild the old papers which are degraded, this has been showed by a study (Santos et al. 2016). This test was conducted first on the papers with known fibre composition. For this study, the characterization of deteriorated papers was performed followed by reinforcement and then the characterization was done once again. This methodology was applied on Japanese paper (JP), which is a material that is used by conservators, to differentiate between both the materials as reinforcement. The mechanical properties of paper lined with BC and JP were found to be equivalent. Papers lined by using BC have modified optical properties than those reimposed with JP. Also, letters are clearer in the books lined with BC. Only the papers reimposed with BC exhibit changes in pore size. Decrease in burst index also observed due to aging process. This study provided information that BC improves degraded paper quality, without making any change in the properties in it, and this improvement remains for a long time. These are the reasons why we should opt for BC (Santos et al. 2016).

36.2.4 Fluorescent Paper

The principal method of coating fluorescent substances to produce fluorescent paper onto the bases of paper has the problem of poor durability and low efficiency. The nanoporous structure of BC can be used to improve the stability of fluorescent particles. Zhang et al. (2019) used a novel method by making complex of Europium (Eu)/BC first and processing cellulosic fibers and complex into paper sheets thus producing fluorescent papers. Stable complex of Eu/BC can be formed by BC in this composting method through its nanoporous structure while the cellulosic fibers which are plant based reduce the stiffness and the cost to the materials. The fluorescent paper showed a great efficiency and fluorescent property. There was an increase in fluorescent intensity or the UV absorbance of EU/BC based fluorescent paper with Eu-BC content increase. After 200 times of folding the fluorescence intensity decreased only by 0.7% which proves the fact that EU/BC based fluorescent paper has great durability and stability (Zhang et al. 2019).

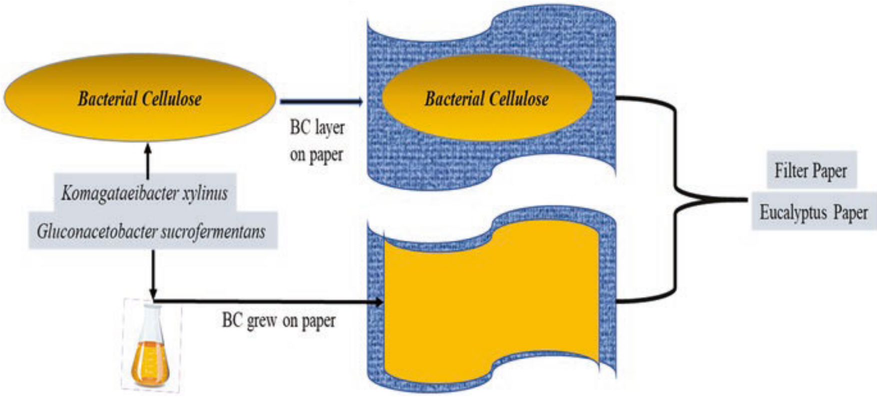

Fig. 36.5 Concept for use of Bacterial cellulose for increasing barrier properties of paper products

36.2.5 New Value-Added Products

Bacterial cellulose has been combined with wood cellulose by Fillat et al. (2018) order to obtain biomaterials that have increased barrier properties. Different parameters were assessed for this purpose i.e. two types of combined biomaterials (bilayer and composite) and two different drying temperatures (room temperature and 90 C). The study has used two bacterial strains (*Gluconacetobacter sucrofermentans* and *Komagataeibacter xylinus*) to produce BC, while eucalyptus paper and filter paper was used to hold bacterial cellulose (Fig. 36.5). Increased barrier properties papers were obtained were obtained by the BC addition to every one of the paper supports. Higher improvements due to the filter paper's lower initial barrier properties were produced in this kind of paper. Smoother surfaces provided by BC with higher gloss without any detrimental effect. The use of *K. xylinus* gave higher resistance to absorption of water due to it long sized fibers than the fibers from *G. sucrofermentans*, as analysed by scanning electron microscopy (Fillat et al. 2018). Gloss and smoothness were especially increased in the biomaterial's bilayer although in the composite resistance to water and air was further improved. In this type of biomaterial high temperature drying had detrimental effect. Obtained products were analysed through SEM had showed an intimate contact among wood paper and BC fibers. Results obtained reveal the contribution of BC to improve the paper properties and its potential in making new value-added products (Fillat et al. 2018).

36.2.6 Composite Papers

The comparison of BC based composite paper and pure pulp paper was studied by Iguchi et al. (2000), it was noticed that the folding tolerance of composite paper increased by four folds after the addition of 15% BC also the Young's modulus increased from 2 to 3.5 (GPa). In the assessments done by Cheng et al. (2011), it was seen that carboxymethyl cellulose-bacterial cellulose composite paper (CMC-BC) showed high mechanical strength, high Young's modulus and tensile strength than ordinary paper. BC is also contributing in the manufacturing of banknotes and bible papers (Iguchi et al. 2000) because these paper products are used for longer duration.

36.2.7 Conductive Papers

Apart from these manufacturing of conductive papers can also involve the use of BC due to the stupendous physical properties it provides to the paper like flexibility, elevated reflectivity, light weight, ease of motility and broad viewing angles (Shah and Brown 2005). Similarly, an in situ oxidative polymerization of aniline was done by Hu et al. (2011) to produce a group of nanostructural membrane of polyaniline/bacterial cellulose (PANI/BC). In Gutierrez et al. 2012 Gutierrez et al. assessed the conductive characteristics of TiO2 nanoparticles and TiO2/bacterial cellulose hybrid inorganic/organic fibers.

36.2.8 Specialized Fire-Resistant Papers

Basta and El-Saied (2009) reported that BC can be used as flame retardant, *Gluconacetobacter* subsp. *Xylinus* was used to produce this type of BC and glucose was replaced by glucose phosphate in the cultivation medium as the carbon source and for nitrogen source corn steep liquor was used. The processing technique which was investigated did not cause any unacceptable effluents or any toxic chemicals that could pollute the surrounding hence making the process safe for the environment. Using non-isothermal TGA and DTGA the fire-retardant behaviour of BC was studied. Methods like least square method and Coats–Redfern equation were used to estimate the degradation order and the activation energy of each stage of degradation (Basta and El-Saied 2009). Thermogravimetric analysis, optical properties and strength of BC-phosphate that was added to added paper sheets were tested as well. It was confirmed that glucose along with glucose 6 phosphate was significant in the production of high yield of PCBC1 (phosphate containing bacterial cellulose). Incorporation of 5% of phosphate containing bacterial cellulose with wood pulp during formation of paper sheet was found to improve strength, fire resistance properties and kaolin retention significantly as compared to BC incorporated paper sheets (Basta and El-Saied 2009). This modified bacterial cellulose is thus a valuable product for the specialized paper preparation in addition to its filler aid function. This study majorly focusses on production of BC in situ in pulps that are recycled to increase the fiber quality in the suspension. The effect of dosages on different levels of the pulp on the optical, physical mechanical properties of hand-sheets was estimated (Basta and El-Saied 2009).

36.3 Industrial Production of BC

Though, BC at large scale has been used in many areas but still its use at industrial level in pulp and paper sector is in research phase. The reason for this may be the large amount of cellulose required for paper making. The requirement is so high that conventional paper making from hard wood is not enough and industries have moved towards many other raw materials like Agro-based raw materials to full fill the cellulose need which cannot be alone fulfilled by wood in this period of economy where people searching for environment friendly industrial processes. A study has shown large scale production of BC by fermentation can be achieved at 15 g/L yield in 2 days (Donini et al. 2010), but still it is far behind than what needed to paper production at industrial level.

Apart from paper industry, BC production can be an alternative in various other areas, such as in food industry. A commercial BC product popularly known as Nata de coco is produced from fermentation of coconut water. The per ton price of Nata de coco varies from 200 to 1000 US$ based on its purity and quality (Ul-Islam et al. 2020). Success of Nata de coco motivates for the need of more research in large scale production of BC for its application in pulp and paper sector.

36.4 Conclusion

Researchers across the world are considering BC as a promising material which can be used to make products keeping sustainable development in mind. Though already been used in various sectors, now studies are focusing in its use in Paper sector. Over plant cellulose, BC has many advantages. For producing BC no need to cut trees, it is highly pure and can be blended with plant cellulose as well. Already many researches are going on and have reported vast potential of application of BC in Pulp and Paper industry. It has shown to enhance strength properties of paper when mixed with proper ratio. Also, studies have reported BC use in forming environmentally friendly Biomaterials, value-added products, fine papers, fire resistant paper, nanofibers, flexible magnetic paper, electronic papers and new Bio-composites. Therefore, future is bright for the application of BC in Paper sector for enhancing pulp and paper quality, to reduce chemical ad water load, to make new environment friendly materials.

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Chapter 37
Effect of Agro-Waste as a Partial Replacement in Cement for Sustainable Concrete Production

Gaurav Shupta, Ajay Goyal, Akhil Shetty, and Abhishek Kanoungo

Abstract An investigation was conducted in the present work to study the strength characteristics of concrete blended with rice-husk ash (RHA) and fly ash (FA) as partial replacement for cement. Fly ash is obtained from thermal power plants and RHA is an agricultural waste. Both of these materials are available abundantly in India Transportation and disposal of these wastes is a major environmental and health problem. Using them as alternative additional cementitious materials (SCMs) provides a lucrative waste up-cycling opportunity. The strength characteristics of concrete samples with and without FA and RHA were measured and compared by conducting compressive strength, split tensile strength & flexural strength tests. Varying combinations of FA and RHA (0%, 10%, 20%, and 30%) were used as a replacement of cement. The results suggested that at a combination of using 7.5% RHA and 22.5% FA, replacing the cement; the compressive strength, split tensile strengths and flexural strength of concrete increased by 15%, 0.67% and 24% respectively. These results clearly indicated that use of FA and RHA in concrete blend is an efficient and local approach towards sustainable construction.

Keywords Concrete · Fly ash · Rice-husk ash · Agricultural waste

37.1 Introduction

Concrete is a substance produced by a mixture of cement, water and aggregates. Concrete admixes may be applied to improve some of the desired characteristics (Tabsh and Abdelfatah 2009). In the construction industry, solid waste and reclaimed materials are used to sustain the environment, conserve materials and increase the

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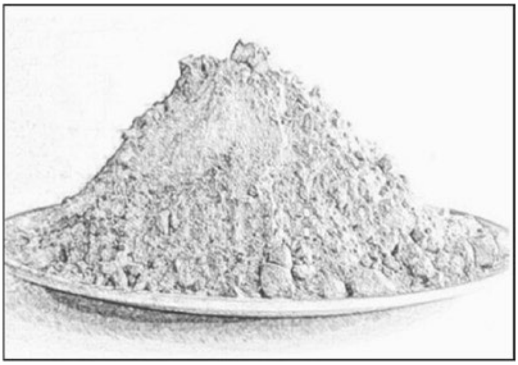
Fig. 37.1 Rice husk ash



quality of the construction materials (Pappu et al. 2007). Several ingredients are added to obtain the ideal concrete, for example fly ash and rice husk admixture (Sharma and Akhai 2019a, b). The effective proportioning, processing and compacting of the materials to produce solid, stable concrete is essential (Ozbay et al. 2009). Fly ash is a residue that we get after the coal has been burned (Sharma and Akhai 2019a, b). Fly ash contaminates our atmosphere by blending with the air, so the risk of fly ash to the environment is removed when it is used to enhance the properties of engineering materials (Thareja et al. 2017). Several studies report usage of FA in the soil as well (Arif 2017). Initial concrete strength is decreased by supplanting cement with fly ash while later after curing for a few days, the strength, along with durability improves (Saha 2018). The inclusion of RHA increases the early strength of concrete (Givi et al. 2010).Rice-husk ash is a by-product that is often obtained in the industry after burning rice husk at high temperatures (Madandoust et al. 2011). A significant quantity of rice husk can be obtained as a by-product in Asia and many different places of the globe (Pode et al. 2016). Approximately 40% of rice husk is comprised of cellulose, 30% of a lignin group and 20% of silica and therefore a significant volume of silica content is there so RHA can be used to render extremely porous concrete (Figs 37.1 and 37.2).

As a result, in applications such as controlled permeability concrete and roller-compressed concrete, RHA was also successfully used (Chindaprasirt et al. 2007). As FA and RHA can provide a strong strength, apart from environmental benefits, so the principal purpose of this analysis was to substitute cement with RHA and FA at different amounts and obtain optimum ratios (Tables 37.1 and 37.2).

37.2 Background

Building ventures around the world utilize concrete and, whereas COVID-19 presently impacts the planet, no shutdowns within the building industry are recorded and are designed considering air filtrations (Akhai et al. 2020a, b, 2021). The world's net volume of ash is over 100 times that of OPC (Van et al. 2018). Moreover,

Fig. 37.2 Fly ash

Table 37.1 Physical properties of fly ash

Colour	Bulk density	Specific gravity	Fineness
Whitish gray	1118 kg/m^3	2.12	2838 cm^2/gm

for about half the world's population, rice could also be a staple feast so rice makes up nearly 55% of the world's harvest action-driving plenty of rice straw and husk in rice-producing nations (Tan et al. 2020). Burning and landfill, all of which cause environmental defilement, are currently the disposal alternatives easily accessible (Rukzon et al. 2009). The recycling of commercial and agricultural waste as mineral additives for new concrete not only saves capital investments but also lowers costs of producing for both building and so-called "by-product" sectors. It results in the possible advancement of a cycle of the non-waste era (Thomas 2018). Various efforts are being made to successfully use fly ash and rice ash. However, the literature released after 2015 has been provided with the primary emphasis. Hwang & Huynh, successfully developed bricks by the use of FA and RHA by analyzing the properties of the brick and its conformity to the associated requirements. It was found that enhanced life was induced by the use of FA and RHA, used for eco-friendly polymerisation of bricks (Hwang and Huynhet 2015). Ziegler, Daniele, et al., in their study found that FA can successfully substitute halloysite as a raw material, and RHA can effectively substitute nanosilica powder while manufacture of geopolymeric paste and both of these substitutions have a favourable influence on the environment (Ziegler et al. 2016). Eliche-Quesada, D., et al., through their findings demonstrate that ceramic bricks comprising 10% rice-husk ash and 30% wood ash may accomplish the technical and mechanistic prerequisites of masonry units of clay (Eliche-Quesada et al. 2017). Van Tang et al., tried to find out about FA and RHA's effect on the mobility of concrete mixtures by statistical modelling via regression equations. In high-rise buildings built in the hot and humid environment of Vietnam, it was found that the regulation of concrete mixture mobility during the transport of fresh cement to the form was accomplished by optimizing the amount of RHA and FA in concrete (Van et al. 2018). Sethi A, et al., during their works investigated FA & RHA in terms of workability and compressive force of concrete

Table 37.2 Physical properties of rice husk ash

Colour	Bulk density	Specific gravity	Fineness	Average particle size	Mesopores	Heating value
Gray with slight black	106.1 kg/m^3	1.97	2774 cm^2/gm	149.47 μ m	79%	9.72 MJ/kg

after 28 days of curing. Results showed that when combined in concrete up to 5% by weight of cement enhances its compressive strength by 6% (Kumar et al. 2016). In another similar study the concrete had been prepared by mixing fly ash and rice-husk ash added in various percentage 0%, 10%, 20%, 30%, 40%, 50% and 0%, 5%, 7.5%.10%, 12.5%, and 15% respectively. The compressive strength was analyzed for at least 7 days and 28 days curing. High compressive strength was achieved when FA and RHA were used up to 30% and 7.5% respectively (Sam et al. 2020). The use of a mixture between FA and RHA will provide a strong strength, so the principal purpose of this analysis is to substitute cement with RHA and FA at different amounts.

37.2.1 Fly Ash

Fly ash (FA) typically comes out of the electricity production house vents, while bottom ash is taken from the base of the furnace. Earlier, FA used to be usually discharged via the smoke pile into the environment, but contamination control technology required over recent decades now requires collection before its discharge. It is usually retained at electricity production plants site in countries like the US (Liu et al. 2016). The FA generated varies substantially reliant on the type of coal used and its makeup; nevertheless, Silicon dioxide and lime calcium oxide are found in large amounts in all FA. In concrete manufacturing, FA is usually used to supplement Portland cement which has technological as well as economic advantages and is increasingly utilized in geopolymer and zeolite synthesis (Cretescu et al. 2018).

37.2.2 Rice-Husk Ash

Rice-husk ash (RHA) is the fine pozzolanic ingredient considered in this study for the concrete supplement due to its suitable characteristics and benefits such as increased strength, increased long-term characteristics, decreased material cost due to cement savings, and environmental benefits such as waste reduction and lesser carbon dioxide emissions (Karim et al. 2012). RHA can be used as a composite for concrete manufacturing since it is a cost-effective substitute for micro-silica fumes, as absorbents for oils, chemicals, and soil enhancing agents. It can also be used as a stimulant to increase soil drainage, unify soil, and upgrade structures, among other things (Akhai et al. 2020a, b). It also helps to better insulate the wall or roof structures by improving the thermal conductivity for decreasing the rate of heat transfer thereby acting as a natural insulator for building structures for improving energy efficiencies.

37.3 Experiment

This research aims to look at how FA and RHA are mixed into cement and how it affects the durability of concrete used in building construction. The findings of compressive strength tests, split tensile strength tests, and flexural tests on concrete samples with and without admixture (FA and RHA) are discussed in this section. The outcomes of experiments that were conducted to determine the influence of waste FA and RHA on the strength characteristics of concrete are presented. At percentages of 0, 10, 20, and 30%, waste fly ash and rice-husk ash were used to partly substitute cement. Experimental Procedures are discussed below:

37.3.1 Compressive Strength of Concrete

It is essential to determine individually the sizes of coarse composites to be used (e.g. 10 millimeter, 12.5 millimeter, 16 millimeter), as well as the amounts of water and cement requisite to make each sample. The varied sized aggregates were mixed thoroughly for at least two minutes in a mixer. At the start, mixing the cement with a mixer is carried out to ensure that the compound has evenly distributed particles. Water is further added at the end-stage, and the mechanical mixer is used to thoroughly mix the components for 5–10 minutes before they are amalgamated. Cubic molds were used in this procedure. You should first clean and then grease the molds. Every piece of the mold is manually compacted, and the mold should be filled in three sections. With a minimum of 25 strikes, the tamping instrument is used to compress the soil. A flat surface is placed to the top of the concrete to smooth it out, and it takes at least 24 hours for the generated samples to solidify. As suggested, the samples were completely submerged in water before being prepared according to the mold. The specimens were analyzed again after 7, 28, 56, and 96 days. "Once the samples have been taken from the crushing tank, the water on their surface is removed, and the tests are carried out immediately." The compressive strength of the sample produced in this investigation is then evaluated using Universal testing equipment. To test the samples, the load is progressively increased on the samples without generating shocks until failure occurs.

37.3.2 Flexural Strength of Concrete

Material's elasticity is measured by how much it deforms when subjected to a load. Factors such as the composite to cement ratio and porosity affect flexural strength. All materials consisting of only one component (such as metals, fibers, and cement composites) are subjected to numerous distinct strains when bent. There is a maximum tensile strength on the outer surface. Due to the development of 'extreme fibers', the tensions on the inner side are minimized. Tensile tension can cause materials that can withstand compression stress to break. Flexural strength is determined by the material's maximum tensile stress just prior to failure. Using universal testing equipment that works on the concept of hydraulic transmission, the flexural strength of any material is measured. When shocks are delivered, levers and knife edges are more vulnerable to damage. Hydrostatic lubrication is used to lubricate the hydraulic ram. As the pressure builds, it is transferred to a cylinder located on the pendulum dynamometer's control panel. Self-lubricating dynamometer form The load is transferred to the pendulum through a lever. The display recorded values based on the movement of the system additionally activates a rack-and-pinion configuration. Load corresponds to the pendulum's displacement and this prevents the pendulum from returning when the sample is sheared. UTMs had been used for testing samples after 28 days. A third-point load was applied to the system, but no force or eccentricity is applied. No locking device was utilized on the rollers since it would prohibit the rollers from moving freely. Ideally, the rollers used were made of steel, and had a diameter of 30 millimeters. The rollers were oiled to facilitate safe movement, and the surfaces were thoroughly cleaned to allow them to spin easily and without creaking.

37.3.3 Tensile Strength of Concrete

Direct and indirect testing was conducted to assess the concrete's tensile strength. A direct tension test on the samples was one of three procedures typically employed to assess this characteristic. This test involves pulling apart a concrete cylinder at both ends until the specimen ruptures. Although applying uniaxial tension to a concrete specimen can be challenging due to the difficulties of attaching the specimen's end caps to a load-bearing frame. Two indirect ways in which the cylinder is squeezed on its side are often utilized. Cement, FA, and RHA percentage variations, as well as varied strengths generated at different curing days, are shown in Table 37.3.

Figures 37.3 and 37.4 reveals the results of compressive strength when of concrete mixed with FA and RHA on 7, 28, 56 and 91 days curing. The effects on compressive strength are plotted here. It is seen that a composite with 22.5% FA with 7.5% RHA gives maximum compressive strength and this combination is best for the utilization purpose of these waste materials as compared to others. Figures 37.5 and 37.6 reveals the results of tensile-strength of concrete mixed with

Table 37.3 Strengths with different curing days

Mix	Fly Ash	Rice Husk Ash	7 Days Curing			28 Days Curing			56 Days Curing			91 Days Curing		
			Compressive strength	Split tensile strength	Flexural Strength	Compressive strength	Split tensile strength	Flexural Strength	Compressive strength	Split tensile strength	Flexural Strength	Compressive strength	Split tensile strength	Flexural Strength
M0	0	0	27.2	2.5	3.03	38.2	2.71	5.61	41.2	2.87	6.02	43.05	2.95	6.08
M1	10	-	27.35	2.67	3.81	38.45	2.91	6.31	41.45	2.99	6.54	43.87	3.14	6.66
M2	20	-	27.5	2.81	4.41	38.9	2.98	7.03	42.8	3.12	7.25	44.85	3.31	7.32
M3	30	-	26.65	2.41	4.13	37.18	2.65	6.45	40.2	2.84	6.4	44.26	2.98	6.7
M4	-	10	23.15	2.31	2.74	30.51	2.51	3.4	32.75	2.58	3.48	38.3	2.71	3.54
M5	-	20	23.27	2.18	2.12	28.6	2.21	3.05	29.63	2.29	3.57	37.1	2.35	3.63
M6	-	30	24.01	2.09	1.71	25.13	2.15	2.7	28.13	2.21	2.76	32.3	2.29	2.83
M7	27.5	2.5	25.51	2.37	4.09	34.43	2.51	6.09	39.36	2.62	6.15	42.25	2.77	6.31
M8	25	5	25.94	2.25	4.79	38.13	2.33	6.89	43.56	2.39	6.95	46.25	2.47	7.21
M9	22.5	7.5	**21.41**	**2.54**	**5.13**	**39.41**	**2.69**	**7.33**	**46.53**	2.82	7.45	49.54	2.97	7.54
M10	20	10	20.89	2.36	4.63	34.04	2.42	6.52	40.26	2.48	6.59	43.24	2.56	6.71
M11	17.5	12.5	19.61	2.01	4.51	33.98	2.11	5.89	38.21	2.15	5.96	40.31	2.27	6.12
M12	15	15	19.06	1.9	4.33	30.1	1.81	5.66	36.25	2.01	5.72	39.36	2.13	5.92

FA and RHA on 7 days, 28 days, 56 days and 91 days of curing. The effects on tensile strength are plotted here. It is seen that a combination of 20% fly ash with 0% rice husk (M2) gives higher tensile strength but it is also clearly seen that a combination of 22.5% fly ash with 7.5% rice husk (M9) for utilization purpose of these waste materials give better flexural strength results in comparison to other proportions. Figures 37.7 and 37.8 reveals the results of flexural-strength when of concrete mixed with FA and RHA on 7, 28, 56 and 91 days curing. The effects on flexural strength are plotted here. It is clearly seen that a combination with 22.5% fly ash with 7.5% rice-husk ash (M9) for utilization purpose of these waste materials give better flexural strength results in comparison to other proportions.

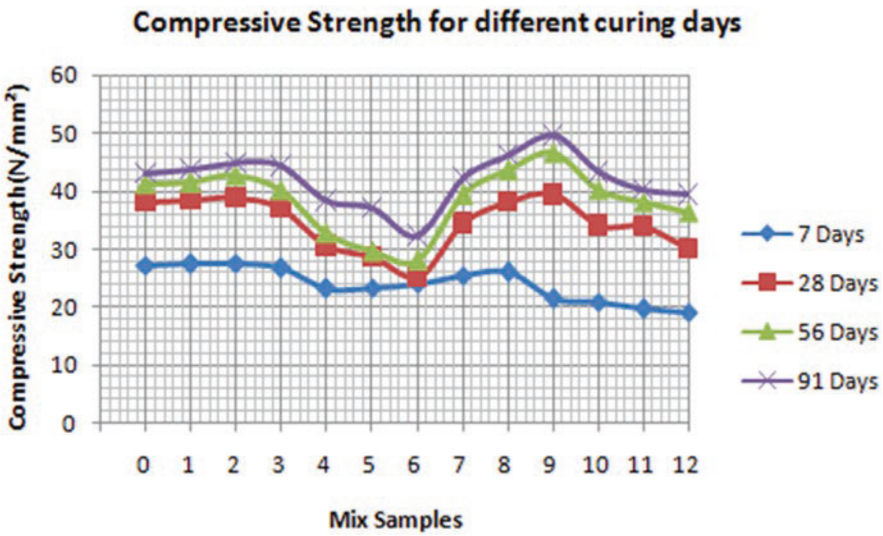


Fig. 37.3 Compressive strengths obtained for different curing days

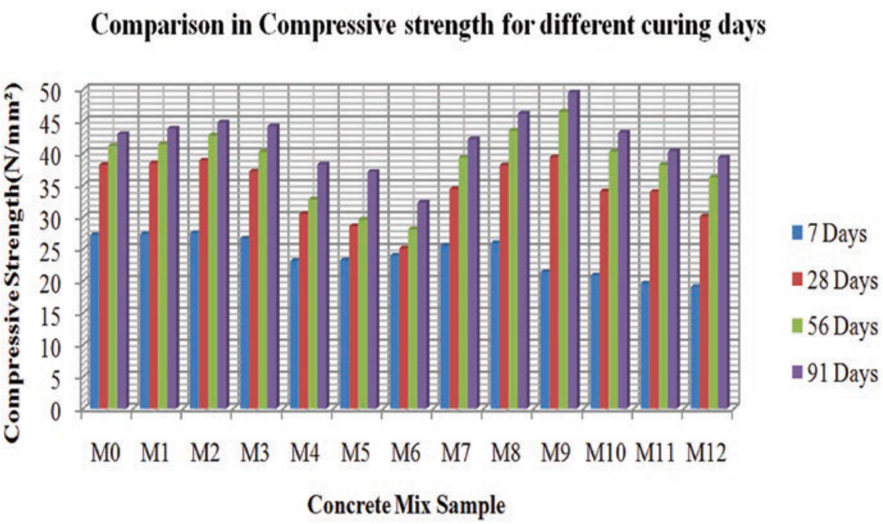


Fig. 37.4 Comparison between compressive strengths obtained for different curing days

37.4 Conclusion

The subsequent outcomes can be derived from this study:

1. FA and RHA are waste materials, so by utilising them the construction costs tend to reduced. The weight of concrete also decreases with the use of these additives,

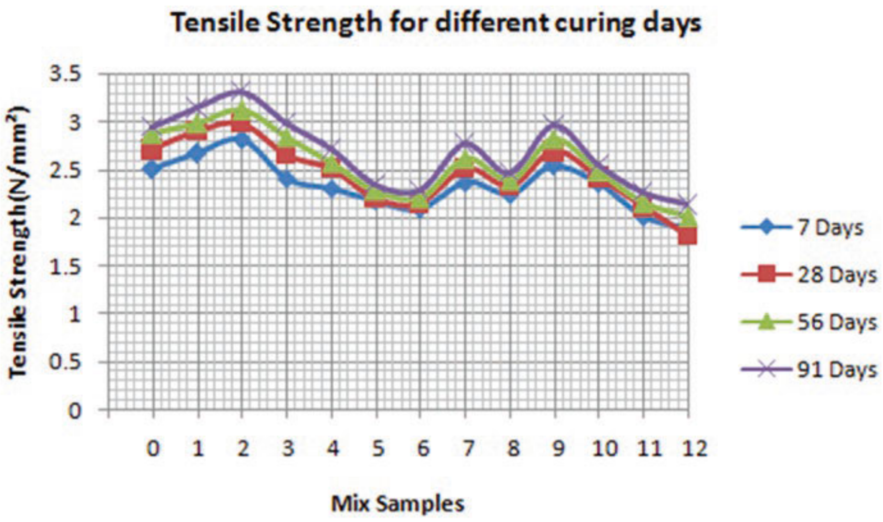


Fig. 37.5 Tensile strengths obtained for different curing days

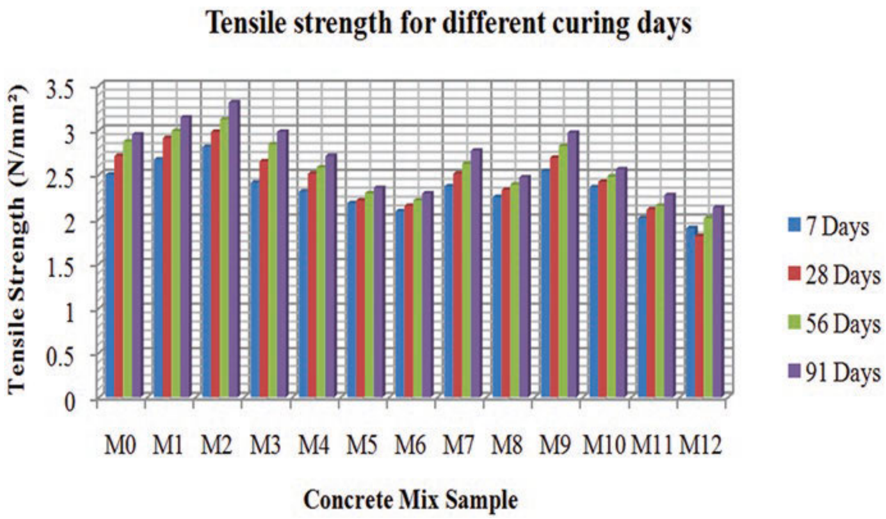


Fig. 37.6 Comparison between split-tensile strength after indicated curing days

thus rendering the lighter concrete that can be used as a low weight building material.

2. At various cement replacement proportions of RHA; there is steady decrease in compressive strength for both 7 days, 28 days, 56 days and 91 days curing period.
3. FA and RHA are increased as substitute to cement by 22.5% of FA and 7.5% of RHA in concrete, the compressive strength is found to be maximum for various

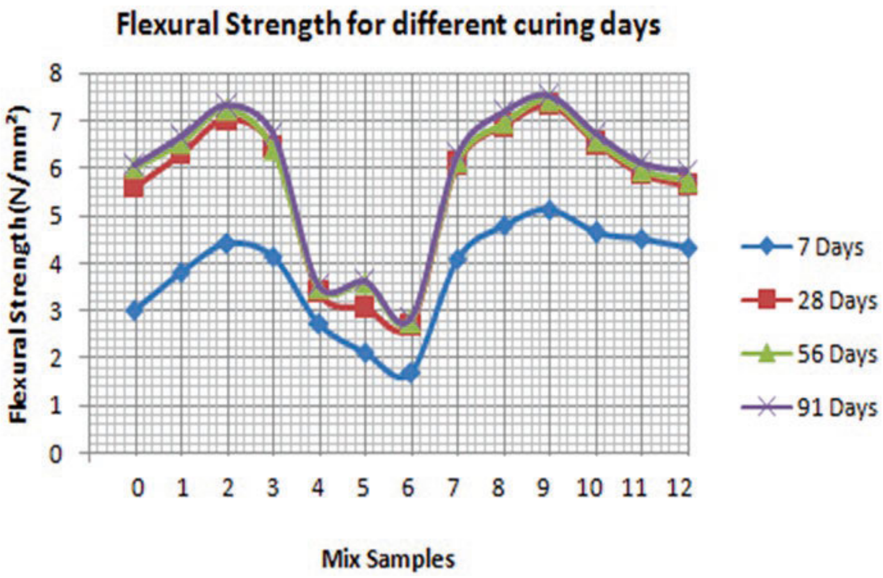


Fig. 37.7 Flexural strength after different curing days

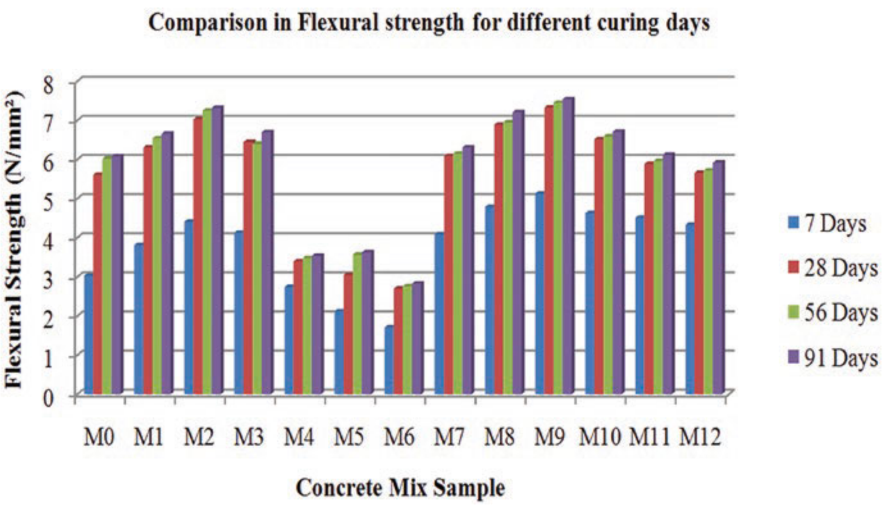


Fig. 37.8 Comparison between flexural strength for different curing days

mixture proportions in comparison to M0. There is 3% increase in compressive strength as comparative to M0.

4. There was not a noteworthy growth in Split tensile Strength and it was just 1% higher than M0 with mixture of 22.5% of Fly ash and 7.5% of rice husk ash.

5. 91 days of curing, a mixture with 22.5% of FA and 7.5% of RHA when compared to M0, obtained maximum flexural strength
6. is inferred from the results obtained that mixture of 22.5% FA and 7.5% RHA mix comes out to be the optimal mix for the best use of RHA and Fly ash

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Chapter 38
Analysis and Evaluation of Geopolymer Concrete from Mechanical Standpoint

Ashish Shukla and Nakul Gupta

Abstract The characteristics of Geopolymer concrete were investigated in this research study utilizing fly ash supplied from Astra Chemicals Chennai. The main objective of this paper is at what level can Geopolymer concrete participate in place of normal concrete used in construction. In addition, different characteristics of Geopolymer concrete consisting of fly-ash and other components were investigated. In making Geopolymer concrete, solutions made of potassium hydroxides "KOH" & silicate formulations have been mixed in varying proportions. The real compression strength of the concrete depends on different parameters such as a ratio of the catalyst solution of Fly-ash verticality of the alkaline solutions ratio of the catalyst chemical curing temp etc. Concrete is now the world's second most widely used material, and cement is mostly utilized in its production. Excess consumption of cement is causing great harm to the environment. Keeping all these things in mind, researchers are engaged in a new discovery by turning to Geopolymer concrete. Fly ash is also a type of non-use material, with the help of which the construction sector has been continuously turned. Keeping this in mind Geopolymer concrete has been constructed with the help of fly ash.

Keywords KOH · Compressive & tensile strength · Concrete · Curing temperature

38.1 Introduction

Concrete is well-known for contributing significantly to greenhouse gas emissions. The cement business is the second-largest emitter of greenhouse gases after the oil and gas industry. By the year 2020, cement output and emissions are anticipated to grow by 100% from present levels, indicating significant implications on global warming indexes. In this context, the use of waste material from various sectors as supplemental cementitious materials in concrete, in addition to cement, has been widely praised for its improved characteristics and potential to minimize the

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environmental effect. Production of a tons of OPC releases one ton of "CO_2," which contributes to global warming, to the atmosphere (Habert et al. 2011; Neupane 2016; Panda et al. 2017). We need to build more cement manufacturing facilities or seek other binder methods to make concrete to address the existing issue. Fly Ash, on an other hand, is produced in enormous quantities by thermal power plant all over the world and is commonly utilized as a filler in low-level zones (Andini et al. 2008; Castel and Foster 2015; Chindaprasirt et al. 2009; Guo et al. 2010; Musson et al. 2000).

Geopolymers are a relatively novel binder, as they are formed of manufacturing waste material like fly ash and may become long-lived and affordable binding components. It can completely replace cement in concrete. In comparison to Portland cement, geopolymers are increasing in popularity because of their reduced CO_2 emissions. The alkaline activation of aluminosilicates produces geopolymers. An alkali metal hydroxide water solution or a liquid alkali silicate activates powdered aluminosilicate by polycondensing it into free aluminosilicate and silicate oxides.

"Geopolymer concrete" is an alternative binding system with fly ash for concrete removal. Geopolymer has the optional characteristics of rock shaping materials, i.e. toughness, chemical inertness, and durability as a type of amorphous aluminum hydroxide substance (Ankur Gupta 2020; Gupta et al. 2020; Kishore and Gupta 2020; McLellan et al. 2011; S.E. 2010; Shukla et al. 2020a; Vasconcelos et al. 2011).

Geo-polymer is an inorganic polymer alumino-silicate produced from alkaline activation of different geological aluminosilicate paraphernalia or by-products such as metakaolin, Furnace slags, and Coal ash. Aluminosilicate materials undergo a chemical reaction in an alkaline environment, yielding a 3-dimensional polymeric network. While this Alkali activation process is yet unknown, the chemical properties of the alkali activator & primary sources have a significant impact on the final geopolymerization products. In combination with Geopolymer binding aggregates, Geopolymer composites are made. Ideologies as they have very strong early strength, they are suitable for the design, repair, and pre-casting of infrastructure, They can monitor their set times and stay intact very long without any repair (Antunes Boca Santa et al. 2013; Dias and Thaumaturgo 2005; Li and Xu 2009a; Parashar et al. 2020; Shukla et al. 2020a, b; Temuujin et al. 2009). Geopolymer properties involve freeze thaw resistance, high early strength, low shrinkage, corrosion (Buchwald et al. 2009; Deb et al. 2014; Luhar et al. 2018; Nazari and Sanjayan 2015; Ryu et al. 2013; Shukla et al. 2020b; Van Jaarsveld and Van Deventer 1999; Xu and Van Deventer 2000). These greater-alkaline additives do not cause an aggregate alkaline reaction (Ariffin et al. 2013).

The binder is a controversial substance of low carbon dioxide. It's doesn't depend on the limestone calcinations that emits carbon dioxide. This innovation will save 80% of the production of carbon dioxide from the concrete & cement sectors (Embong et al. 2016; Frigione 2010; Singh et al. 2015; Yan and Sagoe-Crentsil 2012).

38.2 Experimental Program

Geopolymer concrete has been produced in this research using fly ash pozzolans (extremely low in appearance calcium) instead of PPC cement or other cement kinds. The fly Ash (Pozzolans) based Geo-polymer mixture, in the inclusion of admixtures, ties together the loose fine aggregate, coarse aggregates & other un-reacted substances to form the Geopolymer mortar/concrete (Olivia and Nikraz 2012; Pacheco-Torgal et al. 2008; Sata et al. 2013; Slavik et al. 2008; Temuujin et al. 2010; Vora and Dave 2013). Work has been done on the development of Geo-polymer concrete using common methods of concrete technology, as in the example of OPC concrete at GLA University Civil Engineering Laboratory, Mathura. The aluminium and silicon combine with an alkaline solvent in the fly ash (Hardjito et al. 2004; Li and Xu 2009b; Posi et al. 2013; Shi et al. 2012). This is a mixture of "KOH" KOH and silicate formulations for the formulation of the Geopolymer Paste which joins aggregates and other unreacted components.

38.3 Materials Used

By using close to zero-calcium fly-ash (ASTM Type F) acquired from Astra Chemicals, Chennai, Geopolymer concrete can be produced. Zero-calcium fly ash produced from an over-product of burning lignite or bituminous coal is the bulk of the fly-ash available worldwide. In the shape of pallets, industrial-grade "KOH" potassium hydroxide (99% pureness) & "NaOH" sodium hydroxide liquid (SiO_2–36.7% & Na_2O–18.2%t) is used as alkali activators with 45.1% distilled water. Pellets of "KOH" potassium hydroxide were diluted according to the required ratio of molar in the presence of the required volume of water. For concrete, the University (Mathura Region) fine aggregate & coarse aggregate were used. The key point to remember is that the mass of water is the most significant component in each of these alkaline solutions. The concrete super-plasticizer has been used to enhance the workability of the concrete.

38.4 Research Methodology (Fig. 38.1)

38.5 Proportion of Mixture and Procedure

In this report, the various mixture proportions used to construct the experimental Geopolymer concrete moulds are listing in Table 38.1.

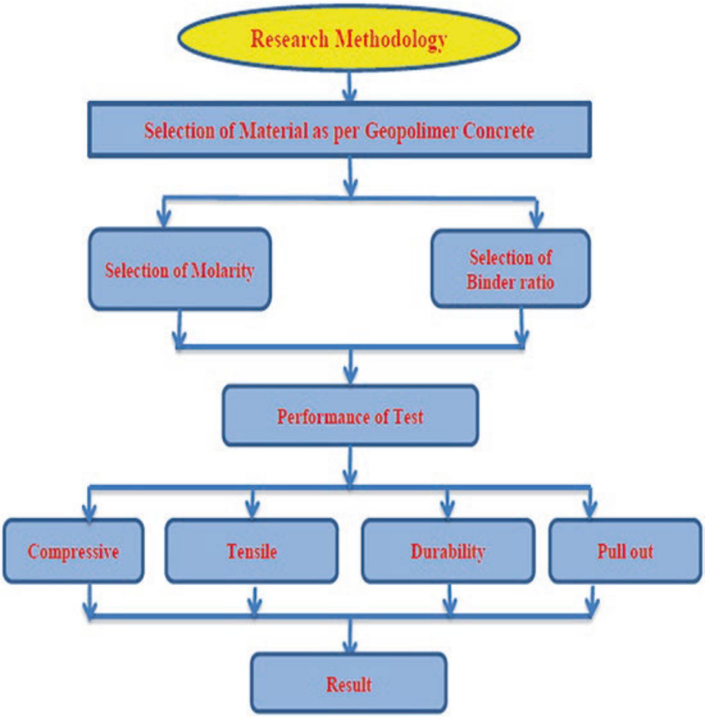

Fig. 38.1 Research methodology process

Table 38.1 Proportion of material mixture

Materials/Units		Mixture with morality				
		Mix. A	Mix. B	Mix. C	Mix. D	M25
KOH		2.51	2.51	2.51	2.51	–
Fly-ash (kg/m^3)		423	423	423	423	423 OPC
Coarse aggregate (kg/m^3)	20 mm	665	665	665	665	750
	10 mm	445	445	445	445	503
Fine aggregate (kg/m^3)		507	507	507	507	565
Alkaline solution		0.37	0.37	0.37	0.37	–
Molarity		Eight mol.	Ten mol.	Twelve mol.	Fourteen mol.	Sixteen mol.

As shown in Fig. 38.2, all of the components were mixed manually in the laboratory at room temperature, with the aggregate and fly ash first uniformly blended, and then the alkaline solutions were produced a day earlier and superplasticizers applied to the aggregate & fly ash combination. The sodium hydroxide and potassium hydroxide solutions were first combined and blended to generate a homogeneous mixture of the solutions before being applied to the solids. Figure 38.3 shows

Fig. 38.2 Dry mixture of Geopolymer concrete

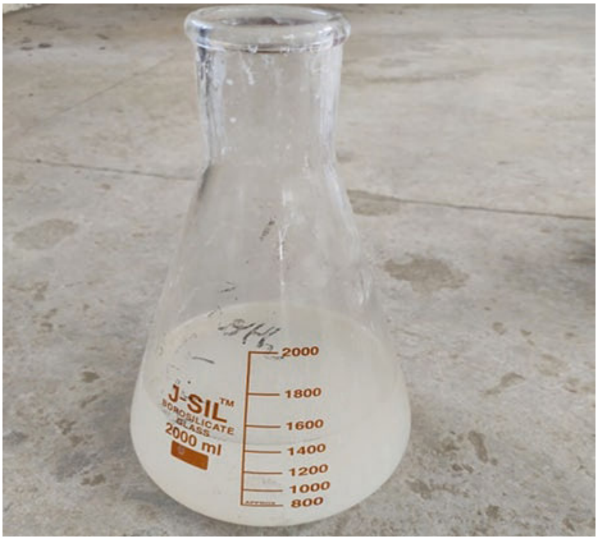

Fig. 38.3 Alkaline solution

the alkaline solution mixing into the dried concrete. The mixture has been mixed until all the ingredients are mixed. In this research, Geopolymer concrete mixes are usually mixing by hand. Figure 38.2 shows a dry mixture of Geopolymer concrete. The mixture was left in the sample for a day to thicken. This Geopolymer concrete was created using several researchers' Geopolymer concrete studies in mind.

Fig. 38.4 Sample of specimen

Concrete is created by filling three layers of material while shaping the specimens and compacting each layer with rods. The Geopolymer concrete is put into a warm air oven for twenty-four hours at a temperature of sixty degree celsius and then placed the following day at room temperature (Fig. 38.4).

38.6 Result and Discussion

Various sorts of testing on Geopolymer concrete were carried out in this study, taking into account a variety of factors. Compression strength, tensile strength, durability testing, and pull-out testing are among the numerous tests that are performed. Compressive strength testing has been done at the Civil Engineering Laboratory of GLA University, Mathura using a compression testing machine, and all other tests have been done in this department. All these tests have been done at intervals of Three days, Seven days, Twenty-eight days, and Fifty-six days.

Figure 38.5 depicts the compressive strength test specimens, which were heated in an oven at 60 °C for one day before being tested at predetermined intervals. Figure 38.6 shows that after testing, the specimen was shattered evenly on all sides

Fig. 38.5 Curing of specimen at 60 °C in hot air oven

Fig. 38.6 Compression testing machine

and the upper layer & lower layer of the specimen remain uniformly. As a result of compression strength & tensile strength testing, it is observed that as the molarity is

Fig. 38.7 Specimen after the compression test

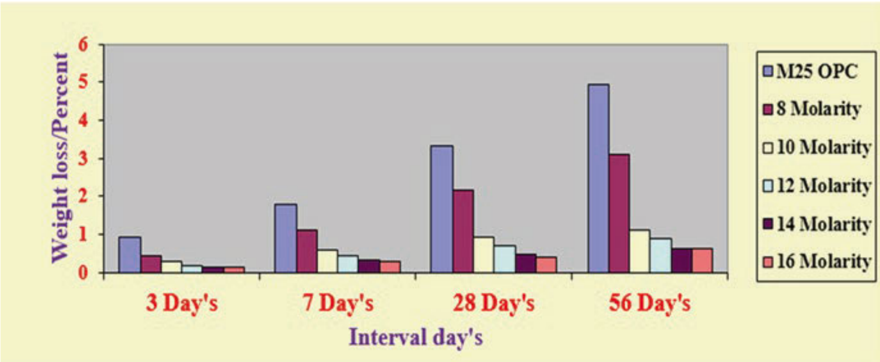

Fig. 38.8 Graph 1: Compressive strength test at various day's interval

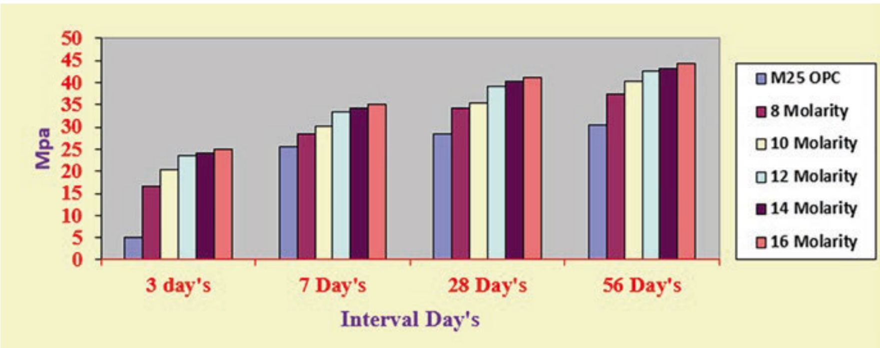

Fig. 38.9 Graph 2: Split tensile strength test at various day's interval

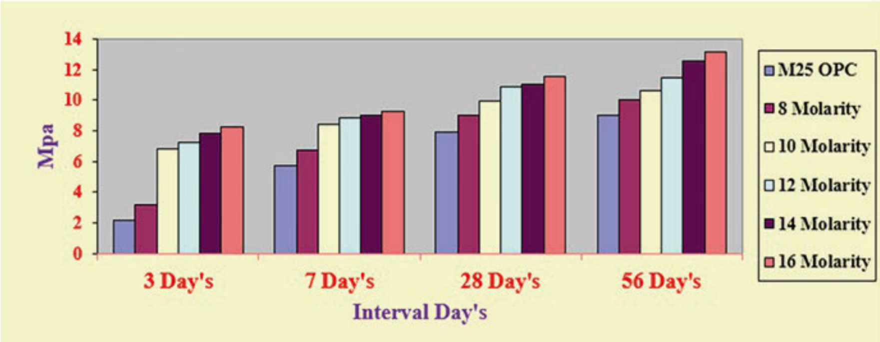

Fig. 38.10 Graph 3: Pull out test at various day's interval

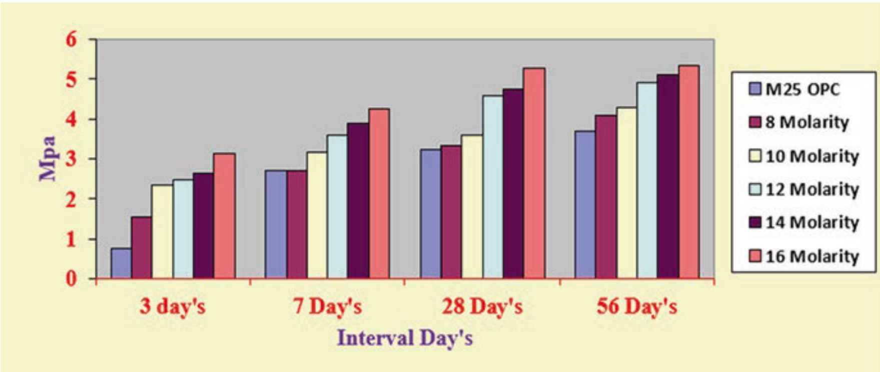

Fig. 38.11 Graph 4: Durability test at various day's interval

increased and the interval of curing days is increased, the results have been good (Figs. 38.7, 38.8, 38.9, 38.10 and 38.11).

38.7 Conclusion

Compressive strength of concrete made of "OPC" Ordinary Portland cement increases by one and a half times that of controlled concrete, replacing M25 grade concrete with a strength of M45 grade concrete. The tensile strength of concrete made of OPC cement also results in an increase of about one and a half times as much as for compression strength. And similar results have also come in the Pull Out Test. Finally, as a result of the durability test of concrete, it was observed that there is a reduction in the weight of concrete around 10 times. This result has been found in a gap of 58 days. It was also found that the concrete split tensile strength, compressive strength, & all the tests result in a good increase when the concrete is continuously increasing the molarity and the interval of the curing days. In Geopolymer concrete, it has been found that the weight of concrete made of OPC cement results in a relatively greater reduction of Geopolymer concrete. Continuously increasing the molarity in concrete reduces its weight loss. After casting the Geopolymer concrete samples, curing them in the oven for more than 1 day, very subtle cracks occur on the top surface of the concrete.

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Chapter 39
Municipal Waste Management in India: A Critical Review of Disposal System and Model Implementation

Amandeep Singh, Abhishek Kanoungo, Ajay Goyal, Isha Gupta, and Akshay Chaudhary

Abstract India is being called as the third largest world economy after China & United States of America due to rapid industrialization and population growth. In year 2020, the population growth rate in India was 1.1%. The index of industrial production reached to 134.44% in April 2021 with 27% rise in registration of new corporate companies with 17% rise in limited liability partnerships for financial year 2020–2021. As there is a surge in every growing sector in India, it requires incorporation of an efficient waste management disposal system by the Indian Government in industrial, commercial, municipal and agriculture sectors. India generates 62 million tons (MT) of waste annually, 43 MT of which is collected, 12 MT is treated and 31 MT is dumped in the landfills according to 2016 report by Ministry of Housing and Urban Affairs (MoUHA). It is estimated that between 80% and 90% of the municipal waste is discarded untreated in the landfills without proper management practices and undergoes open burning that leads to air, water and soil pollution. This review paper summarizes, the laws enacted in India, progression on waste management disposal system in terms of reuse, reduce and recycle of the waste. It is a true challenge in India to set out rules and work according to

Indian states marked as asterisks are the major producers of wastes, considered in the current study, and that these have the waste processing plants status as operational/ non operational. Thus, the ground reality is inappropriately being linked to the segregation of the wastes collected from the source, the segregated waste goes unprocessed, due to non operational status of plants mentioned by Central Pollution Control Board.

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set standard on the field in managing the waste, therefore the paper proposes a model to improvise best practices to regulate the waste disposal in India.

Keywords Central Pollution Control Board · Ministry of New and Renewable Energy · Ministry of Housing and Urban Affairs · Reduced derived fuel

39.1 Introduction

India is a growing country which contributes 12% of global municipal solid waste (MSW) generation. Perhaps after having specific laws to handle the waste materials, the collection, segregation and disposal systems could not surpass the pollution levels in India to decline with the ongoing waste disposal methods used in India. Ghaziabad city in Uttar Pradesh State of India was ranked as the most polluted city in India with air quality index of 177 in year 2020 (www.iqair.com 2020) with Uttar Pradesh being second highest populated state in India collecting 15,500 MT waste/day and processing 53% of it. The scientists believe that an increase in population will lead to generation of more MSW in the coming years (www.worldbank.org 2020). 33.6% of total population of India is living in the urban areas (Ritchie et al. 2018). With increasing population, the development growth in the urban areas, more people have migrated from rural to urban areas, which have challenged the local environment at many places within the municipal boundaries (Moya et al. 2017). The kind of waste which is being generated leads to challenges in handling and processing of the waste by the municipalities. As per the report of Ministry of Renewable Energy, 2018 the Indian states Maharashtra, Uttar Pradesh, Tamil Naidu, Karnataka, Gujarat, National Capital Region and West Bengal has huge waste generation potential. In populated cities MSW consist of 70% of heterogeneous type of solid waste of the total generated waste per day (MNRE 2018) which has more of paper, glass, metals, plastics, textiles & less of paints, used medicine, pesticides, e waste and batteries (Sridevi et al. 2012). The MSW thus has 52% of organic or biodegradable, 37% of non biodegradable and 17% of recyclable waste. The South Asian countries including India adopts 75% of waste as open dump, 4% landfill, 16% composting and 5% recycling (Kaza et al. 2018). After Collection of MSW it can be segregated into recyclable and non recyclable items and could be processed further by technologies and infrastructure available within government and non government agencies. As per the report of Ministry of New & Renewable Energy (MNRE), 2018 waste processing facility have been set up in almost every state in India. India requires regularizing the waste management disposal system in which the recovery from waste can reduce the volume of dumping waste in the landfills. India stands at an alarming situation where waste management disposal requires high priority besides proposing solutions rather than implementation. The concept of reduce, reuse and recycle is now popularly growing among communities outside India to lower the environment pollution. Therefore, India needs to put some concrete steps to project laws of implementation which can reduce the landfill disposal, increase the working infrastructure and evolve the innovation infrastructure to reduce the waste generation.

39.2 Literature Review

In the annual year of 2014 to 15 Central Pollution Control Board (CPCB) of India published 91% of waste collection, from which 27% of 91 was treated and the remaining 73% was disposed at the dump sites. It also stated that per person waste generation has increased with a growth rate of 0.26 kg/day to 0.85 kg/day (CPCB 2018). The citizens are unconscious of waste control measure related issues, and their careless attitude towards the waste thus creates very difficult challenges for the municipalities. The country produces more than 1.5 lakh MT of solid waste, with 15,000 MT of garbage remaining exposed every day, it has become a crucial reason for rising pollution levels. Out of 1.5 lakh MT/day generated waste only 90%, 1.35 lakh MT/day is collected as reported by MoHUA. Of the total collected waste, only 20%, 0.27lakh MT/day is processed and the remaining 80%, 1.08 lakh MT/day is dumped in landfill sites (MoHUA). The main MSW disposal in India are open land filling, composting, vermicomposting & biomethanation of biodegradable waste and processes such as incineration, refused derived fuel (RDF) and waste to energy (WTE) for non biodegradable waste to produce electricity (Reddy 2014). According to CBCB report many cities have adapted these technologies to process the waste to energy, Chandigarh city processes 60 MT/day to produce energy and supply electricity to nearby industrial units. Delhi NCR generates 16 MW, 12 MW & 24 MW of power by processing 2000, 1300, 1300 MT/day waste at three different locations by RDF technology. The WTE plants seems non operational, under construction, non-commissioned and yet to be proposed in many of the Indian States. It concludes that the states are not doing enough to manage the MSW. This would result in huge accumulation of landfill waste at the dumping sites. Besides following the technologies in India to process the waste, land filling method landfill gas recovery projects were not successful in India (Reddy 2014). The landfill disposal in India causes soil pollution, formation of leachates (Swati et al. 2018). Thus, the waste being dumped at such sites have all kinds of biodegradable wet and dry waste and non biodegradable dry waste which causes fire due to formation of methane gas (Stagstad et al. 2013) and breeding haven for mosquitoes and bringing in diseases like malaria, dengue, west Nile fever and respiratory problems (Ghosh 2016). Therefore, landfills can best work only after considering the important parameters in construction, the properties of biodegradable matter used and hydrogeological parameters of local sight. There is a scope of evolution of simple landfills to bioreactor landfills as these optimize the solid waste stabilization under controlled recirculation of leachate and gases (Ahmad et al. 2020).

39.2.1 Waste Monitoring in India

The waste consists of all the solids arising from human and animal activities which are normally discarded as useless or unwanted. It consists of highly heterogeneous mass of discarded materials from commercial, industrial, agricultural and mining activities. The MSW has waste from commercial institutes and residential houses discarded in the municipal or notified areas in either solid or semi-solid form, which doesn't have high risk industrial wastes but including some amount of secured bio-medical waste. It consists of non-hazardous constituents but many a times dangerous too, like products packaging, discarded cloths, glass, bottles, newspaper, paint, batteries, industrial dust, ash, tyres, metallic cans and containers, dead animals, medical waste, discarded machinery, electrical components, sewage, sludge and toxic waste water. The current production of Indian MSW lies between 100 and 500 gm/person/day respectively in the small and large towns. Among it only 13–20% is the recyclable content (MoSPI) (Table 39.1).

Solid waste thus collected can be categorized into:

1. Biodegradable/organic waste
   - Kitchen waste
   - Garden waste vegetables
   - Flowers, leaves, fruits, papers
2. Non-biodegradable waste
   - Construction waste
   - Demolition waste
   - Dust, debris
3. Recyclable waste
   - Plastic, paper, glass, plastic or glass bottles

In a letter to the Ministry of Housing and Urban Affairs it has been reported that waste production is increasing at very fast rate over last few years in India with 147,613 MT of solid waste is formed per day, from 84,475 wards in 35 states and union territories. An average adult produces 450 grams waste per day, and which has increased with a rate of 1.3% per annum (Fig. 39.1).

Table 39.1 Percent wise total solid waste collection

Kind of waste	Percentage probability of collected waste
Biodegradable/ organic waste	52%
Non-biodegradable waste	32%
Recyclable waste	17%

Source: Ahluwalia et al. (2018)

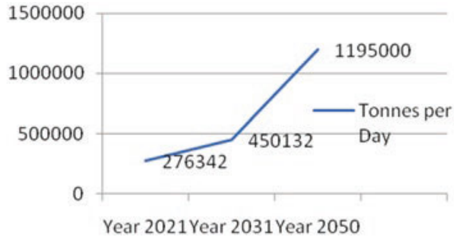

Fig. 39.1 Waste generation per day in India by 2050. (Source: Kumar et al. 2020)

39.3 Methodology

The municipal waste management is a rising problem in India. Though the Indian states have started to follow the processing technologies but there are major loop holes as per the literature available. The highest populated states in India are Maharashtra, Uttar Pradesh, Tamil Naidu, Karnataka, Gujarat, National Capital Region and West Bengal. These states carry huge potential to generate the waste. The literature survey shows the non operational processing plants in these states. In view of the current scenario when most plants are either under construction or non operational, certain specific solution is the need of hour by these states to collect, monitor and control the MSW.

The current study in this article includes the review of waste collection methods adopted in India by the states and union territories.

The parameters taken:

(i) Percentage wards inside the state achieved door to door collection.
(ii) 100% waste segregation achievement by the wards under states and UTs.
(iii) Most populated states under hypothesis having per day waste production capacity.
(iv) Waste processing percentage.
(v) Technologies being adopted to process the waste (Fig. 39.2).

As per the observations, out of 35 Indian states and Union territories, six states (Gujarat, Karnataka, Maharashtra, Tamil Nadu, Uttar Pradesh, West Bengal) and one UT (Delhi) have emerged as highest producer (MNRE 2018) of MSW in year 2020 (Singh 2020). The State of Maharashtra* which is 2nd highest populated state seems to have been processing the waste in its one operational plant out of three installed waste processing units, while the units are non operational in Tamil Nadu*, Uttar Pradesh* and West Bengal*. While Gujarat* and Karnataka* does not have any waste processing facility and the UT Delhi has all facilities operational.

As observed from the Tables 39.2 and 39.3, the processing plants are non operational or not constructed in 18 low populated Indian states which has its urban population below one million, thus declaring them as low producer of MSW, but equally responsible for not managing the solid wastes. Whereas the 15 densely populated states as listed in the Table 39.3 are marked as the highest producer of MSW with only **Delhi***, **Maharashtra*** and Telangana having the waste processing facility.

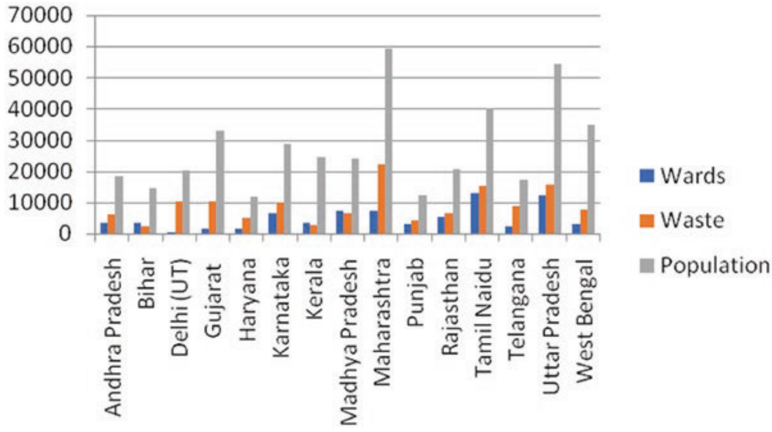

Fig. 39.2 Highest waste generation states in India

Table 39.2 Waste processing plants status in India

States	No of plants	Status
Andhra Pradesh	10	Non Operational
Chandigarh	1	Operational
Delhi*	**3**	**All Operational**
Goa	1	Operational
Himachal Pradesh	1	Under Construction
Madhya Pradesh	1	Non Operational
Maharashtra*	**3**	**1 operational**
Odisha	1	Non Operational
Punjab	8	Non Operational
Tamil Nadu*	**12**	**Non Operational**
Puducherry	1	Non Operational
Telangana	1	Operational
Uttar Pradesh*	**4**	**Non Operational**
West Bengal*	**1**	**Non Operational**

Source: Central Pollution Control Board (CPCB) (2018) [14]

39.4 India Post Independence Laws and Acts

When Laws became more stringent in India, Many states opted for waste segregation collection in the form of door to door collection and processing of biodegradable and non biodegradable form of waste. Table 39.4 summarizes the laws published by the Indian Government from 1974 to 2017 in managing the waste and keeping the environment safe.

Table 39.3 Waste generation by wards under Swachh Bharat Mission, as of January 2020

States/UTs	Total wards	Total waste generation (MT/day)	Urban population projection in 2020 (N X 1000)
Andhra Pradesh	3409	6141	18343
Bihar	3377	2272	14708
Delhi (UT)*	**294**	**10500**	**20171**
Gujarat*	**1427**	**10274**	**32791**
Haryana	1496	4783	11839
Karnataka*	**6464**	**10000**	**28681**
Kerala	3536	2696	24591
Madhya Pradesh	7115	6424	24037
Maharashtra*	**7322**	**22080**	**59121**
Punjab	3123	4100	12331
Rajasthan	5389	6500	20623
Tamil Nadu*	**12814**	**15437**	**39985**
Telangana	2112	8634	17135
Uttar Pradesh*	**12007**	**15500**	**54127**
West Bengal*	**2938**	**7700**	**34865**

Source: MoUHA&MoHFW (2020), Census (2011), Urban Population (2020), Planning Commission (1996)

As found from the above table, there is no law in Indian legislation, which promotes the process of recycling of MSW.

39.5 Waste Collection Method Adopted in India

A report which was published by the Indian Council for Research on International Economic Relations in the year 2020 month of January stated that the UT Delhi has lowest rate of garbage collection at 39% and Ahmadabad as the highest at 95%. In some states the waste is getting collected from houses to house by MC employees, which is then segregated into wet/dry waste bins as per color codes allocated. Apart from MC the self employed garbage collectors and waste pickers collect approximately 10000 T of usable waste everyday without wearing protective equipment. Thus the government of India has asked the states to include the informal people for incentives & salary for an effective waste collection, recycle and reuse under the SBM-U. According to 2020 report submitted by Swachhata Sandesh Newsletter by the MoHUA, as of January 2020, 74% of the total wards have achieved the 100% waste segregation.

Andaman & Nicobar Islands, Chandigarh (UT), Chhattisgarh, Daman Diu, Dadra Nagar Haveli, Puducherry and Sikkim are states have achieved the segregation of waste by all of their wards. The six states and a UT under consideration in

Table 39.4 Laws published by department of science and technology, Ministry of Environment and Forests

S. No.	Rules & acts by Indian government	The law enacts that
1	**Water (Prevention and Control of Pollution) Act, 1974 (Galea 2010)**	The amount or quantity of the pollutant which is allowed to discard through industrial processes into the water bodies with the published standard value and describe the fines for not abiding by the law.
2	**Water (Prevention and Control of Pollution) Cess Act, 1977 (Galea 2010)**	It states the collection on cress on water consumed by Industries and also states the standards of water required to be consumed from a distance and the water source installation.
3	**Air (Prevention and Control of Pollution) Act, 1981 (Galea 2010)**	This act prohibited the use of air polluting fuels and substance as a way to provide cleaner air. Any industries operating within the pollution control area have to seek permission from CPCB. National Ambient Air Quality Standards (NAAQS) prescribed emission standards for all Industries.
4	**Air (Prevention and Control of Pollution) Rules formulated in 1982 (Galea 2010)**	For dealing with radioactive waste under the Atomic Energy Act, 1982.
5	**Environment Protection Act, 1986 (Galea 2010)**	This act published by the central government is concerned about the protection of the environment and improves the quality of the environment through setting of standards for emissions, discharge of pollutants, fixing industrial land, management of hazardous effluents, improvement of public health and welfare.
6	**The Environment Protection Rules, 1986 (Galea 2010)**	Procedure for taking samples, analysis and lab reports for emissions and discharge of environmental pollutants. Hazardous waste management rules of 1989, Biomedical waste rules, 1988, Municipal Waste rules, 2000.
7	**The National Environment Appellate Authority Act, 1997**	To hear appeals for the restriction of areas where industries operate.
8	**Factories Act, 1948 and its amendment in 1987**	The first body after Independence to show concerns for the environment protection with its primary objective of welfare of the workers and stating the use of handling of health affecting materials by the workers may lead to poorer environment conditions.
9	**National Environment Tribunal Act, 1995**	Penalty for damage caused during poor handling of hazardous material by the Industry.
10	**Bio-Medical Waste (Management and Handling) Rules, 1998 (Galea 2010)**	Rules to discard bio waste generated from being used on human beings in any form and defining method for duty of holder in segregation, package, transport and storage.
11	**The Ozone Depleting Substances (Regulation and Control) Rules 2000 (Galea 2010)**	To phase out and stop the usage of such substance that causes harm to the ozone layer depletion and report such substances to the authority during chemical process, transportation etc

(continued)

Table 39.4 (continued)

S. No.	Rules & acts by Indian government	The law enacts that
12	**Municipal Solid Waste (Management and Handling) Rules, 2000 (MoSPI)**	States that waste generated in commercial and residential areas excluding dangerous industrial waste but have treated medical waste can be diposed in municipal controlled sanitary landfills.
13	**The Hazardous Wastes (Management, Handling and Trans boundary Movement) Rules, 2008 (Galea 2010)**	Transport, packaging, storage, handling, export, sale, treatment, maintenance of records, liability.
14	**The Plastics (Manufacture, Usage and Waste Management) Rules, 2009 (Galea 2010)**	To regulate the use of plastics during manufacture (degradable or non degradable), sale, stock, distribution and use, guideline for recycling of plastic.
15	**The E-Waste (Management and Handling Rules) 2010 (Galea 2010)**	Recycling, Handling and Collection of E-Waste.
16	**Solid Waste Management Rules, 2016, Ministry of Environment Forest and Climate Change, Ministry of Urban Development (SBM GoI 2016)**	Waste segregation at Source into Biodegradables, Dry and Domestic Hazardous Waste.
17	**National Strategy, Government of India 2017**	To phase out single use of plastic by 2022.

the hypothesis are yet to achieve the segregation of 100% by their wards. The segregation is being conducted at the source of collection.

39.5.1 Waste Handling in India

The collection and handling of waste in Indian states is primarily executed by municipalities, inducting on the ruling passed by the Ministry of Environment Forest and Climate Change. The waste is being collected in the colored bins and segregation is being done at the source of collection by visiting house to house "Swachhata Sandesh Newsletter," January 2020.

A report submitted by MoHUA, 2020 for door to door collection of waste is shown in Fig. 39.3, shows most of the states following the protocols.

Table 39.5 states that out of 16 low populated states that had lower probability of MSWP, seven states achieved the 100% waste segregation status from door to door collection of waste. Though the waste is getting segregated at the collection source, but there are certain numbers of wards remaining in the 19 states having high waste production capacity still to achieve the reliable setting of segregation.

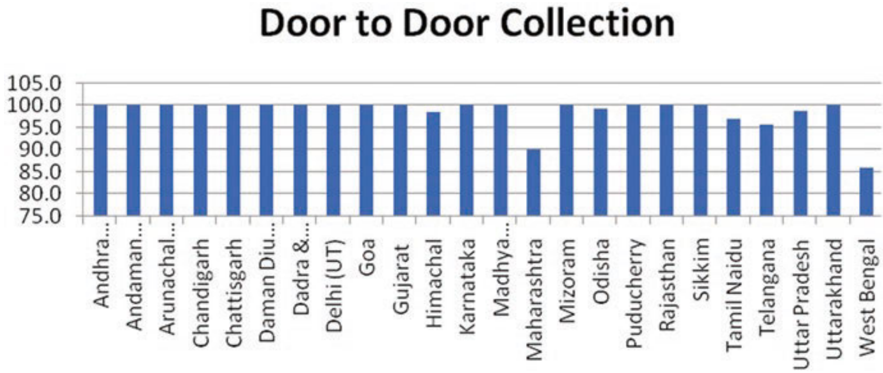

Fig. 39.3 Door to door waste collection, supervised by municipalities. (Source: MoHUA 2020)

Table 39.5 Indian States yet to achieve 100% waste segregation

States	Total wards	Wards with 100% waste segregation	Wards yet to achieve segregation
Andhra Pradesh	3409	3300	109
Arunachal Pradesh	75	11	64
Assam	943	368	575
Bihar	3377	1107	2270
Delhi (UT)*	**294**	**59**	**235**
Goa	217	173	44
Gujarat*	**1427**	**1187**	**240**
Haryana	1496	935	561
Himachal	497	490	7
Jammu	1081	137	944
Jharkhand	932	752	180
Karnataka*	**6464**	**3694**	**2770**
Madhya Pradesh	7115	7005	110
Maharashtra*	**7322**	**6346**	**976**
Manipur	306	196	110
Meghalaya	114	27	87
Mizoram	264	230	34
Nagaland	234	30	204
Odisha	2024	1402	622
Punjab	3123	2664	459
Rajasthan	5389	4419	970
Tamil Nadu*	**12814**	**10891**	**1923**
Telangana	2112	1008	1104
Tripura	310	243	67
Uttar Pradesh*	**12007**	**8294**	**3713**
Uttarakhand	1170	669	501
West Bengal*	**2938**	**558**	**2380**

Figure 39.3, shows the status high and Low producers of MSW achieving the 100% door to door collection facility with Delhi*−100%, Gujarat*−100%, Karnataka*−100% whereas Maharashtra*−90%, Tamil Nadu*−97%, Uttar Pradesh*−98.88% and West Bengal*−87%. The waste is getting collected at point of source but lacks in the proper method of segregation. The waste management system in India stills lacks regularity. Therefore some steps and actions must be taken to avoid irregularity involving such a huge statistics of waste collection management and its processing.

39.5.1.1 Logistics Involved

It is a challenge in India to properly manage the waste collection and disposal system. After the waste is collected, the task is to safely transfer the waste to nominated sites for processing, as many cities still do not have adequate transport mechanisms. The common infrastructure set up by many municipalities across India includes handcarts, tricycles with containers and mini trucks having colored bins as waste collection and segregation vehicles as a mode of reliable transport for different locations within cities and states.

39.5.2 Waste Awareness Programs by Indian Government

The general awareness program primarily focusing on open defecation was proposed by Indian Government as Clean India Mission or 'Swachh Bharat Abhiyan' in year 2014. The mission addressed the problems of open defecation and sanitation in urban and rural areas of India, due to lack of public and private toilets. Not having a toilet at home in rural areas of India was a common problem back then. The government urged citizens to participate in the movement for trash free India and provide sustainable sanitation features for 'Clean India Mission'. Since then, it has taken many steps to spur its implementation which includes educational tours in schools, colleges and universities, clean city ranking contests, the clean city awards etc.

39.5.2.1 Swachh Survekshan (Table 39.6)

Table 39.6 Swachh Survekshan, 2016 to 2020

	First survey	Second survey	Third survey	Fourth survey	Fifth survey
Year	2016	2017	2018	2019	2020
Top five cities	Mysuru Chandigarh Triuchirappali New Delhi Visakhapatnam	Indore Bhopal Visakhapatnam Surat Mysuru	Indore Bhopal Chandigarh Vijayawada Mysuru	Indore Ambikapur Mysuru Ujjain New Delhi	Indore Surat Navi Mumbai Vijaywada Ahmadamad

Source: Singh (2020)

39.5.2.2 Swachhta Hi SewaCampain, 2017

It was started with sprits of maintaining cleanliness through stakeholders in the National Movement which included, SewaDiwas Cleanliness services, SamagraSwachhata involving cleanliness drive by municipalities and participation by the citizens and SarvatraSwachhata having massive cleanliness drives by NGOs.

39.5.2.3 Performance Rating of Clean Cities, 2018

To ensure that the various cities in the country must keep them free from littering and manage the municipal waste, a rating scheme for valuing their clean initiatives was started by MoHUA. The rating was carried out on the basis of 12 cleanliness parameters.

39.5.2.4 Compost Banao, Compost Apnao Campaign

Nationwide campaign under SBM to utilize kitchen waste into something useful, to fertilize the soil in the gardens and agriculture lands, a little difference could initiate the processing of biodegradable waste into useful manure or compost. This could avoid the transport and mixing with non biodegradable waste at the landfills dumping sites.

39.5.3 Waste Disposal Methods in India: Current Scenario

India is currently dealing with its waste management crises. Therefore some of the technological inputs which have been adopted by Indian states, process the waste which includes composting of biodegradable wastes being collected at source, Bio methanation of organic matter to convert into useable biogas for cooking etc., Recycling of paper, board, plastics, thermocol, garden waste, E waste & C and D waste to mitigate green house gas, refuse-derived fuel containing all processed solid waste obtained as byproducts having a certain calorific value to work like a fuel, incineration or burning of waste organic matter in taken up to convert the waste into energy i.e. heat into electricity production, Pyrolysis is burning of organic matter in an inert atmosphere to convert it into ash and charcoal, waste-to-wealth is recovery of valuable items from waste commonly referred to as up cycling of waste. In some of the Indian states waste is still not getting processed and is being dumped openly in the landfills (Singh 2020). These processes had been earlier explained in details by MSWM manual book as a part of Clean India Mission in 2016. Table 39.7 states the status of some of these processes being followed by Indian states.

As observed, the data published by the MSW in their manual book of year 2016 (SBM GoI 2016), if compared with the published reports, the status of the states having the processing facilities reported by CPCB in 2018 given in Table 39.2 versus reports published by MNRE 2018 in Table 39.7, shows highly populated states under current hypothesis have been using the waste processing facilities. The data being projected concludes that besides having the waste treatment methods adopted by the states, data is inadequately available to project the status progression on output by the waste processing plants in each of the technological inputs being utilized as reported by CPCB in 2018.

There are lapses seen in processing of waste in most of the Indian states including, the one's which have higher potential of waste generation. The data on percentage processing through the specific technology adopted by states in India remains unpublished by the state governments. The recycling of waste is nowhere mentioned in the published report, Table 39.8 highlights the status, as observed, the land filling option for waste disposal is still being encouraged without proper regulations in its profiling in Delhi, Karnataka and Maharashtra, seems these states have achieved total waste collection from every household but lacks in segregation and processing of waste being collected. While Gujarat is the top state achievers in collection, segregation and processing of waste, with initial reporting of non existence of processing plants in the state. Tamil Nadu and Uttar Pradesh are weak in garbage collection, but segregating and processing the garbage at optimum level. West Bengal seems to be poorly performing in collection, segregation and processing besides having attained a ranking in highly populated state in India.

Figure 39.4, highly populated states as per the hypothesis are yet to achieve the hundred percent waste processing status, there are lapses in waste segregation in these states, Delhi 55%, Gujarat 87%, Karnataka 54%, Maharashtra 58%, Tamil Nadu 68%, Uttar Pradesh 58% and West Bengal at 9%.

39.5.3.1 Recycling Methods in India

Recycling methods have been stated in the manual book published by the MSW 2016, but as observed from the published reports, none of the Indian states showed any progression on the recycling.

The manual book part ii of MSW states, recycling procedures on (SBM GoI 2016)

(a) Advantages of recycling
(b) Assessment of recyclables
(c) Stages of material recovery
(d) Material recovery facility
(e) Informal sector involved in recycling
(f) Recycling of plastics
(g) Thermocol recycling
(h) Recycling paper and board
(i) Recycling of garden and yard waste
(j) Construction and demolition waste
(k) E waste
(l) Greenhouse gas mitigation potential from recycling and reuse

Table 39.7 Report of waste disposal processing facilities in Indian states tonnes/day (T/D)

States	Total Waste Generation (TPD)	Solid Waste Generation Status T/D			Waste Processing Facilities				Treatment Methods
		Collected	Treated	Landfilled	Composting	Vermicomposting	Biogas	RDF/Palletization	
Andhra Pradesh	6440	6331	500	143	Nil	18	8	Nil	Biomethanation, WTE(23.16 MW) Vermicomposting
Andaman and Nicobar	70	70	5	NA	-	-	-	-	-
Arunachal Pradesh	13	11	Nil	Nil	Nil	Nil	Nil	Nil	-
Assam	7920	6336	200	Nil	1	-	-	-	Landfill,
Bihar	1670	0	Nil	Nil	Nil	Nil	Nil	Nil	Landfill
Chandigarh	370	360	Nil	230	Nil	Nil	Nil	Nil	Landfill
Chattisgarh	2245.25	2036	828	1294	yes	no	no	no	Composting, Vermicomposting
Daman Diu	85	85	0	-	-	-	-	-	-
Dadra & Nagar Haveli	-	-	-	-	-	-	-	-	-
Delhi (UT)*	9620	8300	3240	5060	1	-	-	-	Composting, WTE (52MW), Landfill
Goa	450	400	182	-	7	-	-	-	Landfill
Gujarat*	10480	10480	2565	7730	0	93	1	3	RDF, Biogas, Vermicomposting
Haryana	4837.35	3102	188	2163	4	0	0	4	Composting, Landfill
Himachal	276	207	125	150	-	-	-	-	-
Jammu	1634	1388	3.45	425	NA	-	-	-	-
Jharkhand	3570	3570	65	3505	-	-	-	-	-
Karnataka*	8842	7716	3584	3946	104	57	27	4	Composting, RDF, WTE (1 MW), Landfill, Biogas, Vermicomposting
Kerala	1339	655	390	-	-	-	-	-	-
Madhya Pradesh	6678	Nil	Nil	Nil	10	-	-	1	Composting, Vermicomposting, WTE (15.40 MW)
Maharashtra*	21867	21867	6993	14993	43	31	42	5	Composting, Vermicomposting, WTE (12.59 MW) Bioreactor, Biogas, Landfill
Manipur	176	125	-	-	-	-	-	-	-
Meghalaya	187	156	36	122	1	1	-	-	Composting
Mizoram	552	276	Nil	-	-	-	-	-	-
Nagaland	344	193	-	-	-	-	-	-	-
Odisha	2574	2283	30	-	30	-	-	-	Composting
Puducherry	513	513	10	503	-	-	-	-	-
Punjab	4456	4435	3.72	3214	Nil	1	Nil	2	Landfill, WTE (9.25 MW)
Rajasthan	5037	2491	490	-	-	-	-	-	-
Sikkim	49	49	0.3	-	-	-	-	-	-
Tamil Nadu*	230	210	-	207	12	-	3	19	Composting, WTE (6.4 MW), Biomethanation, RDF
Telangana	6628	6625	3175	3050	10	2	1	3	RDF, WTE (18
Tripura	414	368	250	164	1	1	Nil	Nil	Vermicomposting, Composting
Uttar Pradesh*	15192	11394	1857	-	13	NA	NA	4	RDF, Composting

39.5.3.2 Waste Products Re-usage and Startups

Startup India was rolled out in year 2016 to support entrepreneurs who wanted to bring a change in the nation for creating jobs rather than seeking the jobs. All the programs under this initiative are managed by a team that works under Department of Industrial Policy and Promotion. Since its start many waste management startups have been initiated in India taking total number to 960 (MoCIGoI).

Table 39.8 Observations from states in hypothesis under parameters considered

States	Parameters under study				
	i (%)	ii (%)	iii (MT/D)	iv (%)	v
Delhi (UT)	100%	29.06%	10500	55%	Composting, WTE (52MW), Landfill
Gujarat	100%	83.18%	10274	87%	RDF, Biogas, Vermicomposting
Karnataka	100%	57.14%	10000	54%	Composting, RDF, WTE (1 MW), Landfill, Biogas, Vermicomposting
Maharashtra	90%	86.67%	22080	58%	Composting, Vermicomposting , WTE (12.59 MW) Bioreactor, Biogas, Landfill
Tamil Nadu	97%	84.99%	15437	68%	Composting, WTE (6.4 MW), Biomethanation, RDF
Uttar Pradesh	98%	69.07%	15500	58%	RDF, Composting
West Bengal	86%	18.99%	7700	9%	

(i) Percentage wards inside the state achieved door to door collection.
(ii) 100 percent waste segregation achievement by the wards under states and UTs.
(iii) Most populated states under hypothesis having per day waste production capacity.
(iv) Waste processing percentage.
(v) Technologies being adopted to process the waste

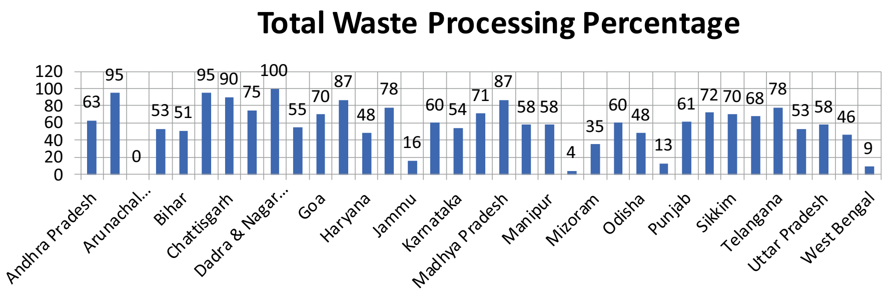

Fig. 39.4 Waste processing in percentage by Indian states. (Source: MoHUA 2020)

39.5.4 Strategies Adopted by Other Countries to Manage Waste Problem

The Countries have been using WTE past many years, the published literature shows Japan topping the list in production of energy from the waste with highest number of WTE plants 310 whereas the other countries in series of ranking are Sweden (49%, 24), Netherlands (39%, 13), Germany (38%, 65), France (34%, 123), Austria (30%, 11), China (16%, 77) and USA ranks last processing at 7% with 86 number of WTE units (Cyranka 2016).

In Japan, they managed to counter the waste dumping in the landfills as they got shorter of land space. Many people opposed to the construction of new landfills pertaining to environmental threat. Therefore the government proposed policy to reduce the waste generation itself in year 1991. It promoted many recycling laws during this period and focused on recycle derive new technologies and forming reduce, reuse and recycle for creating a material-cycle society as a part of their basic plan. This took them long to initiate, promote and govern the overall process. By applying such a planned systematic program, they have successfully managed to bring down the final disposal waste from 160 MT of waste generation/year to 12 MT of final waste disposal through incineration or other methods for year 2011 [23]. Thus, Japan has managed the zero solid waste principle very effectively and minimized usage of scarce land space for landfills.

39.5.5 India's Regional Comparison Study

Data published by Ministry of Statistics and Programme Implementation by government of India, has shown comparative regional study conducted between small, medium and large size cities in India to ensure better human safety and health through systematic disposal of an effective waste management system. Waste Samples were collected and studied for its toxicity that it could cause in polluting the air, water and soil in the urban areas of Ahmadabad, Chennai, Bangalore and Dehradun. The data was categorized into primary and secondary that had two kinds of parameters. The study concluded that waste recovery from these landfills has a huge scope due to the presence of valuable metals and improvement of human health. Observations pointed towards poor profiling of these landfills, irregular inspections on its maintenance, many of the landfills were located near river basin, posing a threat to river water and organisms. The study proposed for an improved construction of sanitary landfills as being used in many European countries (MoSPI).

39.5.6 Model Proposal and Implementation

The local bodies in Japan are finding an opportunity in business amounting to 20 billion US dollars with a constant annual growth from their waste market. The waste recovery and recyclables having material as metal, paper and glass are collected and entirely reused or refurbished many a times before sending them to reprocessing plants. This is their strategy to save energy and create jobs to support the livelihood by expanding their recycled products sales in the international market.

39.5.6.1 An Insight into Japan's Recycling Industry

The Japanese government emerged out as a social group to reform a team of close supervision with the local governments, business owners and local people of all ethnic groups to tackle the problem of waste. Since post war period from year

1950, Japan has primarily focused on public health, prevention of pollution to the environment and creating a sound material cycle society adhering to problems from time to time. At the very beginning of year 1998, Japan was very serious on its recycling law implementation until today. Japan has consistently progress through all these years along with the unique objective to provide healthy living environment to all the people living in Japan. The article published by Ministry of Environment, Japan government reveals that there were many units running on different capacities from 1965 to 2000 processing a vast categorization of waste than most countries.

The Japan government was very active since 1973 in improvising an efficient landfill disposal avoiding the problems of leachate, water contaminating on other surrounded bodies.With a revision in the waste management act, 1991, Japan established a material cycle policy that reduced its waste disposal capacity to bare minimum, through their best practices to achieve such a tremendous change in implementation and successful accomplishment to meet the objectives.

39.5.6.2 Proposal Schema for States in India

(a) Generation reduction, reuse and recycle to form a cycle of repeated material use until its final disposal.
(b) Promotion policy in the country's urban regions creating little changes in production, consumption and lifestyle, eventually forming full forced plan.
(c) Promote production of local, regional and state level waste recycling facilities & creating a market demand for the use of waste recycled products by the brand promoters.
(d) Awareness program on Recycling Waste along with Clean India Mission Initiatives on regular basis via conferences, ranking programs, public opinions & awareness, workshops, community participations and volunteering can be encouraged.
(e) Involvement of all stakeholders viz. Private businesses, government offices and ministries, political parties, municipalities, urban local bodies, residents and non residents for the rightful equal endured conclusion on derived objectives.
(f) Special incentives for informal and formal people involved in segregation of foremost recyclable parts such as glass bottles, plastic, metal, paper and card board.
(g) Appreciation functions from the government to honor all the stakeholders involved on timely basis.
(h) Construction of Sanitary Landfills as per modern construction methods.
(i) Recovery of waste goods from segregated garbage having proper physical entity for reuse.
(j) Opening of businesses to support selling of recycled products.

39.6 Conclusions

There is no periodic data available on the authorized portals to summarize the solid waste data. The projections on waste data vary widely between private agencies looking after the work. After waste segregation at source, it's being poorly managed by the transporters. The waste collection efficiency is 100% where people can readily pay the cost of collection, whereas in other towns and rural areas, people dispose the waste at open lots, therefore fine and littering penalties must be made compulsory on prepaid basis with every registered house, As observed open dump Land filling is still being opted as an easy alternate for waste disposal in India, therefore modern approach to construction of sanitary landfills is the optimal solution and alternate to recover the landfill gas and avoid pollution and contamination of ambient bodies.

The need of hour is sustainability of resources, which can be optimized through publishing of strict laws and amendments on recycling in India by following best practices adopted by Japan, Austria and other countries. The authorities in India are inadequate in providing the durable infrastructure to tackle the waste in towns and rural areas. There is no finding to support the analysis submitted by MoHUA, 2020.

Waste to energy is a new concept in India, but it lacks functionality as waste is not being segregated before its conversion to energy in highly populated states in India, Delhi segregating at 29.06% and alarming condition of West Bengal as the poorest segregator, at 18.99% and processor of waste, at 9%. With SARs COV 2 pandemic widely spread across India, the situation to handle bio medical waste such as PPE/safety kits, surgical masks, gloves to prevent virus from spreading through the mismanagement of waste has posed another challenge in India. Therefore India needs to learn from its counter country Japan in managing the waste problem, easily and effectively.

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Chapter 40
Experimental Study on Light Weight Geopolymer Concrete Using Expanded Clay Aggregate

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Abstract In this modern world, for the past many years, the construction industry has been making some progress by using waste materials in concrete. The geopolymer concrete is made from the by-products like fly ash and GGBS which are generated from the industries which are enabled to minimize the waste products and also to reduce the CO_2 emission by decreasing the usage of Portland cement. The goal of this work is to learn the properties of geopolymer concrete by replacing the normal coarse aggregate with lightweight expanded clay aggregate. The works mainly aim to reduce the structural weight of the concrete by using expanded clay aggregate which has the advantage of being lightweight. The Expanded clay material has chemical resistance, fire resistance, easy to handle and also to transport. The Na_2Sio_3 (alkaline solution of sodium silicate), as well as NaOH (sodium hydroxide), are used for the polymerization process at 10 molarity of NaOH. The normal coarse aggregate is substituted partially with expanded clay with different proportions with 0%, 20%, 40%, 60%, 80%, and 100%. The geopolymer concrete specimen which is made by lightweight expanded clay aggregate such as cube, cylinder, and prism were tested to find their characteristics strength on the 3rd, 7th & 28th days and finally, the results have arrived for the various percentage of replacements. From the results, it is found that around 35% of the weight is reduced when compared to normal geopolymer concrete at 80% replacement by expanded clay aggregate.

Keywords GGBS · Geopolymer concrete · Expanded clay · Fly ash · Lightweight concrete · Pumice stone

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40.1 Introduction

One of the most commonly utilized artificial materials in the world is concrete. It is an important construction material. In Concrete, Portland cement is used as a primary binding agent. Portland cement manufacturing accounts for approximately 4% of global warming, releasing 5–6% of the co_2 produced by human activity and the energy consumption of this process is also high. So this is an alarming time to switch over to new materials and technologies which are eco-friendly and have less energy consumption. Geopolymer technology has the potential to decrease the amount of CO_2 emitted by the cement industry. Fly ash, GGBS, and other industrial waste materials are used to make geopolymer concrete. The primary goal of using lightweight aggregate is to decrease the structure overall dead weight and also it is easy to carry and transport when compared to the normal weight aggregate. It has a low density and excellent thermal insulation, it also resists fire and has a cheap transportation cost. There are many lightweight aggregates are used in concrete like pumice stone, expanded clay, scoria, shale, and others. In this study, expanded clay aggregate is used as a lightweight material which has been replaced partially with normal coarse aggregate. Here, fly ash and GGBS are taken as a binder material and alkaline liquid by combining sodium silicate as well as sodium hydroxide.

40.2 Literature Review

(Bahrami and Nematzadeh 2021) experimented by using cinder as a lightweight material for the M30 grade of concrete at 10 M of NaOH. The strength was carried out for the different proportions of lightweight material and various curing days. The results show 40% replacement of cinder gives better strength. (Karthika et al. 2021) studied by using GGBS as well as fly ash is one of the materials which has binding property at the ratio of 50:50 and pumice stone as lightweight material of different percentages with the 8 M of NaOH and with a ratio of 2.5 of sodium silicate and design mix of 1:1.3:2.8 for the M20 grade concrete. An increase in pumice stone indicates a little reduction in density and strength basis for the performance aspect. This material was tested for compressive, flexural as well as Split tensile strength. Using a combination of M40 and poly carboxyl ether additive (Minapu et al. 2014), attempted to correlate traditional concrete with lightweight aggregate concrete. Pumice is substituted with different percentages and several tests have been carried out in comparison with traditional concrete work. There is a reduction in density, followed by an increase in pumice stone. 30% provide better results in comparison to the other percentage (Shinde et al. 2016), made lightweight Geopolymer cementitious material by using alkaline liquids like sodium silicate as well as sodium hydroxide are utilized for the polymerization process. A variety of mixed percentage molarities were evaluated by casting cubes, which were then tested for compressive strength and density. Geopolymer concrete cubes acquire strength in only 24 hours without water curing at room temperature, according to the conclusions. Another way to improve Geopolymer concrete's strength is to reduce its solution molarity in the mix. (Medri et al. 2015) were studied lightweight geopolymer concrete. Different geopolymer binders and expanded vermiculite sizes were investigated here, and the panels were created with high acceptable density and characteristics when compared with other construction materials like plasterboard were found. Compressive strength reduced by 35.5%, 41.2%, & 53.8% depending on the ratio. Moreover, it demonstrates the link between thermal conductivity and density. The mechanical characteristics of lightweight aggregate were investigated by (Caiza et al. 2018). Mineral admixtures and pumice stone such as silica fume and fly ash replace coarse aggregate in concrete. Both silica fume and fly ash have better strength. When 20% of the pumice stone is substituted, the strength remains the same.

40.3 Materials and Methodology

For producing the lightweight geopolymer concrete, the materials such as GGBS, fine aggregate (Sand), Fly ash, Sodium silicate, Sodium hydroxide, Coarse aggregates (20 mm), Lightweight aggregates (expanded clay), and Water are used. The basic material properties for aggregate and expanded clay are shown in Table 40.1.

40.3.1 Fly Ash

Fly ash is one of the by-products which is in the form of fine powder produced as a waste product by electric power and steam generation facilities. The polymerization process requires fly ash, which is the most important raw material in the production of geopolymer concrete. It is used to reduce the CO_2 emission when replacing the Portland cement. Class F fly ash is generated by burning anthracite, whereas class C is formed by burning lignite. In fly ash, there are many types, and each one has its special properties and uses. In this work class F fly, ash has been used.

Table 40.1 Basic properties of expanded clay, fine, and coarse aggregate

Properties	Fine aggregate	Coarse aggregate	Expanded clay
Specific gravity	2.56	2.64	1.02
Water absorption	0.928%	1.26%	19%
Fineness modulus	2.78	6.87	6.24
Bulk density	1668 kg/m^3	1772 kg/ m^3	314 kg/ m^3

Fig. 40.1 Expanded clay. (Reproduced from https://en.wikipedia.org/wiki/Expanded_clay_aggregate)

40.3.2 GGBS (Ground Granulated Blast Furnace Slag)

Cementitious in nature, GGBS is one of the by-products of the iron manufacturing process and thus environmentally safe.GGBS concrete is substantially more immune to chloride diffusion than Portland cement concrete. When compared with Portland cement production, the GGBS manufacturing process uses below 20% of the energy and generates 10% of the CO_2 emissions. Concrete's durability may be improved by adding GGBS to the mix to minimize damage causes.

40.3.3 Expanded Clay

A particular kind of clay is used to make these aggregates, so they may expand more easily. Using pulverized coal and oil as fuel, the powdered clay is burned at temperatures up to 12,000 °C in a rotary or vertical shaft kiln with an additive that causes bloating which is shown in Fig. 40.1. When compared to other lightweight aggregates, it has high compressive strength.

40.3.4 Fine Aggregate

Fine aggregate is a material that passes through the BIS test sieve no. 4.75 mm. M-sand is often used as a fine aggregate. Fine aggregate is mainly used for achieving good workability. The sand act as filler material and increases the volume of concrete by increasing the air voids.

40.3.5 Coarse Aggregate

In the BIS test using a 4.75 mm sieve, the material that is retained is considered as "coarse aggregate." The shattered stone is often utilized as a coarse aggregate. Depending on the task, the aggregate size may be up to a certain size. In this work, 20 mm nominal chips are used. Only one-third of the concrete section should have a coarse aggregate for the thin slab and the walls.

40.3.6 Water

In the Geopolymer Concrete, for making the solution of sodium hydroxide and distilled water were used based on the mix proportion.

40.3.7 Alkaline Solution

In the alkaline liquid, a solution of sodium silicate and sodium hydroxide was selected. There were commercial-grade flakes of 97% pure NaOH and potassium hydroxide solids. Sodium hydroxide comes in pellet form, whereas sodium silicate comes in liquid form. The sodium hydroxide to sodium silicate ratio is 3.5 mass of sodium hydroxide is 45.1 kg/m^3 and sodium silicate is 112.6 kg/m^3. For casting, the alkaline solution must be prepared at least 24 hours before it is used.

40.4 Proportion

To prepare a lightweight concrete, mix proportion has been arrived by having sodium silicate, NaOH solution, GGBS, superplasticizers, and water with the molarity of 10 M which is shown in Table 40.2. The mix ratio proportion for fly ash, fine aggregate, and coarse aggregate have arrives as 1:1.41:3.28 which is shown in Table 40.3.

Table 40.2 Mix proportion

Sodium silicate (kg/m^3)	NaOH solution (kg/m^3)	GGBS (kg/m^3)	Molarity	Water (kg/m^3)	Superplasticizer (kg/m^3)
112.60	45.10	78.86	10 M	59.14	11.83

Table 40.3 Mix Proportion Ratio

Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
315.44	554.40	1293.60
Proportion		
1	1.41	3.28

40.5 Replacement of Expanded Clay Aggregate

In the geopolymer concrete, the normal coarse aggregate was replaced with lightweight expanded clay aggregate by 0%, 20%, 40%, 60%, 80%, and 100% which has designated as M_1, M_2, M_3, M_4, M_5, and M_6 respectively. The weight of expanded clay aggregate and normal coarse aggregate for various replacement percentages is shown in Table 40.4.

40.6 Test Result

In this study, the Compression, Tensile and Flexural tests have been performed as per the codal recommendation and standard procedure.

40.6.1 Compressive Strength

The cube dimension of 150 x 150 x 150 mm is tested per the IS: 516: 1959. Under a universal testing machine, tests for compressive strength were carried out and loads recorded. In this work, the compressive strength test is carried out for 0%, 20%, 40%, 60%, 80%, and 100% replacement of the expanded clay aggregate with the normal aggregate at 3rd, 7th, & 28th days ambient curing. The testing setup is shown in Fig. 40.2 and Table 40.5 shows the concrete compressive strength for various mix ratios. The graphical representation of the compressive strength of concrete for the various ratios is illustrated in Fig. 40.3.

Table 40.4 Replacement percentage of expanded clay

Material	Weight (Kg/m^3)					
Mix ID	M_1	M_2	M_3	M_4	M_5	M_6
Expanded clay percentage	0%	20%	40%	60%	80%	100%
Fine aggregate	554.40	554.40	554.40	554.40	554.40	554.40
Normal weight coarse aggregate	1293.60	1034.88	776.16	517.44	258.72	–
Lightweight aggregate	–	52	104	156	208	260
Flyash content	315.44	315.44	315.44	315.44	315.44	315.44
GGBS	78.86	78.86	78.86	78.86	78.86	78.86
Sodium hydroxide solution (NaOH)	45.10	45.10	45.10	45.10	45.10	45.10
Sodium silicate solution (Na_2SiO_3)	112.60	112.60	112.60	112.60	112.60	112.60
Water	59.14	59.14	59.14	59.14	59.14	59.14
Superplasticizer	11.83	11.83	11.83	11.83	11.83	11.83

Fig. 40.2 Compression test of cube performed by using universal testing machine

Table 40.5 Compressive strength for geopolymer concrete

Percentage of expanded clay	Compressive strength @ 3 days (N/mm^2)	Compressive strength @ 7 days (N/mm^2)	Compressive strength@ 28 days (N/mm^2)
0%	22	30.13	41.91
20%	18.48	26.04	34.82
40%	14.4	18.22	23.46
60%	11.91	16.4	22.08
80%	9.33	13.24	15.06
100%	7.46	9.64	11.24

40.6.2 Density Test

The average density of each specimen is used to determine the density. These specimens have been tested with various percentages of expanded clay proportion of the lightweight concrete which is shown in Table 40.6. The density for various percentages of expanded clay in lightweight concrete is graphically depicted in Fig. 40.4.

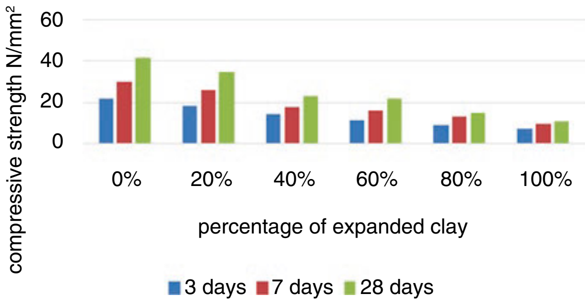

Fig. 40.3 Comparison of compressive strength of concrete for various percentage of replacement by expanded clay

Table 40.6 Density of lightweight concrete in kg/m^3

Percentage of expanded clay	Density kg /m^3
0%	2613
20%	2357
40%	2136
60%	1940
80%	1769
100%	1478

40.6.3 Split Tensile Test

It is used to find out a concrete's tensile strength. Cylinders 300 mm long and 150 mm in diameter are tested by the IS:516:1959. Split tensile tests were performed under a universal testing machine and the loads were recorded. The split tensile configuration is illustrated in Fig. 40.5. and the tensile strength of concrete for different mix ratios is illustrated in Table 40.7. Concrete split tensile strength for different mix ratios is shown graphically in Fig. 40.6.

40.6.4 Flexural Strength Test

The size of the prism chosen for this experiment is 500 x 100 x 100mm. The capacity of a material to resist deformation under load is known as its flexural strength. The prism was placed in a Universal testing machine by which a two-point loading test has been performed as shown in Fig. 40.7. The average flexural result for each percentage of expanded clay is noted. The flexural strength of concrete for the different ratios is presented in Table 40.8 and the graphical representation of the flexural strength of concrete is depicted in Fig. 40.8.

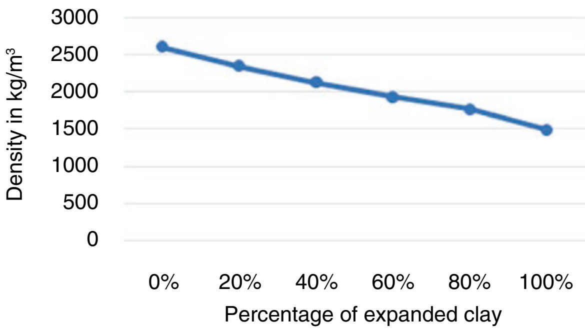

Fig. 40.4 Comparison of density in kg/m^3 for various percentage replacement by expanded clay

Fig. 40.5 Split tensile strength of cylinder performed by using universal testing machine

Table 40.7 Split tensile strength for geopolymer concrete

	Split tensile strength		
Percentage of expanded clay	3 days (N/mm^2)	7 days (N/mm^2)	28 days (N/mm^2)
0%	2.16	3.27	4.83
20%	1.89	2.84	3.94
40%	1.58	2.29	3.14
60%	1,17	1.82	2.79
80%	0.86	1.26	1.92
100%	0.69	0.98	16.3

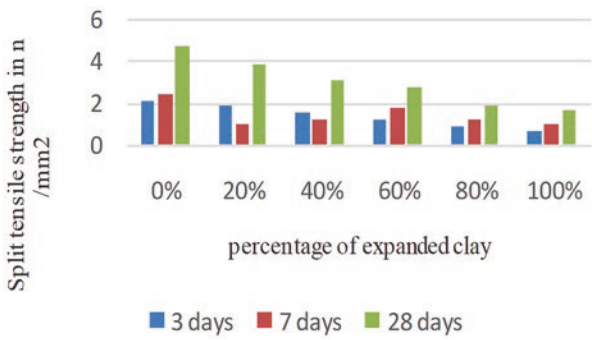

Fig. 40.6 Comparison of split tensile strength of concrete for various percentage of replacement by expanded clay

Fig. 40.7 Flexural strength of prism performed by using universal testing machine

Table 40.8 Flexural strength for geopolymer concrete

Percentage of expanded clay	Flexural strength @ 28 days
0%	6.36
20%	5.65
40%	4.83
60%	3.92
80%	2.65
100%	1.54

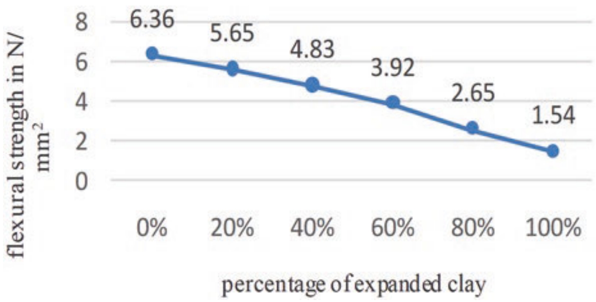

Fig. 40.8 Comparison of flexural strength of concrete for various percentage of replacement by expanded clay

Table 40.9 Cost comparison of normal and lightweight aggregate concrete

Normal concrete (Rs)	Lightweight aggregate concrete (Rs)	Cost difference (Rs)	Difference in percentage
9893	13,140	3247	28.19

40.7 Comparision in Rates of Normal and Lightweight Geopolymer Concrete

When coarse aggregate has been substituted by an expanded clay aggregate for 20% (Mix ID M_2), it is suitable for construction. The cost comparison of normal and lightweight aggregate concrete has been calculated for mix ID M_2 and the percentage difference is given in Table 40.9.

40.8 Conclusion

In nowadays construction industries need eco-friendly construction materials to reduce global warming. Geopolymer concrete is an innovative construction material that is made by industrial by-products such as GGBS as well as fly ash which is to minimize the use of Portland cement to reduce environmental pollution. The expanded clay is replaced by the normal coarse aggregate such as 0%, 20%, 40%, 60%, 80%, and 100%. Based on the results for 3, 7, and 28 days which are presented graphically.

- Based on the results, concrete unit weight lessens when the proportion of expanded clay increases. Around 35% of the weight is reduced compared to normal geopolymer concrete at 80% replacement of expanded clay aggregate.
- The replacement of concrete by up to 20% reduces the unit weight, but it does not provide enough strength to be utilized for structural applications.

- Compression When the percentage of expanded clay increases more than 20%, strength decreases but unit weight increases.
- Even though the cost of lightweight aggregate is slightly high when compared to standard concrete, but by having the advantage of the lightweight property, this concrete may use where the self-weight of the structure has to reduce
- The results of these experiments indicate that substituting 40% and 60% lowers self-weight, but is only acceptable for non-bearing structures. The use of a bearing structure is appropriate when normal coarse aggregate is substituted with an expanded clay of 20%.

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Chapter 41
Seismic Response of Composite Bridges: A Review

S. Bharani and M. N. A. Gulshantaj

Abstract Due to past recent earthquakes, bridge failure is more common due to the lack of strength. Extensive damage may occur not only in the substructures, which are expected to yield but also in the components of the superstructure involved in transferring the seismic loads. This leads to giving more importance to the strengthening of structural components using various innovative techniques. The recent techniques which improve the performance of the structures and environmental durability of the structures are likely to be adopted. The current research area is mainly focused on the use of alternative materials to conventional concrete such as fiber-reinforced plastic composites (FRP composites). The use of FRP composite in RC bridge components will increase the factors such as ductility, response factor, energy dissipation, etc. These also improve the adequate strengthening of structure and reduce the cracking pattern.

Keywords Composite bridges · FRP laminates · Seismic response · Bridge components · CFRP

41.1 Introduction

The seismic events create great devastation in terms of life, money, and failures of structures. The main cause of bridge failure is due to the extreme load during the earthquake. A properly designed bridge according to standards should also fail. That is because; it needs additional strengthening along with proper design. The structural strengthening of bridges can be done by following methods such as the post-cast shear wall, concrete jacketing of a column, Base Isolation, Mass Reduction Technique, Wall Thickening Technique and retrofitting using composites.

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Fig. 41.1 showing the composite bridge and its components. (Fang et al. 2019)

The main research needs associated with conventional strengthening methods is the optimization of the retrofit design to achieve a satisfactory structural performance level at a minimum cost based on reliably characterized seismic demand and structural capacity.

The FRP composites is a fibre reinforced polymer which belongs to the category as a composite material. The FRP Composites are mainly used to strengthening the structural components, which will replace the old construction technique. This forms a sequence of the network containing different types of material attached. This material is called anisotropic because it contains different types of fibre. The different types of material attached will form a sequence around them. The use of Fibre laminates in structural components improves the mechanical properties of the structure in the direction of placement of fibre (Bharani et al. 2021).

These composite material made of fibres has high corrosion resistance, high strength, and thermal properties. These composites are brittle, this affects the material at the increase of loading and due to change in environmental conditions. The temperature change will affect the mechanical properties. The main function of FRP is providing strength and stiffness in the direction of fibre placement. The fibre reinforcement will carry the load along the length of fibre placement. This composite material will replace the steel reinforcement in the structural system cordially but not fully. The use of FRP composite material will improve the cost reduction in the construction industry and make the construction more economical. The bridge and its damages are shown in Fig. 41.1.

41.2 Review of Research Findings

The timber wall made of DD timber frame which was infilled by using locally available stone and mortar. The five specimens of wall panel are cast and it was tested under monotonic loading in two-phase of testing. In the first one, the wall panel of five specimens was tested to observe failure patterns and the later phase was the retrofitting of the specimen at damaged areas/joints with Carbon Fibre Reinforced Polymer wraps and strips. The testing was done to obtain the load-displacement curve, ductility, energy dissipation capacity of the specimen and this result shows higher improvement compared to the conventional specimen in its seismic performance of using timber material in construction (Muhammad et al. 2020).

The STM method (i.e., Strut and Tie model) is used to Reinforced Concrete Deep beams bonded with Carbon Fibre Reinforced Polymer (CFRP) sheets. The new formation of the effectiveness factor of the concrete strut ad tie was formed in this investigation. The result obtained from the works of literature is compared with the results obtained from the RC deep beam bonded with this composite fibre sheets.in this testing, the proposed model has two modes of failure mechanism adopted, one is crushing strength of concrete and the other is diagonal splitting, and these two were later modified with ACI code and AASSHTO. This new model was compared with the already existing model and this shows significantly improved results compared to the existing one (Ammar N. Hanoon et al. 2017).

The RC frames are cast as per the ACI code(seismic provision). The numerical modeling and Experimental investigation were carried out to find the parameters of flange – web joints under quasi-static cyclic load test. In two specimens, one was not retrofitted and the other was retrofitted with CFRP Laminates. In Experimental investigation, the test was carried out at each drift applying full three scales of cyclic loading. The STM model was created and analysed by using ANSYS software. The result of both investigations shows that the specimen/model bonded with FRP laminates shows better results compared to the conventional specimen (Maheri et al. 2019).

The RC column with Previously damaged structures by seismic force and new RC column under Pseudo – seismic loading are used for testing. Both types of the model with lap-spliced bar are retrofitted with FRP sheets externally and finite element model was created to verify the results. The investigation is done by using the equation KANAPE and EC8.3 to get a better accuracy of results. The shear strength of a new column will be higher the damaged column strengthened by FRP because of obtaining less chord rotation parameter (Evgenia et al. 2019).

The Reinforced Concrete walls are bonded with Flax fibre Reinforced Polymer externally in the form of strips. The specimen with or without Flax-FRP results is compared to the CFRP specimen in the literature review. The results of the above specimen under cyclic seismic loading shows that the FFRP shown good performance equals to CFRP. This FFRP should be used as a good alternative as natural fibre reinforced polymer composites) (Luccio et al. 2017).

The seismic response of the retrofitted brick masonary house was tested. The different types of composite materials are used, and the models are tested under dynamic shake table test. Four types of one-fourth scale specimens were tested which are unreinforced brick masonary house model, brick masonary house model retrofitted with Polypropylene band, FRP composites and both FRP & Polypropylene band. The result shows that the Combination of FRP and PP band shows better results compared to all other types of specimen because of its good ductility and energy dissipation capacity (Umair et al. 2016).

The specimen of retrofitted and unretrofitted column are tested in a different direction under lateral loading. The CFRP wraps are used for retrofitting of RC columns. The test result shows that the loading direction plays an important role in the seismic performance of the specimen. The increase of loading decreases the shear resistance, lateral drift, and energy dissipation in the unretrofitted column. The retrofitted column will exhibit the failure mode in a different direction of loading (Daiyu et al. 2018).

The STM (strut and tie model) was developed and it is retrofitted with CFRP composites. The results of this STM model are compared with the result obtained from the two scales experimental model of RC beam-column retrofitted with CFRP jackets. This proves that STM was one of the best alternative methods in the aspect of seismic assessment of the Beam–column joint (Yasuteru et al. 2017).

The RC wall panels were initially damaged by applying cyclic lateral load and these seismically damaged panels are externally bonded with the CFRP composites. The use of glass and carbon fibre grid provides better confinement at the ends. The ATENA 2D software was used for numerical analysis to obtain the maximum lateral load. The result of all panels are compared with the numerical analysis shows that it improves the load-bearing capacity and displacements values (Todut et al. 2015).

The strut and tie model was developed to evaluate the shear strength of concrete deep beams. The deep beam was divided into two parts: uncracked and cracked parts. The experiment and numerical results of the existing deep beams are taken for parametric study, and the results show that the uncracked section is more interlock to the shear resistance (Chen et al. 2018a, b).

The comparison of two deep beams was taken into consideration. The carbon fabric reinforced cement-based mortar and carbon fibre reinforced polymer-based mortars are used to strengthen the deep beam. The maximum lateral loads of this beam are calculated by the strut and tie model method. The results show that the CFRP grid strengthening system is better compared to others (Rizwan et al. 2018).

The investigation of Engineering cementitious based Hybrid FRP steel-reinforced columns. The specimens of a steel-reinforced column, ECC provided at the plastic hinge, Steel – FRP Reinforced column were tested. The column with hybrid steel FRP shows less deformation compared to the conventional one. This method significantly improves the seismic behaviour of the Reinforced column and reduces the deformation and shrinkage of the column (Fang et al. 2019).

The seismic retrofitting technique of using ultra-high-performance FRP jackets to strengthen the RC piers. The FRP was wrapped around the RC piers and the specimen of various height was tested under cyclic loading. The FE modelling of the RC pier with FRP was analysed and the result of both experimental and FEM was validated. The RC pier with less height will have better results and shows high seismic-resistant behavior (Teng et al. 2019).

The Reinforced concrete bridge column was tested under uniaxial cyclic loading. The ECC was used mainly because of its Strain hardening behaviour. The RC column, a column with ECC plastic hinge and wrapped with PP - ECC jackets were tested under cyclic load. The results show the Column with wrapping jackets improves structural performance (Zhanga et al. 2019).

The investigation of the retrofitting behaviour of beam-column joints under the shear test. The beam-column joint specimen was damaged by applying cyclic load and the specimen was retrofitted using the CFRP sheet at a critical section. This retrofitting technique improves the structural performance of the beam-column joints (Khaled et al. 2019).

The FRP composite vehicular bridge was designed and on a small scale and it was tested under static and dynamic loads. The Finite element model of this bridge was developed and the flexural behaviour was analysed in numerical modelling. The result was used to develop the design procedure to develop the composite bridge (Tomasz et al. 2019).

The innovative bridge column model incorporating ECC with Aluminium – magnesium – copper (superelastic alloys) bar were tested under seismic loads. The experimental data are compared with the numerical data and it is validated. The result of the numerical modelling provides the data that cannot be obtained through the experiments (Farshid et al. 2019).

The seismic behaviour of the RC shear wall was analysed under seismic load to determine the structural performance of the wall. The RC wall represents the existing shear wall of a five-storeyed building and the specimen was strengthened by CFRP composites. The shear strength of the CFRP specimen was improved with other parameters (Samiullah et al. 2019).

The gravity railway bridge pier is retrofitted with carbon Fiber-reinforced polymer. The pier model of the 1/8th scale was tested to obtain the seismic performance of gravity bridges. The results show that the use of CFRP and steel materials will improve the performance of bridge piers in seismic prone areas (Xingchong et al. 2018b).

The bridge decks were constructed using FRP composite and the FEM model of the bridge was created to analyse both theoretical and experimentally. The static and dynamic test was conducted and the bridge was continuously monitored by using the optical sensor. The sensors are used to monitor the long time performance of FRP of bridges (Xingchong et al. 2018b).

Numerical modelling of Cable-stayed Bridge was analysed under seismic loading using SAP 2000 software. The base isolation has been created for heavy earthquake and it has been executed in the Bridge. The 3D finite element model was created and the nonlinear dynamic time history analysis of the cable-stayed bridge has been carrying out. Deck Displacement, acceleration, base shear, base moment, bending moment, the response of tower and performance of the cable and isolators was investigated (Siwowski et al. 2018).

The structural behaviour of the original bridge for earthquake forces. The bearing made of rubber is equipped with a cable-stayed bridge and it is investigated. This was done by using the nonlinear dynamic time history analysis method. In this system, they conclude that the bearing system will improve the structural performance of the bridge and transmit the seismic force to the superstructure (José et al. 2017).

The FRP composites are used to retrofit the RC bridge piers for seismic collapse assessment. The analysis reveals the conditional probability of earthquake intensity at a particular damage stage. In a circular pier, the fragility curves are developed and

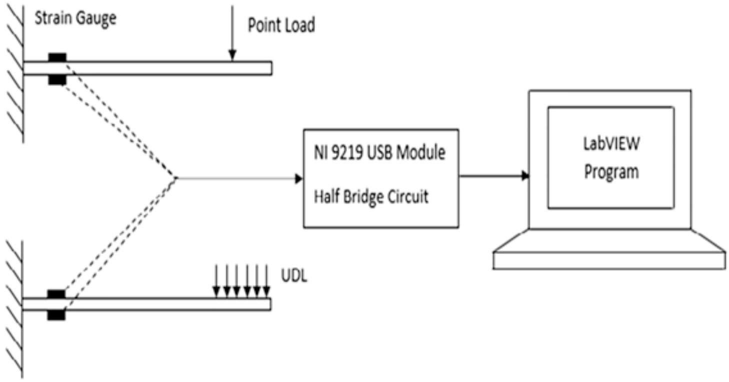

Fig. 41.2 showing the experimental setups interfaced with LabVIEW (Hamel et al. 2020)

the various parameters are taken into performance analysis to investigate the non – linear behaviour (Parghi et al. 2016).

The girder collision at the abutment and wing wall due to seismic force was investigated. The ABAQUS is used to create the 3D FEM model of 2-span concrete girder bridge and it is examined for different approaches. The results show that the structural parameters were affected by the displacement restriction (Desy et al. 2016).

The LABVIEW software is used to record or monitor the vibration in an MDOF system. The active dynamic vibration absorber is used by the LABVIEW to continuously monitor the frequencies and it consolidates the result from the various frequency (Ismail et al. 2012).

The LABVIEW is used to detect the crack in a conductive material. It is the non-destructive testing method to detect the crack pattern without damaging the material. The eddy current test is used to detect the crack on the material and it is continuously monitored by using the wires that connect the automatic test and the materials (Hamel et al. 2020).

The flexural formula for cantilever beam can be calculated by using Ni-LabVIEW software. The ANSYS software is used for numerical modelling of the same to get the results. The experimental setup of this model is shown in Fig 41.2 (Anirban et al. 2018).

41.3 FRP Composites

41.3.1 Fiber Reinforced Polymer Composites

Fibre Reinforced Polymer (FRP) composite is a composite material made of polymer and fibre. It is the form of two materials and it is artificially made in the industry. The FRP composites are made up of different types of fibres combined to form

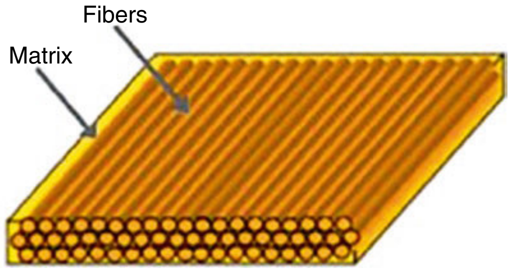

Fig. 41.3 Formation of FRP (Abbood et al. 2021)

a network. This is mainly used to replace the existing construction material. They are not brittle compared to the other materials. The use of fibre in the FRP will distribute the load equally and improves the properties of the composites. The FRP used in the building construction proves that it will be safer and economic because of its properties. The use of steel and aluminum will lead to corrosion and this can be avoided by using FRP composites. The FRP is used in the construction of boats, parts of the instruments and many other applications.

41.3.2 Components of Composites Materials

Fibres The fibres are the materials that are obtained from natural and artificial sources. The various fibers from the artificial sources are steel and glass. The fibres extracted from the natural sources are jute, coir, aramid, sisal and many other fibres. In these fibres, some are used for composite materials. The type of fibre used defines the properties of composite materials.

Matrices The matrices are the resin used to form the polymer by using fibre. The most used resins are epoxy and vinyl ester and it is used at different temperature. This improves the bonding strength and it is resistant to chemicals. The formation of the FRP matrix is shown in Fig. 41.3.

41.4 Types of Fibre Reinforced Polymer (FRP) Composites

41.4.1 Glass Fibre Reinforced Polymer (GFRP)

The limestone, silica sand, folic acid, and another compound are mixed and it is melted under high temperature. The strands obtained from the molten glass are cooled to drawn the fibres in a platinum plate. The obtained glass fibres are converted to various forms to get the composites. The polymer reinforced with the glass fibre to form the glass fibre reinforced polymer. The resin is used as a polymer

Fig. 41.4 Various types of FRP (Abbood et al. 2021)

matrix. These composites will have high mechanical strength, low moisture, and high electrical insulating properties. It has good impact resistance compared to other fibre. The various forms of GFRP are shown in Fig 41.4.

41.4.2 Carbon Fibre Reinforced Polymer (CFRP)

Carbon fibres are having high stiffness, elastic modulus, and lower elongation and vice versa. They are water resilient in nature and resistant to chemicals. They are resistant to creep and corrosion and can withstand fatigue. The carbon fibre laminates are shown in Fig. 41.5.

41.4.3 Aramid Fibre Reinforced Polymer (AFRP)

The aramid fibres (aromatic polyamide) are obtained from the trademark Kevlar. They are having high elastic modulus and elongation capacity. The application of these fibres are helmets, bulletproof, etc. They cannot be used in high temperature, and it does not work well in ultraviolet radiation. It has the property of resistance to steel corrosion.

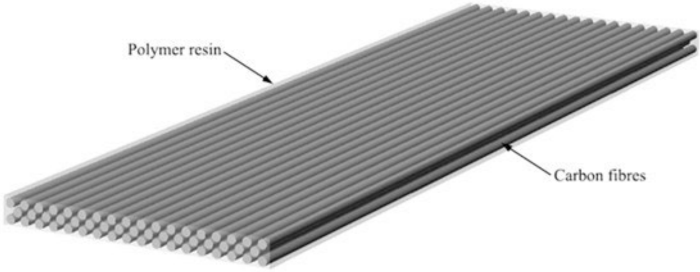

Fig. 41.5 Carbon fibre reinforced polymer (Liu et al. 2015)

41.5 Strengthening of Bridge Components by Using FRP

The strengthening of Bridge components is needed when the bridges are prone to seismic areas and it needs to be strengthened to avoid damages by an increase of loads and nearby activities. The individual bridge components are strengthened by FRP laminates externally or internally using FRP bars with the replacement of reinforced steel bars. The conventional concrete method will not be able to meet the seismic requirement, this cause damages to the bridge components and even leads to failure. This technique will enhance to development of a new concept in the civil Engineering field to adopt the structure resistant to earthquakes. According to the type of FRP composite used, it will improve both shear and durability capacity of the structure. The epoxy resin is used to bond the bridge components and FRP together. The FRP laminate is used in the form of sheets, wraps, strips, and laminated boards. The types of FRP are used based on the requirement of the bridge components.

41.6 Conclusion

(a) The Retrofitting of walls using FRP composites improves the ductility and load-carrying capacity of walls with a significant level (Muhammad et al. 2020)
(b) The strengthening of Bridge components using FRP laminates improves the stiffness and strength of the structure (Xingchong et al. 2018b).
(c) Nonlinear static pushover analysis (NSPA), and incremental dynamic analysis result of bridge piers strengthened by FRP improves its stability and shows improvement in other parameters (Todut et al. 2015).
(d) While investigating seismic behaviour, the normal column having low lateral strength, deformation, degradation compared to column retrofitted with FRP composites (Evgenia et al. 2019).
(e) In a beam-column joint, the use of the CFRP joint improves the shear strength of the retrofitted specimen. The use of wraps is quite useful in improving its shear strength (Yasuteru et al. 2017).

(f) The ultra-high performance of fiber-reinforced jackets used in the bottom of the pier improved the flexural behaviour of the pier (Parghi et al. 2016).
(g) The crack pattern and the seismic response should be easily analyzed experimentally using LabVIEW software. This software will process the data obtained during testing and shows better result compared to other software (Anirban et al. 2018).

41.7 Discussion and Future Scope

The innovative materials such as CFRP, GFRP, AFRP, etc, can be used as a replacement of steel and aluminium. They are used to eliminate the corrosion, fatigue failure, shear failure in the seismic prone areas (Bharani et al. 2021). These materials used in the concrete structural component such as beams, column and beam-column joint as a retrofit. These materials will improve the mechanical and durability properties.

They can be able to withstand the harsh environmental conditions and it improves the corrosion resistance of the element. These innovative materials help the Engineers to complete the project without difficulty. In repair works, the damaged structure can be easily retrofitted by using these composites. They can be used for strengthening the structural element while construction. They can be a good replacement for traditional materials.

These new designs will reduce the size of the structural element with the same loading condition. In the future, it will be used to retrofitting the existing bridge pier, decks, and other elements. The future scope of using FRP composites is mainly focused on the analysis of its response to seismic loading and categorizes its performance according to the environment.

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Chapter 42
Assessing and Correlating the Flow Duration Curve and Drought Index for the Environmental Flow Requirements

C. Prakasam, R. Saravanan, Varinder S. Kanwar, and M. K. Sharma

Abstract Environmental flow is the minimal flow required for the ecosystem for its sustainability. The environmental flow and its assessment are slowly gaining its attention throughout the world, hence there is a greater need for the Environmental Flow Requirement assessment. Pertaining to this, National Green Tribunal has passed an order stating to maintain the 15% average of the lean season flow as the minimal flow. In assessing the environmental flow requirements, the flow data corresponding to the inflow and discharge is quite questionable. In order to validate the results, the alternate method should be used as there are various methods for this purpose, here in this research work the drought index Standard Precipitation Index is correlated with the Flow Duration Curve results to arrive at possible environmental flow state in the study area. The Pandoh Hydropower project with an installed capacity of 990 MW is located in Mandi, Himachal Pradesh is partially run of river project. The rainfall station nearby the projects is Sundernagar, Kullu, Mandi, Bhuntar and 38 years of rainfall data is available for analysis purposes. The results from the Flow Duration Curve and Standard Precipitation Index correlated to arrive at 50% as the percentage exceedance necessary environmental flow requirements for the Pandoh basin.

Keywords SPI · FDC · Environmental flow · Hydropower project · NGT

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42.1 Introduction

Environmental flow is the phenomenon that has been suggested as a mitigation measure for the impact due to the operation and construction of the hydropower project. The environmental flow is defined as the minimal water release in the downstream side of the river for the ecosystem sustainability. The assessment of environmental flow requirements can be done employing various methodologies each having its advantages and disadvantages. The hydrological method which utilizes the flow data to assess the e-flow requirements has many advantages, however, the data deficiency and authenticity of the data is still a question. The Flow Duration Curve methodology in which the plot between the percentage of exceedance and discharge is jotted down and 95% of the discharge is taken as the required environmental flow estimation for at least of 30-years data. SPI method overcomes this disadvantage as it empowers estimation of the start and end of dry spell just as its level of intensity (Ljubenkov et al. 2016). The negative values of SPI signify the rainfall deficiency, and vice versa for positive values (Amrit et al. 2019). Computation of the index for a particular scale of time at any area requires the solid match of a Gamma frequency distribution conveyance as the most probable likelihood work, to the information. Mishra et al., (2019) an exertion is made to depict the ecological stream state of a watershed with the assistance of the drought index such as SPI a record frequently utilized in drought monitoring utilizing rainfall. SPI is exceptionally well known and generally utilized for dry spell observing. Smakhtin et al., (2000) the possible extension of the spatial interpolation method for daily streamflow time-series generation that uses both observed flow and rainfall records. The original structure of the spatial interpolation algorithm is reviewed, and the modifications required to incorporate rainfall records are described (Karlsson et al. 2014). The ability of the hydrological model to foresee environmental change sway was explored by taking a gander at exhibitions outside the alignment time frame. The hydrological models can't be relied upon to foresee environmental change impacts on release as precisely later on, contrasted with the exhibition under current conditions, where they can be aligned (Saravi et al. 2009). The SPI index's efficiency has been determined using the Time Scale-Magnitude-Frequency (TMF) and Time scale- Duration-Frequency (TDF) for monitoring the 1999 drought. About 15 relationships were established, that institute the basic water resource design tool and serves the purposes. The maps were created spatially showing the drought's extreme conditions (Juliani et al. 2017). For the Minas Gerais, a semi-arid climate region Severity-Duration-Frequency curves were developed and derived an isohyet map analyzing 17 rainfall stations. SPI was used in identifying the drought events for a time scale of 12-month.

Ali et al. (2019). The SPI index determines that the rainfall plays the vital role in affecting drought duration and intensity (Liu et al. 2021). Used the SPI index to effectively reflect the drought effect in the Sichuan Province using the 44 rain gauge station data. The drought impact was increasing in the western region and occurrence of drought was more in central mountainous regions and southwest plateau

(Javed et al. 2021). Assessed the best suit agricultural drought index method for the Qinghai-Tibet area. The spatial patterns of multivariate standardized drought index matched with vegetation health index the best than standardized precipitation index and standardized soil moisture index (Sobral et al. 2019). The drought indices allow the drought event characterization. The commonly used index and World Meteorological Organization (WMO) recommended index is Standardized Precipitation Index (SPI) (Zuo et al. 2021). Explored the likelihood of conniving the (SPI) using less rainfall data time series in China. The data used was from 1961 to 2019 covering 2416 rain gauge stations. The feasibility to calculate SPI for short-sequence stations and spatial interpolation-based distribution of precipitation parameters of the long-sequence station has been confirmed (Prakasam et al. 2021). The environmental flow is the minimal flow required for maintaining the health of the ecosystem (Prakasam et al. 2020). The impact due to the hydropower project in the downstream side has been highlighted through GIS application for the Pandoh Hydropower project (Tomaszewski et al. 2021). Low-flow periods are the flow corresponding to the 90 and 95 percentiles in the FDC plot as constant, multiannual truncation level (Salinas-Rodríguez et al. 2021). Hydrological methodologies are the most efficient approaches for environmental flow (eflow) assessments (Eriyagama et al. 2021). Followed the methodology where the author estimates the FDC and correlate it to the environmental management classes. The Class A corresponds to healthy river and Class F corresponds to highly degraded river.

This research work attempts at correlating the FDC values and SPI indices to evaluate the environmental flow requirements for the study area.

42.2 Study Area

Pandoh dam is part of the Beas River basin and it is of 2134 m in length, 457 m in width, and a depth of 15.58 m are situated in Mandi district of 134 hectares' catchment area encompassed by Shivalik mountains at 899 m altitudes. It is owned by the Bhakra Beas Management Board (BBMB) and completed in 1977. The lake pursues a strait and expansive course between three soak slopes (Fig. 42.1).

The wellsprings of water to the lake are watershed, atmospheric inputs, and baseflow. For the generation of hydroelectric power, an earth-shake fill dam. The Pandoh Block of Mandi district is surrounded by temperate forests. The highest rainfall occurs of about 63% occur in the Mandi district in June – September with 1,568.5 mm as average annual precipitation followed by the least rainfall from January to March. The area is prone to drought and in the years 2002, 2004, 2005 and 2009 were drought year.

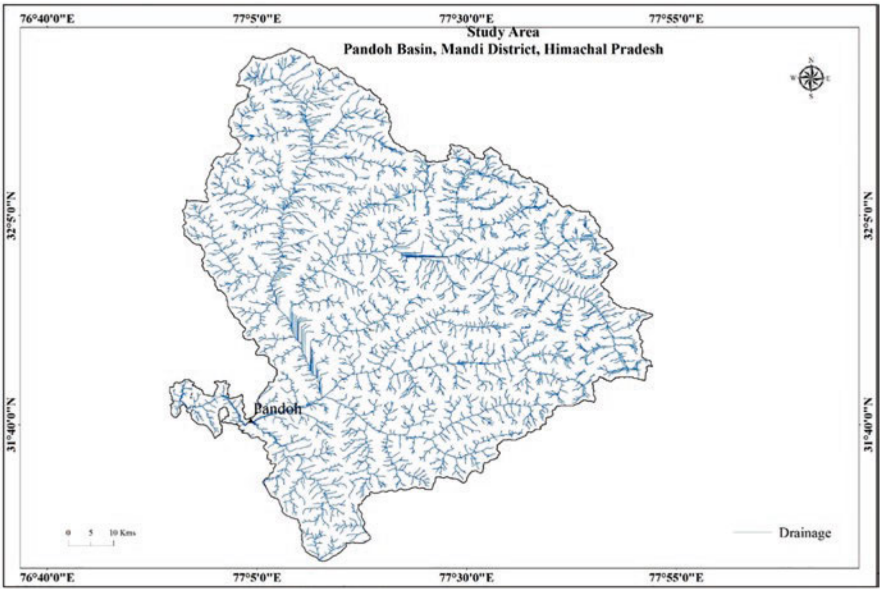

Fig. 42.1 Pandoh dam

42.3 Materials and Methods

The commonly used drought monitoring index is the Standard Precipitation Index (SPI). The significant encounter for the water administrators to satisfy the water necessities of individuals without granting any breaking down impact on the natural administrations, gave by the solid streams (McKee et al. 1993). It is calculated with the precipitation data of long term measured for the study area. The precipitation data is fitted into cumulative probability distribution such as gamma distribution and then transformed or normalized into standard normal variable equal to zero (Edwards 1997). The normalized values ranges represent the drought conditions varying from extreme drought condition to extreme wet condition for the variable Z with variance 1 and mean 0. The Negative values speak to the lack of precipitation, while positive value estimates the overflow precipitation. Further, the negative value's magnitude is classified to show the drought's severity i.e., higher the negative value of SPI the probability of drought is likely to be severe. SPI has points of interest over different records, as, it requires just precipitation for the drought monitoring for small to large timescales i.e., from 1 month to 24 months. For the meteorological drought analysis and monitoring many articles have used SPI (Hayes et al. 1999).

Table 42.1 represents drought conditions based on SPI (McKee et al. 1993).

FDC (Flow duration curve) is a plot between the percentage of time that flow in a stream is likely to exceed some specified value of discharge in y axis. The release from the dam might be day by day, month to month, the yearly, or the whole time of

Table 42.1 SPI values and corresponding drought condition

SPI	Condition
SPI value greater than 2.0	Drought condition is Extremely wet
SPI value between 1.5 to 1.99	Drought condition is Very wet
SPI value between 1.0 to 1.49	Drought condition is Moderately wet
SPI value between −0.99 to 0.99	Drought condition is Near normal
SPI value between −1.0 to −1.49	Drought condition is Moderately dry
SPI value between −1.5 to −1.99	Drought condition is Severely dry
SPI value less than –2	Drought condition is Extremely dry

Table 42.2 FDC percentage and the conditions

Percentage	Flow condition
FDC percentage between 0 to 10	High flow in the river
FDC percentage between 10 to 40	Moist conditions in the river
FDC percentage between 40 to 60	Mid-range flow in the river
FDC percentage between 60 to 90	Dry condition in the river
FDC percentage between 90 to 100	Low flow in the river

record contingent upon our advantage. In FDC stream records are broke down over indicated spans to create stream term bends which show the connection between the scope of releases and level of time that every one of them is risen to or surpassed. The flow indices Q90 and Q95 are known as low flow indices. The Q95 represents the discharge value exceeded or equaled 95% of the time as per the data. The duration curve is divided into 5 zones and it is shown in Table 42.2. The current flow condition in relation to the percentage in of five classes while the SPI value is divided into seven classes, hence the proposed FDC value with respect to the current NGT order on the environmental flow, the flow conditions are classified into seven with 15–20% as a base. It is given in Table 42.3.

42.4 Results

The analysis is an attempt to correlate the SPI indexed value and the percentage of exceedance. By correlating their condition, the required percentage can be allotted as the environmental flow based on the precipitation data by developing a general relationship between these parameters. The SPI analysis has been carried out for (1984–2018) years and the plot are given in Fig. 42.2. These values represent the severity of either drought or wet conditions. In the study area for the record of the precipitation from the IMD Shimla, the index shows that the watershed doesn’t fall under drought zone. The normalized variable value lies in the level of (−0.99 to 0.99) Near normal for most of the assessed years except for 2002, 2004, 2005, and 2009 where the drought severity prevailed. In the FDC analysis, the flow corresponding to the 5th percentile is considered the high flow and the 95th percentile is

Table 42.3 Comparison between SPI and proposed FDC

SPI	Condition	FDC (% of exceedance)
SPI value greater than 2.0	Drought condition is Extremely wet	0–15
SPI value between 1.5 to 1.99	Drought condition is Very wet	15–20
SPI value between 1.0 to 1.49	Drought condition is Moderately wet	20–25
SPI value between −0.99 to 0.99	Drought condition is Near normal	25–50
SPI value between −1.0 to −1.49	Drought condition is Moderately dry	50–75
SPI value between −1.5 to −1.99	Drought condition is Severely dry	75–90
SPI value less than –2	Drought condition is Extremely dry	90–100

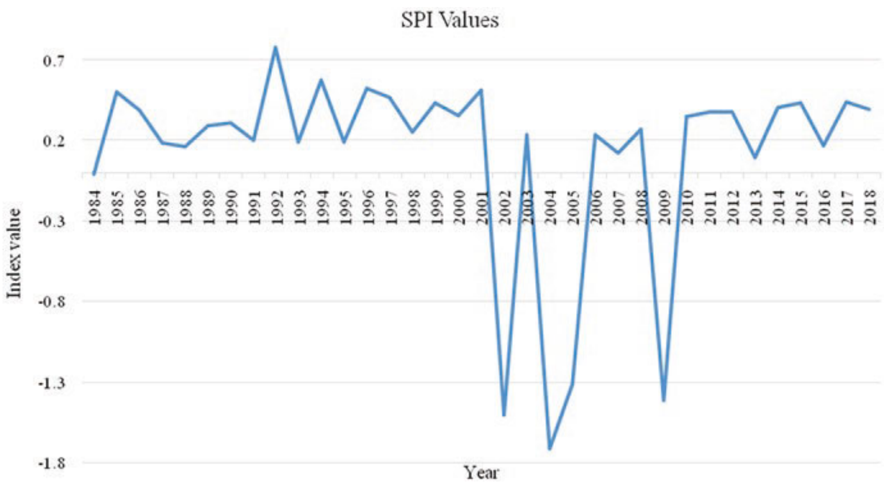

Fig. 42.2 SPI values

low flow. The baseflow represents the low flow zone and flow due to the rainfall represents the high flow. FDC study utilizes the percentage intervals as an overall marker of hydrologic conditions (i.e., Wet to dry conditions). The 90% and 95% probability of exceedance that such discharge will be accessible in the waterway separately. The low flow value maintained in the study area i.e., Q95 for the years 2018 to 2014 are 1329 m^3/s, 1452 m^3/s,1391 m^3/s, 1671 m^3/s, 1638 m^3/s. But based on the SPI value, the area comes under near normal and hence the percentage relationship developed suggests that 50% of the exceedance should be maintained as the required environmental flow. Table 42.4. Represents the required environmental flow condition (Fig. 42.3).

Table 42.4 Required environmental flow

Year	SPI value	50 % flow (m^3/s)
2014	0.41	3690
2015	0.43	3630
2016	0.17	191
2017	0.44	6056
2018	0.40	4459

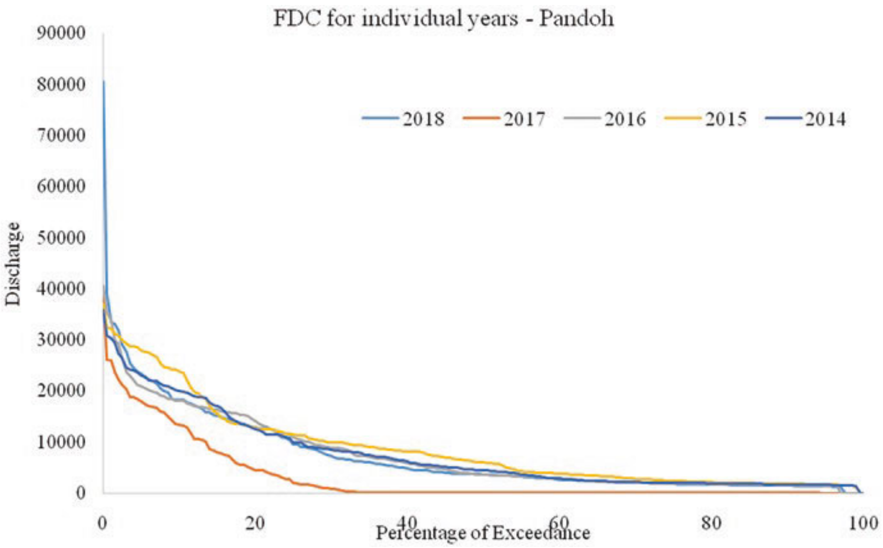

Fig. 42.3 FDC curve

42.5 Conclusions

The fundamental reason for the environmental flow is to satisfy the necessities of an ecosystem, and hence, it assumes a pivotal job in the water planning and management. The Tennant method utilizes the flow data (hydrological data) to infer the ecological stream condition; this stream information is meager or for the most part not accessible, particularly in ungauged catchments. Thusly, the ideas of both the FDC strategy and SPI were coupled to portray the environmental flow condition of the catchment legitimately from precipitation, for spillover is the capacity of precipitation. The research work attempt of developing a correlation between the SPI and FDC shows that rainfall data can be used in the suggestion as for environmental flow assessment. The work has more scope in future by equating the results with the site data and validating the sufficiency of the proposed environmental flow percentage with respect to the drought condition.

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Chapter 43
Effect on Rheological and Hardened Properties of Fly Ash-GGBS Based High Strength Self Compacting Concrete with Inclusion of Micro and Nano Silica

G. Vinod Kumar and B. Narendra Kumar

Abstract Concrete is a most usable material after the water. From last few decades rigorous research has been done in improving the strength and durability properties of concrete using incorporating supplementary cementitious materials (SCM).

This paper presents an experimental study to evaluate the combined effect of SCMs includes fly ash (FA), ground granulated blast furnace slag (GGBS), Micro silica (MS) and Nano Silica (NS) and also complete replacement of natural sand with M-Sand on High strength Self Compacting Concrete (SCC). Total powder (Cement + FA + GGBS) considered as 700 kg/m^3. Seven mixes were prepared represented as M_1 to M_7. Mix M_1 is 10% wt of total powder replaced by fly ash (FA) and M_2 is 25% wt of powder replaced by (10% FA + 15% GGBS). Mixes M3 to M6 were prepared by 5%, 10% of MS and 0.5%, 1.5% of NS by weight of cement added to the (10% FA + 15% GGBS+75% cement) SCC respectively. Mix M_7 is addition of 5% MS and 0.5% NS to the (10% FA + 15% GGBS+75% cement) SCC. The test performed to determine rheological and mechanical properties of SCC. Mechanical test performed after curing for 7 and 28 days. The results shows that the addition of MS and NS the paste became sticky which reduces the flow properties whereas strength properties were improved. Further cost of each mixes are analysed and conclusions drawn.

Keywords Supplementary cementitious materials · Self-compacting concrete · Rheological properties · Nano-silica · Micro-silica · M-sand

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43.1 Introduction

SCC was introduced in Japan in late 1980s and the concept of SCC was introduced by prof H. Okamura. The general requirements of SCC to have flowing ability, filling ability and passing ability and without segregation or bleeding. The advantages of SCC is self-compactable without vibration, reduces labour cost, fast construction, passing through congested reinforcement (Okamura et al. 2003).

Concerning of environmental effects due to CO2 emission from cement production since past few decades in all construction some part of the cement is replaced using SCM called blended cements (Benhelal et al. 2013). These SCMs are fly ash, GBBS, micro silica (MS), rice husk ash etc.

Utilization of manufacturing sand (M-sand) in place of river sand in concrete will be good solution for environment, economical and strength properties of concrete. M-sand is an artificial sand, manufactured from the stone dust processing industry. M-sand has more angular particle shape than natural sand provide good grip with adjacent paste (Gupta et al. 2019).

Generally high strength concrete can made by incorporating micro-silica in concrete and also some advanced materials such as nano materials but these materials are costly. One way to curtile the overall cost of concrete mix by incorporating these materials (MS, NS) along with cheap SCMs i.e., fly ash GGBS in SCC without compromising strength properties (Mahalakshmi et al. 2020).

Some nano materials are Nano-Silica(NS), Nano-Alumina(NA), Graphene oxide, carbon nano tubes, Nano-Titanium etc. Using these material in concrete not only enhance the properties of concrete but brings new properties in to existences. Nano-Silica is a commonly used in concrete among other nano materials and its cost is less compared to other nano materials. The reaction of NS in concrete is similar to MS but due to higher specific surface area of NS it quickly undergoes pozzolanic reaction and generates secondary CSH gel that leads to early strength gain of concrete. Ultrafine particle size of NS effectively fills up the small capillary pore and even gel pores (pores in layers of CSH) in concrete (Zhang et al. 2012).

K. Nandhini et al. work on comparative study between MS and NS. The results observed that addition of 2% NS shows better results than 10% MS addition in SCC whereas 10% MS and 2% NS combination in concrete shows highest strength (Nandhini et al. 2021).

43.2 Research Objective

The aim of this study on efficient utilization of industrial waste fly ash, GGBS, MS, and NS as supplementary cementitious materials (SCMs) in cement concrete. The proportions of these SCMs were based on previous literatures and trail mix. In the context of sustainability, river sand completely replaced with M-sand. Fresh properties and hardened properties of SCC were examined. The cost of NS material is very high and its practical application is limited in concrete, so in this paper tried to curtile the overall cost of the concrete mix. Further cost analysis were calculated for every mix and compared the results.

43.3 Material Used

The materials used are Ordinary Portland cement 53 grade, conforming to (IS 12269–1987). Locally available manufactured sand (M-sand) used as a fine aggregate of zone-II and the locally available 12 mm of maximum size crushed natural stone used as coarse aggregate, conforming to (IS 383–2016) and the physical test on fine and coarse aggregate are tested followed by (IS 2383–1963). The specific gravities 2.65 and 2.67 obtained for fine and coarse aggregate respectively.

Fly ash procured from locally which is a source of thermal power plant, Ramagundam, Telangana. The type of FA used of class F-FA and it has particle size more or less similar to cement but spherical in shape and the specific gravity (SG) was 2.2.

GGBS procured from JSW cement industry pvt.ltd. The SSA and specific gravity (SG) of GGBS are 386 m^2/kg and 2.9 respectively.

Micro silica (MS) used is procured from Astrra Chemicals, Chennai, Tamil Nadu. The size of MS was 0.15 μm and the SSA and SG of MS are 22,000 m^2/Kg and 2.64 respectively.

Nano-Silica (NS) is a ultrafine particle size of range 10^{-9} (nano). Procured from Astrra Chemicals. The NS used of purity of >99.9% silica content. The average grain diameter of NS is 17 nm. The SSA and SG of NS are 2,02,000 m^2/Kg and 2.4 respectively.

Super plasticizer (SP) play vital role when comes to SCC. It increases the flow ability of SCC without addition of extra water. Master glenium sky 8233 used as a SP which is new generation polycarboxylic ether based superplasticizer (Table 43.1).

43.4 Mix Proportion

Total 700 Kg/m^3 of powder (cement + FA + GGBS) used in present study. Mix M_1 is 10% wt of powder is replaced by FA and For all the other mixes 25% powder is replaced by 10% FA and 15% GGBS. The detailed mix proportion shown in Table 43.2. The mix design for M80 grade of SCC using IS 10262–2019 [10]. The mix with 10% FA replace to the powder designated as M_1 and the mix with 10% FA and 15% GGBS replaced to powder as M_2. The mixes M_3 and M_4 are prepared with 10% FA and 15% GGBS replaced to the powder as ternary mix along with 5%, 10% micro silica to make mix as quaternary respectively. Similarly mix M_5 and M_6 are

Table 43.1 Materials Chemical Composition

Chemical composition	Cement (%)	FA (%)	GGBS (%)	MS (%)	NS (%)
SiO_2	22.350	58.38	34.81	99.81	99.9
Al_2O_3	10.880	23.2	17.92	0.031	0.005
Fe_2O_3	5.870	6.87	0.66	0.012	0.001
CaO	55.710	1.78	37.63	–	–
TiO_2	0.490	–	–	–	0.004
Na_2O	0.340	0.45	–	0.004	–
MgO	1.150	2.75	7.80	–	–
SO_3	1.590	–	0.20	–	–
K_2O	0.170	3.99		0.002	–
(LOI)	1.190	0.2	0.35	0.001	0.006

Table 43.2 Mix proportions

Mix Designation	Cement (kg/m^3)	FA (10%) (kg/m^3)	GGBS (15%) (kg/m^3)	Micro Silica (kg/m^3)	Nano Silica (kg/m^3)	Water content (kg/m^3)	M Sand (kg/m^3)	Coarse aggregate (kg/m^3)	SP (kg/m^3)	W/P ratio
M 1	630	70				196	695	753	5.6 (0.8%)	0.28
M2	525	70	105			196	695	753	5.6 (0.8%)	0.28
M 3	525	70	105	26.25 (5%)		196	695	753	7 (1%)	0.28
M 4	525	70	105	52.5 (10%)		196	695	753	7 (1%)	0.28
M5	525	70	105		2.625 (0.5%)	196	695	753	7 (1%)	0.28
M6	525	70	105		7.875 (1.5%)	196	695	753	7 (1%)	0.28
M7	525	70	105	26.25 (5%)	2.625 (0.5%)	196	695	753	7 (1%)	0.28

prepared with 10% FA and 15% GGBS replaced to the powder as ternary mix along with 0.5%, 1.5% Nano-Silica to make quaternary mix. Mix M_7 is 5% MS and 0.5% NS added to the 10% FA and 15% GGBS based SCC.

43.5 Experimental Program

The test on fresh properties of SCC conducted according to EFNARC-2002 guidelines [11]. The test performed are slump flow diameter to find the spreading/flowing ability of SCC. V-funnel test to determine filling ability of SCC in congested reinforcement and L-box test to determine passing ability of SCC.

The hardened properties of SCC determined by conducting compressive test, flexural test and split tensile test at 7 and 28 days of water curing. The specimen size of 150 x 150 x 150 mm used for compressive strength. For flexural test 100 x 100 x 500 mm and for split tensile test 100 mm dia and 200 mm height were used.

The compressive strength and flexural strength test were performed according to (IS 516–1959) guidelines whereas split tensile test by (IS 516–1999) guidelines.

43.6 Result and Discussion

The experiment performed to determine the effect of FA-GGBS based SCC by incorporating MS and NS on fresh and hardened properties are discussed in detail in the following sections.

43.6.1 Fresh Properties

All the rheological properties are performed by referring the guidelines of EFNARC-2002. The slump flow diameter test to determine the free flow of SCC horizontally in absence of obstructions. V-funnel test to determine time required to empty the concrete present in V-funnel called flow time. L-Box test which determines the passing ability of SCC through the congested reinforcement represented by a ratio of (H_2/H_1). Figure 43.1 Shows measuring of different fresh properties of SCC and Fig. 43.2 shows the variation of Slump flow diameters of different mixes it is obvious that presence of FA and GGBS improves the workability because of its spherical size of particles. Mix M_2 shows better workability than M_1 since 25% of cement replaced by 10% FA and 15% GGBS. From M_3 onwards drastic reduction in flow diameter was seen. Addition of micro silica and Nano-Silica reduces the flow property of SCC because of very high specific surface area which demands more water to maintain the flow. In this study water content kept constant and vary the dosage of superplasticizer from 0.8% to 1% of cementitious material to overcome resistance to flow.

Mixes M_4 and M_5 shows the least and comparable flow diameter, which inferred that addition of small number of NS reduces flow property drastically compared to MS. Mix M_7 is a combination of 5% MS and 0.5% NS also shows least flow property.

According to EFNARC guidelines the range of Slump flow diameter between 650 mm to 800 mm. From Fig. 43.2 it shows all the results are within EFNARC guidelines.

Figures 43.3 and 43.4 shows the graphical representation of V-funnel test and L-box test values respectively. Both these test followed similar trend as slump flow diameter test. V-funnel test represents the results as time required to empty the

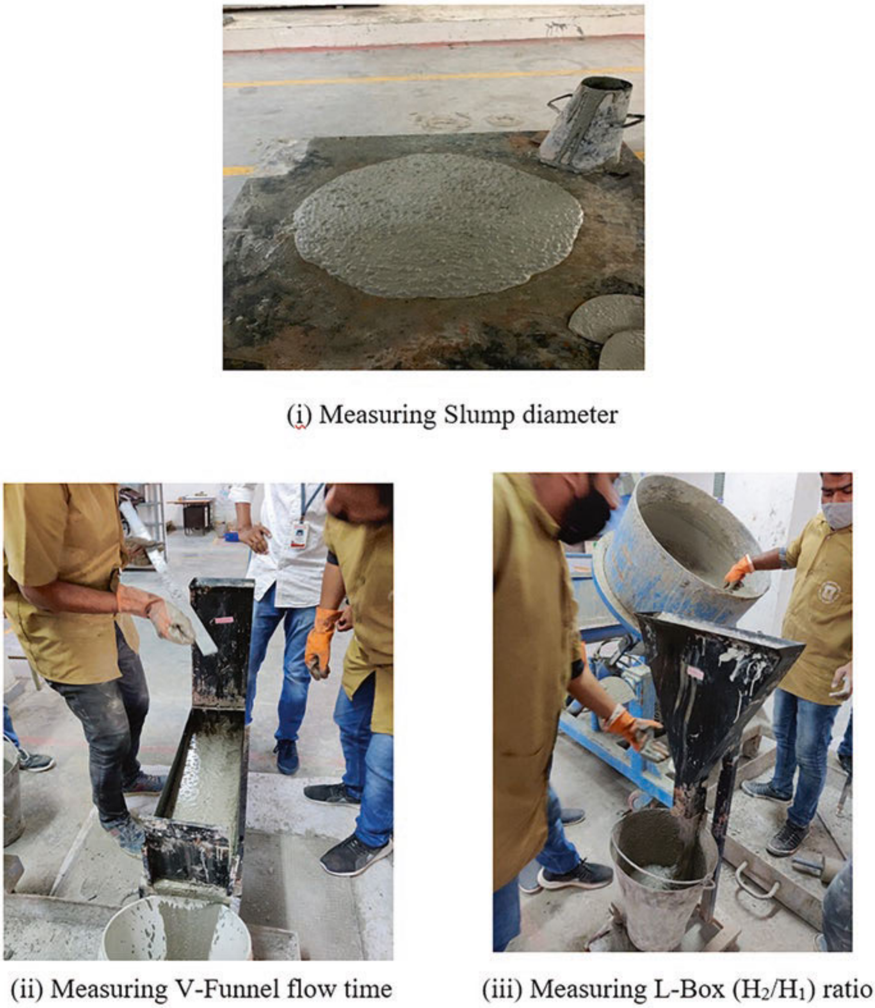

Fig. 43.1 Shows measuring of different fresh properties of SCC

concrete present in V-funnel designated as flow time (sec) and L-box test represents the results in (H_2/H_1) ratio.

According to EFNARC guidelines the limits restricted for V-funnel test between 6 to 12 seconds and for L-box test between 0.8 to1.

From Figs. 43.3 and 43.4 it seems that all the results are within the range given in EFNARC guidelines.

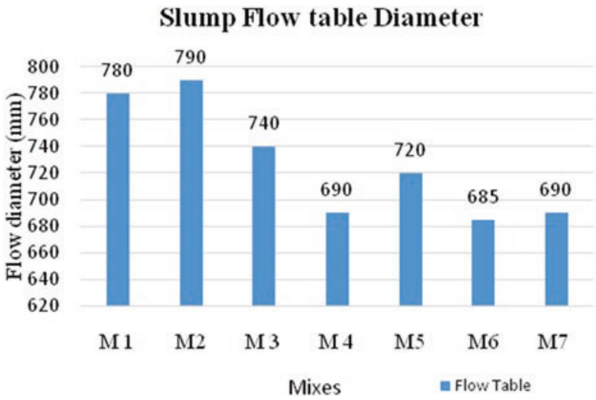

Fig. 43.2 Result variation of slump flow diameter

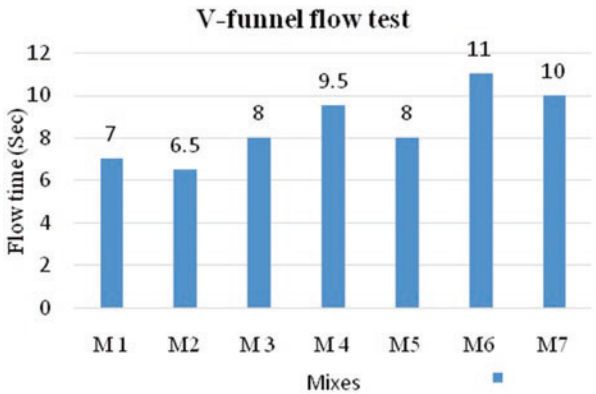

Fig. 43.3 Result variation of V-funnel flow time

43.6.2 Hardened Properties

All the hardened tests such as compressive strength, flexural strength and split tensile strength tests are performed according to the IS 516 guidelines. The detail discussion had done in the following sections.

43.6.2.1 Compressive Strength

Compressive strength test is an important test, based on this test one can judge the quality of concrete. Figure 43.5 shows the testing of 150 × 150 × 150 mm size specimen.

Figure 43.6 shows the compressive strength values of various mixes. Addition of GGBS to mix M_2 increase the strength by 7.45% compared to mix M_1. Mixes M_4

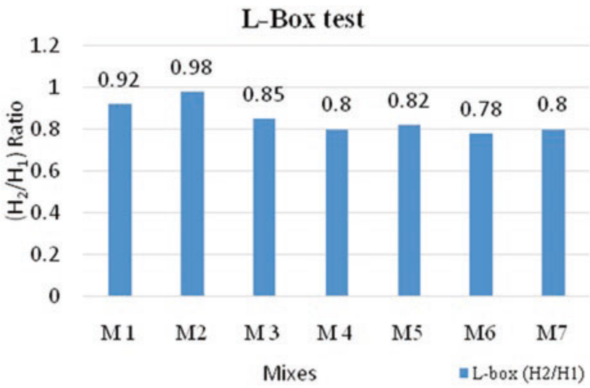

Fig. 43.4 Result variation of L-Box test

Fig. 43.5 Experiment conducted under compressive testing machine

and M_5 shows the almost similar strength with difference of 1.51 MPa between them and mix M_6 with 1.5% of NS improves the strength than mix M_4 (10% of MS). With small percentage addition of Nano-Silica to concrete improves the strength drastically. Mix M_7 which is combination of 5% MS and 0.5% NS observed the peak strength of all mixes 96.25 MPa. NS particle has its particle size in the range of nano (10^{-9}) at this range all the pores, micro to nano size can filled up and makes the concrete dense and strong. Finer the particle size higher the SSA and faster the conversion of calcium hydroxide to CSH gels (Nazerigivi et al. 2019).

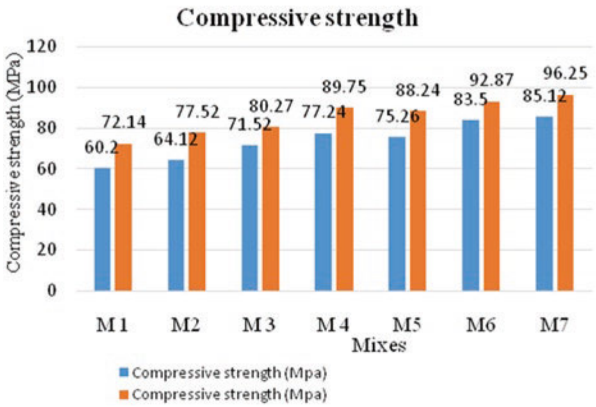

Fig. 43.6 Results of compressive strength test

Fig. 43.7 Flexural strength testing machine

43.6.2.2 Flexural Strength

Flexural strength indicates the bending strength of concrete. The Specimen of size 100 × 100 × 500 mm called as prism casted and tested under four point loading testing machine as shown in Fig. 43.7.

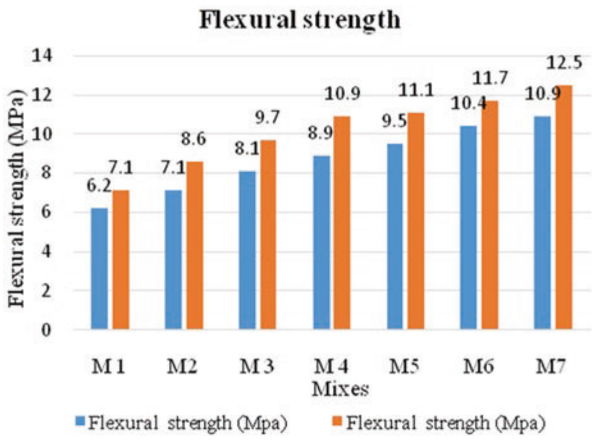

Fig. 43.8 Results of flexural strength test

Figures 43.8 shows the variation in bending strength values of all the mixes tested at 7 and 28 days of water curing. The graph pattern of results obtained for flexural strength are proportioned with compressive strength results expect for mixes M_4 and M_5. In compressive strength M_4 shows slightly higher strength than M_5 but it is reverse in case of flexural ($M_5 > M_4$). Mix M_7shows higher flexural strength among all the mixes.

43.6.2.3 Split Tensile Strength

Split tensile test measure the tensile strength of concrete indirectly. The direct measure of tensile strength of concrete practically impossible. Splitting the concrete into two half under the testing machine indicates the concrete strength in tensile. Figure 43.9 shows testing of cylindrical specimen.

Figure 43.10 shows the variation of split tensile strength values of various mixes and it shows continuous increment in strength from mix M_1 to M_7. The split tensile strength values followed the similar pattern of flexural strength. Mix M1 shows the least strength and mix M_7 shows higher split tensile strength among all the mixes.

43.7 Cost Analysis

The cost of casting and the Economic index (EI) in strength/cost ratio of each mixes represented in Table 43.3. The technique of cost analysis used to calculate EI (strength/cost) based on previous literatures (Devi et al. 2020; Gupta et al. 2019). All the materials cost are based on market commercial rates (INR/Kg). The

Fig. 43.9 Spilt tensile strength testing machine

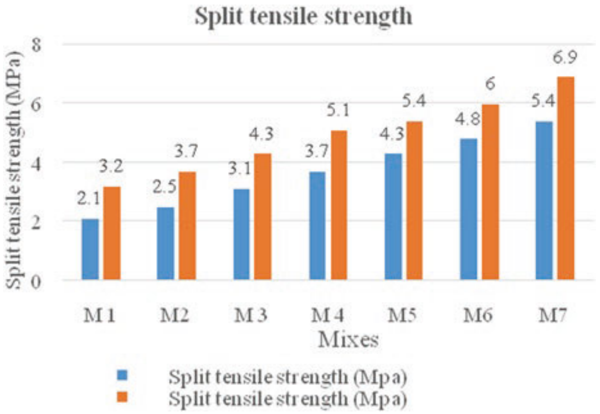

Fig. 43.10 Results of split tensile strength test

motivation of cost analysis is to find the optimum use of Nano-Silica such that the outcome should be better in terms of strength and cost. From Table 43.3 mix M_1 shows poor results in terms of strength and cost. M_2 indicates good EI among all the mixes and mix M_4 shows slightly more EI than M_3. Addition of 0.5% NS in M_5 slightly decreases the EI and addition of 1.5% NS in M_6 shows drastic reduction of EI which is due to the cost of NS. Mix M_7 (5% MS and 0.5% NS) shows comparable EI as M_3, M_4 and M_5 but strength point of view shows highest of all mixes.

Table 43.3 Cost analysis of different mixes

Materials	RS/Kg	M1	M2	M3	M4	M5	M6	M7
OPC	7	4410	3675	3675	3675	3675	3675	3675
Fly ash	1	70	70	70	70	70	70	70
GGBS	3		315	315	315	315	315	315
MS	23			603.75	1207.5			603.75
NS	500					1312.5	3937.5	1312.5
FA (m-sand)	0.7	527	527	527	527	527	527	527
CA	0.5	347	347	347	347	347	347	347
SP	70	392	392	490	490	490	490	490
Total cost per mix (INR)		5746	5326	6027.75	6631.5	6736.5	9361.5	7340.25
Compressive strength		72.14	77.52	80.27	89.75	88.24	92.87	96.25
EI strength/cost		0.01255	0.01455	0.0133	0.01353	0.01309	0.009920	0.01311

43.8 Conclusions

In this study individual and combined effect of micro and Nano-Silica experimented on the 25% replacement of total powder with 10%fly ash and 15% GGBS based SCC. The following are some conclusions drawn based on experimental observations.

1. Fresh properties point of view mix M_2 shows good workable followed by M_1. Addition of MS and NS drastic decrement of fresh properties seen. Mix M_4, M_6, M_7 showed Comparable fresh properties. M_6 showed the least workable because addition of NS made the mix very sticky.
2. Strength point of view M_1 showed the least strength of all the mixes followed by M_2. Addition of MS and NS improve the strength due to their fine particle size and high pozzolanic reactivity.
3. Mix M_4 and M_5 showed strength values are very nearer. Mix M_7 showed highest strength among all the mixes.
4. Using M-Sand in place of river sand in concrete will be good solution for environment, economical and strength properties of SCC.
5. Table 43.3 shows the cost analysis of all the mixes. Mix M_1 showed least performance both in strength and economical point of view. M_2 showed less strength compared with M_3 to M_7 but better among all the mixes in terms of EI (strength/cost).
6. Mixes M_3, M_4, M_5 and M_7 showed approximately equal EI values but M7 showed highest strength and M6 showed least EI value.
7. From mix M7 it is evident that the combination of MS and NS will lead to the improve in strength properties of SCC. Comparing mixes M6 and M7 it can infer that combination of MS and NS made mix economical and higher EI value compared to M6.

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Chapter 44
Mechanical Property Study on Glass Fibre Concrete with Partial Replacement of Fine Aggregate with Steel Slag

E. Merlyn Joy and M. Soundararajan

Abstract The scope of this project is to establish the use of steel slag, and glass fibre in many effective ways to achieve high strength than conventional concrete. Steel slag is a side product from the steelmaking process. When molten steel is separated from impurities in steel-making furnaces, it is formed. We are currently confronted with some of the most serious environmental protection issues. Many of the items we invent for our opulent lifestyles are accountable for harming the environment as a result of poor waste management. To address this problem, concrete might be supplemented or replaced with fibres or other waste materials. The Experimental programme includes study on the flexural behaviour of concrete with glass fibre and steel slag as fine aggregate with partial replacement. The replacement of steel slag is up to 20%, 25%, 30%, 35% and 40%. This paper investigates the M35 grade concrete with steel slag as partial replacement for fine aggregate and the addition of glass fibres was investigated in this paper. The laboratory experiments the compressive strength, flexural strength, tensile strength, ultrasonic pulse velocity, impact test, rebound hammer test, and fire resistance test utilising the ideal percentage of steel slag with glass fibre in the concrete matrix. Based on the findings, it was determined that glass fibre intrusion can replace steel slag by up to 35%.

Keywords Ordinary Portland cement · Steel slags replacement · Glass fibre · Compressive strength · Split tensile strength and flexural strength

44.1 Introduction

Glass fibres are materials created from very fine glass filaments. Cem-FIL Anti Crack – HD glass fibres were utilized. Artificial aggregate made from industrial waste provides an alternative to natural aggregate in the building industry, reducing

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reliance on natural aggregate. Glass article production necessitates the capacity to strike a balance between quality control and productivity. Waste materials are used to conserve natural resources, money, and landfill space while also assisting in the preservation of a clean environment. The waste product of the steelmaking process is steel slag. It's produced in vast amounts in electric arc furnaces, which are used to make steel. Smelting iron ore in a basic oxygen furnace can also create steel slag. The construction industry must look for alternate resources due to impact on cost of natural sand as fine aggregate and its impact on sustainable development. Steel slag is a by-product of the steelmaking process and a typical industrial waste. Natural sand can replace steel slag up to 20–40% of the time, and it performs better. The effect of fibre in concrete was studied in this paper. The percentage of steel slag replaced is ranged from 20% to 40%, with 20%, 25%, 30%, 35%, and 40% being the most common. Fibre Reinforced Concrete, also known as cement mortar composite material, is a modern building material. Concrete without fibre can cause surface cracks. The addition of Glass Fibre to cement mortar prevents surface cracks and shrinkage. According the test results, the optimum value for replacing steel slag with glass fibre was calculated. The compression, impact, ultrasonic pulse velocity, split tensile and rebound hammer test were all performed in concrete specimen.

44.2 Literature Review

V. Subathra Devi, B.K. Gnanavel in their work "As the amount of replacement increases, the workability of concrete diminishes. When compared to coarse aggregate replacement, fine aggregate replacement is more workable. The use of steel slag to replace fine aggregate improves the compressive, tensile, and flexural strength of concrete. N. Mathankumar, Ranjith in their work "It is concluded that for 5–50% replacement the strength increases as compare to 0% replacement. The optimum replacement seems to be 30% as the strength degrades after that. The compressive strength increases as the quantity of steel slag in the mix increases. In addition, it contributes to the reduction in environmental carbon footprint. Divya S Dharan, Aswathylal in their work "The experimental investigations showed to be the most effective method or approach for producing strong and long-lasting concrete. It also solves the problem of steel slag disposal. It has been discovered that mixing 30% steel slag with 1.5% fibre in concrete produces the best results. Vadlapudi Sai Bharath in their work "When compared to other qualities, 50% replacement of slag delivers better strength, according to the compressive strength data. The concrete mix containing 1.5% fibres achieves the highest flexural and split tensile strength, as well as the highest Youngs modulus. The concrete mix containing 1.5% fibres achieves the highest flexural and split tensile strength, as well as the highest Youngs modulus".

44.3 Materials Used

44.3.1 Cement

Cement is a binder material, meaning it sets, hardens, and adheres to other building materials. There are several different forms of cement on the market. The most well-known of these is ordinary Portland cement (OPC). The cement used is of grade 53 (IS 12269) (Table 44.1).

44.3.2 Fine Aggregate

Sand, which make up the majority of the volume in concrete mix compositions, are used as structural fillers. Provide the mixture with dimensional stability. Fine aggregate is aggregate that has been sieved through a 4.75 IS sieve. It gives concrete density by filling voids in the concrete (IS code 383) (Table 44.2).

44.3.3 Coarse Aggregate

Coarse aggregate is the rough gravel retained on a 4.75 mm sieve. The aggregates used in this project were nominally 20 mm in scale. Coarse Aggregates in concrete provide the concrete with body and strength, as well as acting as a filler material to ensure a homogeneous mass. Coarse Aggregates gives volume to the Concrete. The grading of coarse aggregates to follow IS 383–1970 standards. The aggregate used in this project was nominally 20 mm in size (IS code IS 383) (Table 44.3).

Table 44.1 Cement properties

Initial setting time	30 min
Normal consistency	30%
Final setting time	600 min
Fineness modulus	8%
Specific gravity	3.15

Table 44.2 Fine aggregates properties

Moisture content	2.4%
Fineness modulus	3.09
Specific gravity	2.66

Table 44.3 Coarse aggregate properties

Void ratio	0.20
Bulk density	1.753gm/cc
Fineness modulus	3.79%
Specific gravity	2.42

Fig. 44.1 Glass fibre

Table 44.4 Fibre properties

Aspect ratio	857.1
Length	12 mm
Filament	14 microns
Modulus of elasticity	72 Gpa
Bulk density	2680 kg/m^3
Specific gravity	2.68

44.3.4 Glass Fiber

Fiberglass is another name for glass fibre. Glass fibre (or glass fibre) is a substance made up of several highly fine glass fibres. It's a composite made of incredibly fine glass fibres. Fiber is a solid, lightweight, and durable fibre. Glass fibres are inexpensive, have a high tensile strength, are chemically resistant, and provide excellent insulation. Plastic shrinkage cracking is reduced by using glass fibres. It was purchased in Fibre Region, Chennai (IS code IS 7019) (Fig. 44.1; Table 44.4).

44.3.5 Steel Slag

It is a waste product from the steelmaking process. It is produced from manufacturing large quantities during electric arc furnace steelmaking operations. One of the most prevalent industrial effluents is steelmaking slag. Metal oxides and silicon dioxides are commonly found in slag. Obtained from JSW Steel Ltd., Mecheri. IS code used to be (IS2619) (Fig. 44.2; Table 44.5).

44.3.6 Water

Water's quantity and consistency must be continuously regulated because it aids in the production of the cement gel that provides strength. Many properties of concrete, both fresh and hardened, are regulated by the amount of water in it, including workability, compressive strength, permeability, toughness, drying shrinkage, and cracking potential. Impurities should not be present in the water used. Sea water shall not be used. The water utilised in this investigation for mixing and curing was portable water with a pH of 7.0.

Fig. 44.2 Steel slag

Table 44.5 Steel slag properties

Specific gravity	2.93
Shape	Highly angular
Bulk density	1911.11 kg/m^3
Colour	Light to dark brown
Surface texture	Rough

44.4 Experimental Methodology

The experiments conducted on fresh concrete were Slump cone test, Compaction Factor test, Vee bee test, and Flow table test. Test which are conducted on hardened concrete were Compression, splitting tensile, Flexural strength, Rebound hammer, Ultrasonic pulse velocity and Impact test.

Methodology: This paper studies the strength properties of M35 grade concrete made with steel slag and glass fibre. The mix design for concrete of grade M35 had to be decided according to IS code. The specimens were cast using a 20%, 25%, 30%, 35%, and 40% substitution of fine aggregate with steel slag, as well as a 0.5% addition of glass fibre. The specimens were given a 7-day and a 28-day cure, respectively. The specimens were subjected to a variety of tests, including compression, tensile and flexural tests, impact, ultrasonic pulse velocity, and rebound hammer tests.

44.5 Mix Proportion

Mix for M35 grade concrete is carried out according to IS 10262: 2009 (Table 44.6):

44.6 Experimental Work

It is designed to determine the concrete's strength as well as the different levels of fine aggregate replacement with steel slag. IS 10262–2009 is used to design the mix for M35 grade, and the mix proportions are 1:2.54:3.34 with 0.45 as w/c ratio. Castings and tests were performed on the concrete specimen.

44.7 Fresh Concrete

44.7.1 Workability

- Slump test being used to evaluate the workability and thus the flow ability of fresh concrete mix.

Table 44.6 Mix Proportion

Cement	Fine aggregate	Coarse aggregate	Chemical admixture	Water
340 kg/m^3	863.46 kg/m^3	1136.52 kg/m^3	7 kg/m^3	147.75 kg/m^3
1	2.54	3.34	0.02	0.45

Table 44.7 Test results of slump and compaction factor

Steel slag	Addition of glass fibre	True slump value	Compaction factor
0%	0%	40 mm	94.1
20%	0.5%	48 mm	94.0
25%	0.5%	49 mm	92.1
30%	0.5%	51 mm	93.5
35%	0.5%	53 mm	92.3
40%	0.5%	55 mm	91.5

Table 44.8 Test results of vee bee and flow table

Replacement of steel slag	Addition of glass fibre	Vee bee (sec)	Flow table (cm)
0%	0%	7	47
20%	0.5%	6	43
25%	0.5%	5	40
30%	0.5%	4.5	37
35%	0.5%	5.5	45
40%	0.5%	6.6	49

- The compaction factor is defined as weight ratio of partially compacted to fully compacted concrete.
- The vee bee method was used to assess concrete consistency. To determine the quality of concrete, a Vee-Bee consistometer is utilised. This is accomplished by calculating the time it takes to vibrate the concrete into the shape of a conical frustum.
- The flow table test is a method for testing the quality of freshly poured concrete. The flow table test is also used to establish the maximum transportable moisture limit for solid bulk goods (Tables 44.7 and 44.8).

44.8 Hardened Concrete

44.8.1 Compressive Strength

The dimensions of the cubes are 150 × 150 × 150 mm. The loads were registered during compression strength (Dhoble et al. 2018) tests conducted on a universal testing machine (Figs. 44.3 and 44.4; Table 44.9).

$$\text{Compression Strength}\left(\text{N}/\text{mm}^2\right) = P/A$$

where, P – Ultimate load (N)

Fig. 44.3 Compressive testing

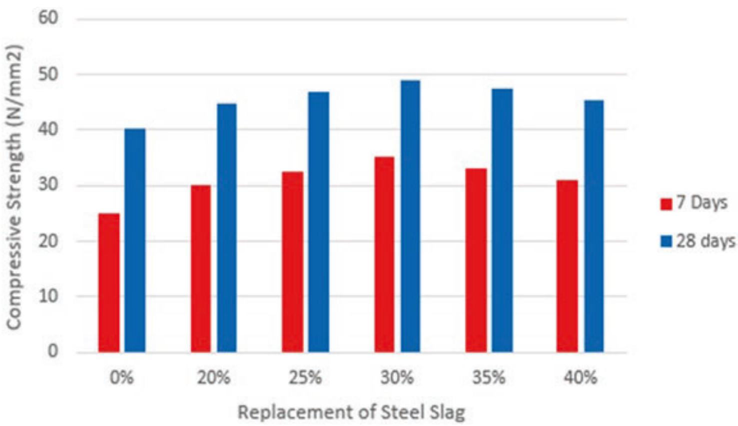

Fig. 44.4 Compressive strength at 7 and 28 days N/mm^2

Table 44.9 Compressive strength result

Replacement of steel slag	Addition of glass fiber	Compressive strength @ 7 days (N/mm^2)	Compressive strength @ 28 days (N/mm^2)
0%	0%	25.01	40.20
20%	0.5%	30.05	44.65
25%	0.5%	32.54	46.80
30%	0.5%	35.20	49.01
35%	0.5%	33.01	47.56
40%	0.5%	31.05	45.50

44.8.2 Split Tensile Strength

The cylinders have a diameter of 150 mm and a length of 300 mm. After performing split tensile tests on a universal testing equipment, the loads were recorded (John et al. 2020) (Fig. 44.5; Table 44.10).

44.8.3 Flexural Strength

The prism is 500 × 100 × 100 mm in size. Flexural strength refers to a material's capacity to resist deformation under load. In UTM, the prism was placed in such a way that a two-point loading test could be performed (Saradar et al. 2018). For each percentage of steel slag, the average flexural result is noted (Figs. 44.6 and 44.7; Table 44.11).

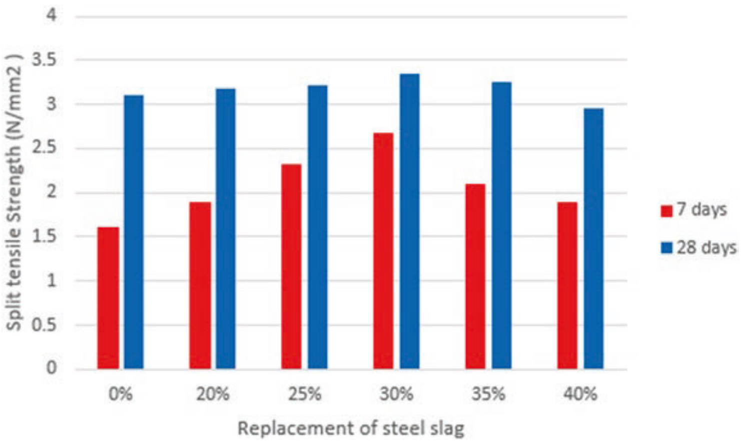

Fig. 44.5 Graph for split tensile test @7 and 28 days

Table 44.10 Split tensile test result

Replacement of steel slag	Addition of glass fiber	Split tensile strength @ 7th day (N/mm^2)	Split tensile strength @ 28th day (N/mm^2)
0%	0%	1.61	3.1
20%	0.5%	1.90	3.19
25%	0.5%	2.33	3.22
30%	0.5%	2.68	3.34
35%	0.5%	2.10	3.26
40%	0.5%	1.90	2.96

Fig. 44.6 Flexural testing

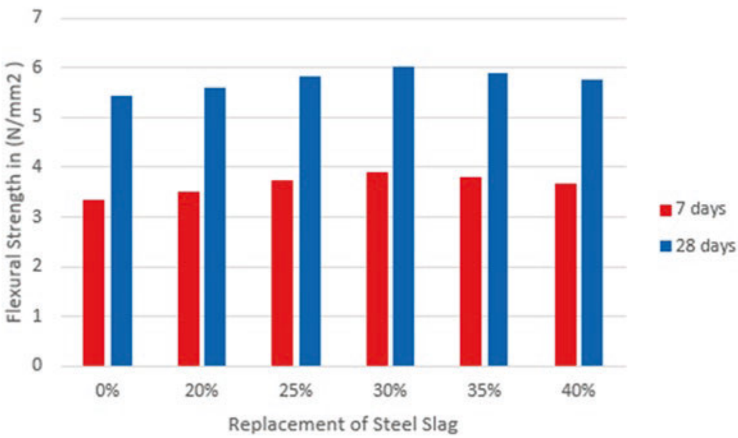

Fig. 44.7 Graph for flexural strength @7 and 28 days

Table 44.11 Flexural test result

Replacement of steel slag	Addition of glass fibre	Flexural strength in 7th day (N/mm^2)	Flexural strength in 28th day (N/mm^2)
0%	0%	3.33	5.44
20%	0.5%	3.50	5.60
25%	0.5%	3.75	5.82
30%	0.5%	3.90	6.01
35%	0.5%	3.80	5.90
40%	0.5%	3.66	5.75

44.9 Ultrasonic Pulse Velocity

It is non-destructive in-situ test that is used to determine the consistency of the concrete. The strength and consistency of a concrete building can be calculated using the velocity of an ultrasonic pulse flowing through it (Anwar et al. 2020).

The pulse velocity is calculated using a specific formula (Fig. 44.8; Table 44.12).

$$v = l / t$$

Where, v = pulse velocity (m/s), l = length (m).

44.10 Rebound Hammer Test

The non-destructive rebound hammer measure (NDT test of Concrete). The concrete's strength is measured without cracking it. It can also be tested on-site rather than in a lab without causing any harm (Anandaraj et al. 2019) (Fig. 44.9; Table 44.13).

44.11 Impact Test

Sudden shock resistance. The capacity of a concrete specimen to withstand repeated blows is normally used to determine impact strength (Table 44.14; Fig. 44.10). The table shows that impact resistance of disc specimens increased with increase in

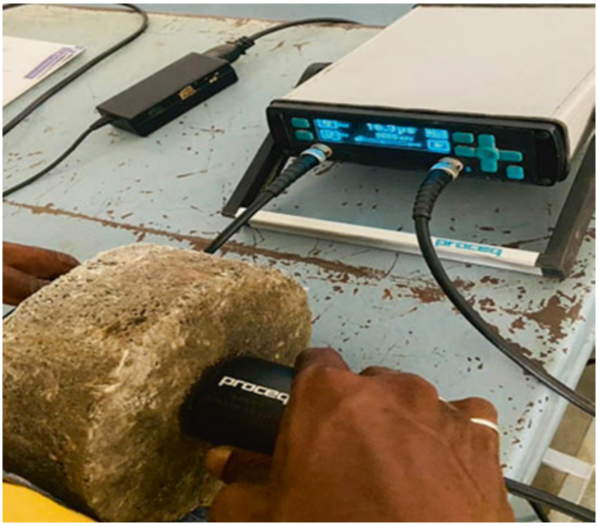

Fig. 44.8 Ultrasonic pulse velocity testing

Table 44.12 Ultrasonic pulse velocity test result

Replacement %	Time (T)	Velocity (V)	Pulse velocity	Concrete quality
0%	15.0	4200 m/s	4.2	Good
20%	14.6	4320 m/s	4.3	Good
25%	13.7	4598 m/s	4.6	Excellent
30%	13.2	4773 m/s	4.8	Excellent
35%	16.3	3865 m/s	3.8	Good
40%	15.6	4038 m/s	4.0	Good

Fig. 44.9 Rebound hammer testing

Table 44.13 Rebound hammer test result

Replacement %	Rebound number (R)	Compressive strength (N/mm2)	Quality of concrete
0	33	34	Good
25	34	37	Good
30	35	39	Good
35	36	40	Good
40	34	37	Good

Table 44.14 Shows the impact resistance for disc specimens replaced with steel slag

Replacement %	Height of falling	No. of blows
0%	48 cm	11
20%	48 cm	24
25%	48 cm	42
30%	48 cm	60
35%	48 cm	43
40%	48 cm	36

Fig. 44.10 Shows the impact test of disc specimens

incorporation of steel slag. For zero percentage inclusion of steel slag the first crack in disc appeared in 11th blows with 48 cm as height of fall kept as constant.

44.12 Fire Resistance Test

The cubes with dimensions of 7.6 mm × 7.6 mm × 7.6 mm were casted, after that, take it out of the mould and soak it in water for 7 days at room temperature. The cubes were then heated in an electric muffle furnace. At four different temperatures (100° C, 500° C, 650° C, and 800° C), These sets were heated for an hour, 2 h, or 3 h.

Table 44.15 Impact test result

Temperature	Steel slag	Glass fiber	Compressive strength in MPa			Percentage residual compressive strength in MPa		
			1 h	2 h	3 h	1 h	2 h	3 h
100 °c	**0%**	**0.5%**	24.5	24.5	24.5	50.0	49.8	49.6
	20%	**0.5%**	27.1	27.1	27.1	52.0	51.8	51.5
	25%	**0.5%**	29.2	29.2	29.2	53.2	53.0	52.8
	30%	**0.5%**	31.4	31.4	31.4	54.6	54.2	54.0
	35%	**0.5%**	29.4	29.4	29.0	53.4	53.2	53.6
	40%	**0.5%**	28.4	28.4	27.9	52.6	52.4	52.0
500 °c	**0%**	**0.5%**	29.6	27.8	24.2	51.6	50.8	50.0
	20%	**0.5%**	30.2	29.4	28.6	52.7	51.9	51.7
	25%	**0.5%**	31.6	30.8	30.0	53.5	53.0	52.8
	30%	**0.5%**	32.0	31.6	30.8	54.2	54.1	54.4
	35%	**0.5%**	31.0	30.2	29.7	53.1	52.6	52.3
	40%	**0.5%**	30.9	29.4	28.5	52.9	52.0	51.7
650 °c	**0%**	**0.5%**	27.2	26.4	25.8	49.2	48.7	48.3
	20%	**0.5%**	28.4	27.6	26.9	50.8	49.6	49.2
	25%	**0.5%**	29.3	28.7	28.1	51.6	51.0	50.7
	30%	**0.5%**	30.5	29.8	29.0	52.2	51.9	51.7
	35%	**0.5%**	28.6	27.2	26.5	51.8	51.3	51.0
	40%	**0.5%**	27.8	26.6	25.3	50.6	50.0	49.4
800 °c	**0%**	**0.5%**	10.3	11.9	10.6	22.4	22.0	21.6
	20%	**0.5%**	12.4	13.2	12.8	24.1	23.7	23.3
	25%	**0.5%**	13.9	13.1	12.7	26.3	26.0	25.7
	30%	**0.5%**	14.8	14.3	13.9	27.5	27.1	26.7
	35%	**0.5%**	13.2	12.6	12.2	25.7	25.4	25.0
	40%	**0.5%**	12.7	11.9	11.4	24.9	24.6	24.2

The sets were then allowed to cool for 24 h at room temperature. The compressive strength of the material has been determined (Table 44.15).

44.13 Conclusion

The following conclusions are taken from the above experimental analysis:

- The strength of steel slag and glass fibre is increased as compared to a 0% substitution. When the replacement increases by more than 30%, the concrete strength decreases.
- The percentage of steel slag in the concrete mix increases, which improves compressive strength. They help to reduce emissions in the atmosphere. Slag has a low water absorption rate when compared to sand. Steel slag can be used as a fine aggregate in concrete instead of sand.

- Concrete bleeding is reduced because fibre limits the permeability of the concrete. Reduced bleeding improves the material's homogeneity and reduces the likelihood of cracks.
- Glass fibre reinforces concrete and regulates crack and post-crack stability.
- Steel slag replacement reduces the cost of concrete while also bringing environmental and technological benefits to all firms operating.
- With the addition of glass fibre, fine aggregates can be used to replace steel slag up to 30% of the time. The sensitivity of the Ultrasonic Pulse Velocity to strength gain or attained by the concrete is affected by its age. As the concrete matures, the sensitivity of the Ultrasonic Pulse Velocity to strength gain or obtained by the concrete increases.
- Because it is a surface hardness test and an age test, the rebound hammer loses sensitivity as the concrete wears.
- In an impact test, the strength is reduced by 35% with a 48 mm fall height.
- After increasing the temperature of concrete to 800° C, a fire-resistant test was performed to determine the residual compressive strength.
- Concrete has been found to have greater compressive and flexural strength as well as the ability to endure elevated temperatures up to a certain point.

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Chapter 45
Mechanical Properties of Geopolymer Concrete Partial Replacement of Fine Aggregate with Waste Crushed Glass

Y. Mahesh and G. Lalitha

Abstract The manufacture of geopolymer concrete fully substitution of cement with fly ash and alkaline solutions. Geopolymer concrete is an advanced construction material to help the sustainable development. In present study, geopolymer concrete prepared was fly ash, alccofine, waste crushed glass and alkaline solutions. The sodium silicate and sodium hydroxide concertation were taken 10M receptively. In geopolymer concrete fine aggregate replaced by waste crushed glass with various parentages of 0%, 10%, 20%, 30% & 40% respectively. Now a days to facing the problem on availability of good quality river sand. Utilization of different materials are M-sand, E-waste, waste crushed glass, replaced as fine aggregate. These materials used in concrete to prevent environment and land filling disposal problem. Waste crushed glass was used as fine aggregate because of it contains high amount of amorphous silica. All samples were tested for strength in compression (100 mm × 100 mm × 100), split tensile strength (100 mm × 200 mm) and flexural beams (700 mm × 150 mm × 150 mm) for 7, 28 & 90 days cured at ambient temperature. The beam was designed as under reinforcement section to finding flexural behaviour of GPC. The results show workability increased with increase amount of waste crushed glass. The maximum strength in compression, split tensile strength and flexural load was obtained 20% replacement of waste crushed glass.

Keywords Fly ash · Alccofine · Waste crushed glass · Strength in compressive · Strength in tension · Flexural load

45.1 Introduction

Concrete has been a significant construction material that has been and will continue to be demanded far into the future. Concrete is a composite material that contains various constituents, including binding materials such as cement, aggregates,

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and water (Singh and Sandhu 2020). The manufacturing process of cement to release huge amount of CO_2 into atmosphere, it causes global warming (Khan and Sarker 2020). The preparation of concrete utilization of industrial by-products like fly ash, alccofine, GGBS, etc. it reduces the CO_2 and cost of construction. One of best alternative to introduce a new ordinary Portland cement free binder is through the alkaline solution and cementitious material is called geopolymer concrete. Geopolymer concrete are made with industry by-products like fly ash, GGBS, alccofine and alkaline solutions (Jiang et al. 2020). Nowadays the construction industry facing the problem to get a good quality of river sand, So the river sand has been replaced with different materials like M-sand, E-waste, waste crushed glass, etc. (Prathiban et al. 2019a, b). Waste crushed glass contains huge amount of silica and less amount of alumina. The waste crushed glass has been used in concrete to reduces land fill problems and prevent environment (Prathiban et al. 2019a, b). The alccofine is industrial by product used in geopolymer concrete with fly ash with different percentages. Increasing the alccofine content improving mechanical properties and decreasing permeability of GPC (Goyal et al. 2019).

The geopolymer concrete fly ash is the main component to production of geopolymer concrete. Fly ash was partially replaced by glass powder increasing fresh and strength properties with increasing waste glass. The alkaline solution reacted with fly ash to form an N-A-S-H and C-A-S-A gel. These gels making is geopolymer mortar denser and stronger (Xiao et al. 2020). The results show WGP replaced as F.A in geopolymer concrete it increasing the strength in compression and bond strength of geopolymer concrete up to 20% substitution. The specimen placed at high temperature conditions because melting the WGP its fill the pores of geopolymer paste (Keerio et al. 2017). The glass powder was used in the manufacture of geopolymer concrete was sub suited by fly ash. Increasing the waste glass powder with increasing workability of concrete compressive, tensile strength concrete up to certain parentage. Glass powder has less water absorption and fills micro pores inside concrete due to the form denser compacted (Nimisha Sasindran and Jose 2017). Alccofine was used in geopolymer concrete to improving fresh and strength properties. The usage of alccofine in geopolymer concrete gives minimum compressive strength because of alccofine to attained early strength (Jindal et al. 2017). The development of high strength GPC by using in geopolymer concrete. Alccofine containing a large amount of silica and partial size very less compare to other cementitious materials. Due to alccofine to fills micro pores inside the concrete to prevent micro crakes (Jindal et al. 2016). The present research work focused on in geopolymer concrete partially replacement of fine aggregate with waste crushed glass. The waste crushed glass contains a large Amount of silica is present because of alternative substitution of F.A. The fine aggregate was substituted bywaste crushed glass with different percentage, percentages of 0–40% with an increment of 10%. All specimens tested for 7, 28 & 90 days cured at ambient temperature.

45.2 Experimental Program

45.2.1 Coarse Aggregate (C.A)

The locally available coarse aggregate was used. Maximum sizes are 20 mm, 10 mm were used in this present research work. The preliminary test was carried on coarse aggregate as per IS 2386-3 the specific gravity of C.A is 2.68.

45.2.2 Fine Aggregate (F.A)

Nearby available fine aggregate was used in present work. The fine aggregated was tested as per IS 383-2016 under zone-II and fine ness modulus is 3.04. The specific gravity of fine aggregate is 2.6.

45.2.3 Fly Ash

Fly ash was procured from near ACC ready mix plant**.** The fly ash (class-F) was used in my research work. The specific gravity of fly ash is 2.0 respectively.

45.2.4 Alkaline Solution

The alkaline solutions are most important role in geopolymer concrete for process of polymerization. In my research work NaOH and Na_2SiO_3 are used for polymerization reaction. The alkaline solution obtained from locally available market.

45.2.5 Super Plasticizer (SP)

The SP used in geopolymer concrete it improve fresh and mechanical properties. In present research work master Galenium 8233 was used as super plasticizer.

45.2.6 Alccofine 1203

Alccofine is an industrial by product used as mineral admixture. The specific gravity of alccofine was 2.83.

45.2.7 Waste Crushed Glass (WCG)

The waste crushed glass contains large amount of silica it has replaced with natural sand. The glass bottle collected from nearby K.S.S recycled plant. The size of glass particles is passing through 4.75 mm. The specific gravity of WCG is 2.5 and fineness modulus was 3.3.

45.3 Mix Proportions

The geopolymer concrete was prepared with fly ash (85%), alccofine (15%), and alkaline solutions. The ratio of alkaline solutions to binger was taken 0.4. The alkaline liquid ratio was taken 2. The SP was taken 2% by weight of binder material. The concertation of sodium silicate and sodium hydroxide is constant 10M of all five mixes. The fine aggregate was replaced by the waste crushed glass with different percentages 0–40% with an increment 10% respectively. The quantity of materials for one meter cubic were given Table 45.1.

Table 45.1 Mix proportions for geopolymer concrete

Mix	Coarse aggregate	Fine aggregate	WCG	Fly ash	Alccofine	NaOH	Na_2SiO_3
M_{G0}	1108.8	740	0	333.07	59.13	52.6	105.2
M_{G10}	1108.8	666	74	333.07	59.13	52.6	105.2
M_{G20}	1108.8	592	148	333.07	59.13	52.6	105.2
M_{G30}	1108.8	518	222	333.07	59.13	52.6	105.2
M_{G40}	1108.8	444	296	333.07	59.13	52.6	105.2

45.4 Test Results

45.4.1 Workability

The workability of concrete is measured by slump cone (Fig. 45.1). Test conducted by as per IS code 1199-1956 respectively. Figure 45.2 shows the variation of slump values having different percentage replacement of waste crushed glass. The increasing workability with increasing waste crushed glass in geopolymer concrete. The waste crashed glass which has less water absorption. The slump values presented in Table 45.2.

Fig. 45.1 Slump cone test

Table 45.2 Slump cone test results

Mix designation	Slump values (mm)
M_{G0}	185
M_{G10}	200
M_{G20}	210
M_{G30}	225
M_{G40}	235

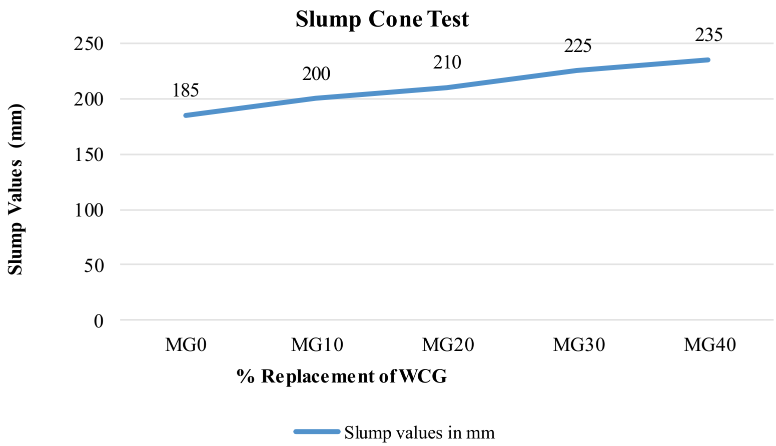

Fig. 45.2 Graph represents of slump values vs % replacement of waste crushed glass

45.4.2 Compressive Strength

The test was conducting according to IS 516-1959 to obtained compressive strength for 7, 28 & 90 days. The cube samples were tested using a compressive strength machine of capacity 3000 KN (Fig. 45.3). Compressive strength development of GPC with different percentage waste crushed glass replaced as fine aggregate. Figure 45.4 shows the various percentages replacement waste crushed glass has an effect on compressive strength. Compressive strength was increasing with waste crushed glass content up to 20%. The 7, 28 & 90 days compressive strength of normal geopolymer concrete was 22.62, 40.02 & 43.26 MPa and replacement of waste crushed glass compressive strength was 26.24, 42.37 & 47.37 MPa. The increasing strength was 16.0%, 5.87% & 9.5% receptively. The increasing strength of geopolymer concrete was mainly due to Accofine has to fill micro pores of geopolymer concrete and glass content high amount of silica less absorption of water. The decreasing compressive strength beyond 20% replacement waste crushed glass due to increasing brittle nature of glass. The compressive strength results presented in Table 45.3.

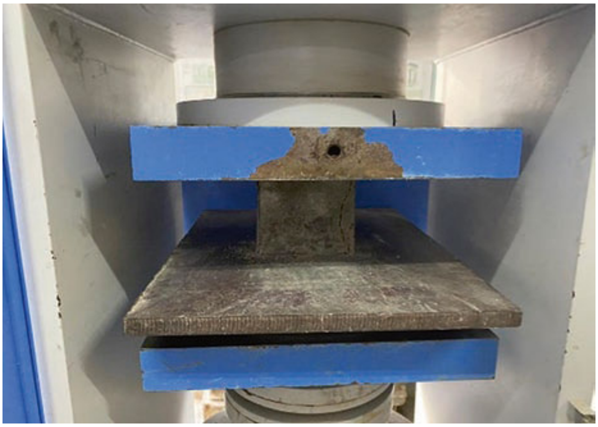

Fig. 45.3 Cube specimen placed in compressive testing machine

Table 45.3 Compressive strength test results

Mix	Compressive strength (MPa)		
	7 days	28 days	90 days
M_{G0}	22.62	40.02	43.26
M_{G10}	24.76	40.27	43.87
M_{G20}	26.24	42.37	47.37
M_{G30}	25.35	40.18	41.12
M_{G40}	24.36	38.65	40.68

$M_{G:}$ Mixes with waste crushed glass

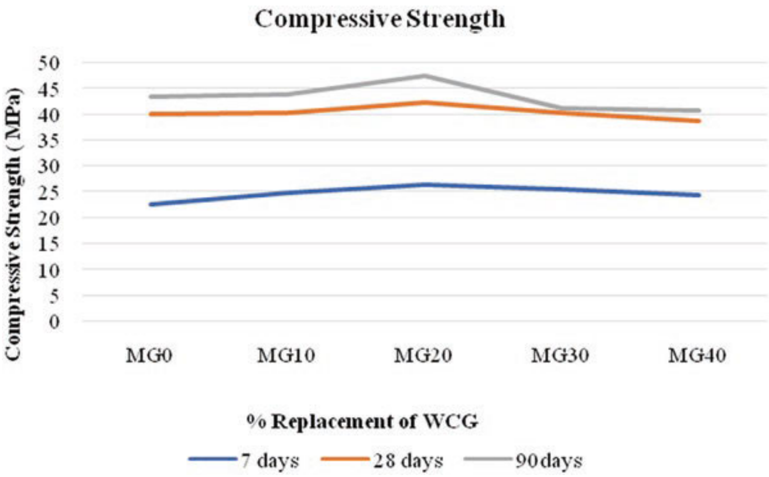

Fig. 45.4 Graph represents of compressive strength vs % replacement of waste crushed glass

45.4.3 Split Tensile Strength

The test was conducting as per IS 516-1956 respectively (Fig. 45.5). The effect of waste crushed glass on split tensile strength is shown in Fig. 45.6. Split tensile strength was increasing with waste crushed glass content up to 20%. The 7, 28 and 90 days tensile strength of normal GPC was 1.2, 3.2 & 3.42 MPa and replacement of waste crushed glass the split tensile strength was 2.3, 4.2 & 4.8 MPa. The improvement in tensile strength was mainly due to alccofine fills micro pores inside the concrete and waste crushed glass contains high amount of silica. The strength in tensile results presented in Table 45.4.

45.4.4 Flexural Test

The Flexural behaviour of geopolymer concrete beams dimensions is (700 mm × 150 mm × 150 mm). The beams design as under reinforcement sections. Beams are were tested for 28 and 90 days at ambient curing. A total of 20 beams are casted four beams are without waste crushed glass and the remaining 16 beams are with waste crushed glass as fine aggregate. The beams are placed on a loading frame machine to applied was constant load (1KN/Sec) at the centre of the beam (Fig. 45.7). The live deflections are measured by LVDT was placed at the centre of the beams. The loading carrying capacity was increasing with waste crushed glass

Fig. 45.5 Cylinder specimen placed in split tensile testing machine

Table 45.4 Split tensile strength test results

Mix designation	Split tensile strength (MPa)		
	7 Days	28 Days	90 Days
M_{G0}	1.2	3.2	3.42
M_{G10}	1.8	3.4	3.65
M_{G20}	2.3	4.2	4.8
M_{G30}	2.15	3.15	3.5
M_{G40}	1.95	2.9	3.0

up to 20%. The 28- & 90-days flexural load of normal geopolymer concrete was 133.87, 165.58 and replacement of waste crushed glass the flexural load was 148.6 & 190.75 KN respectively (Fig. 45.8). The deflection of beams was not much variation for 28 & 90 days. The flexural load presented in Table 45.5.

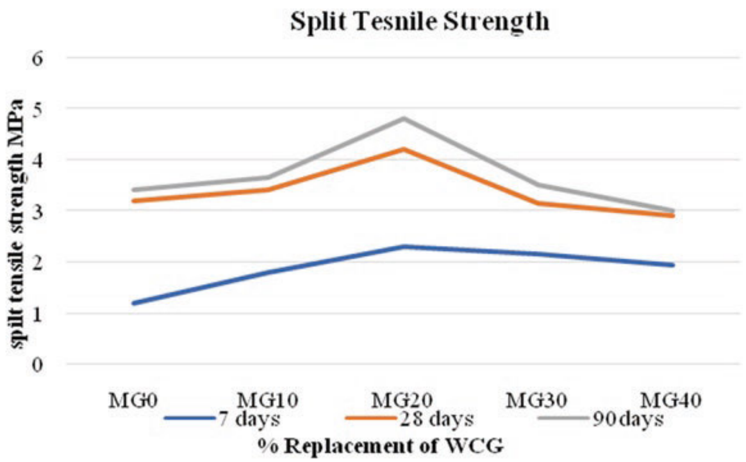

Fig 45.6 Graph which represents of split tensile strength Vs replacement of waste crushed glass

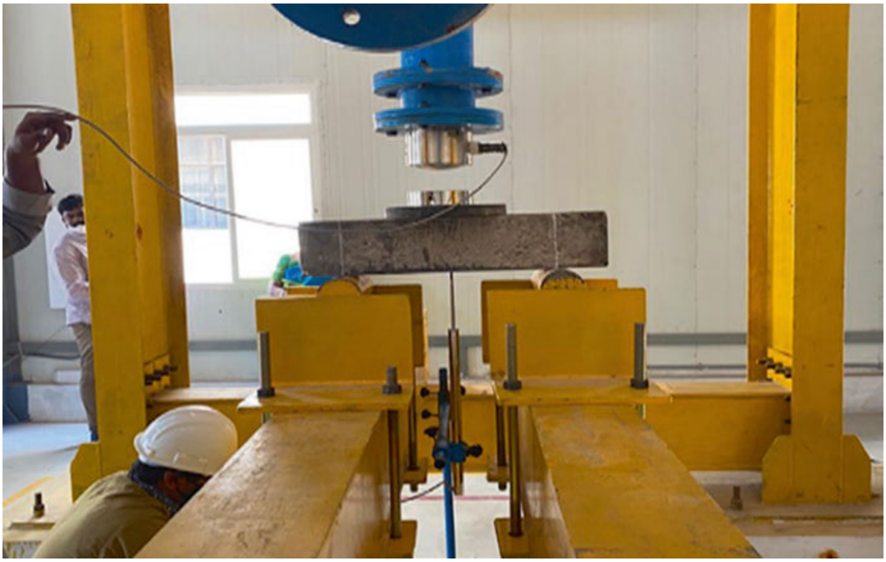

Fig. 45.7 Experimental set up

Table 45.5 Flexural load results

Mix	Design load (KN)	Peak load (KN)		Deflection (mm)	
		28 days	90 days	28 days	90 days
M_{G0}	117.9	133.87	165.58	4.1	4.2
M_{G10}	117.9	140.65	175.52	4.3	4.3
M_{G20}	117.9	148.6	190.75	4.7	4.9
M_{G30}	117.9	139.2	164.28	4.8	5.1
M_{G40}	117.9	130.9	155.27	5.0	5.3

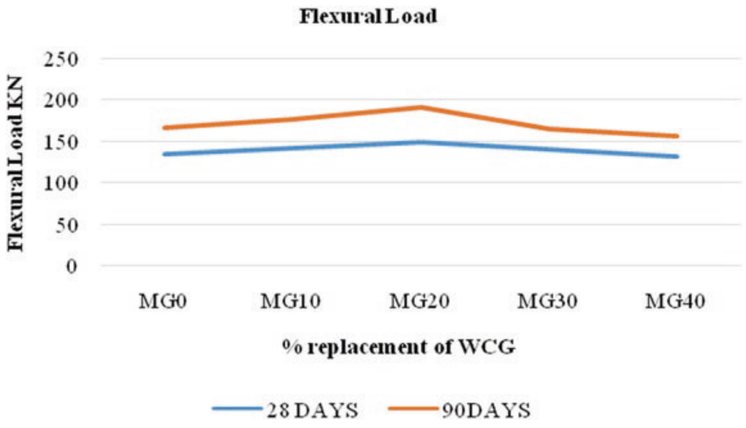

Fig. 45.8 Graph representation of flexural load vs % replacement of waste crushed glass

45.5 Conclusion

In this study presents the usage of waste crushed glass as fine aggregate in geopolymer concrete. Depends on experimental work following conclusions are drawn below.

- The waste crushed glass particle has smoothness of surface and less water absorption due to the workability increased with increase amount of waste crushed glass.
- The mechanical properties of GPC increase with increase amount of waste crushed glass up to 20% replaced as fine aggregate. Beyond 20% replacement the compressive strength decreases.
- The 7, 28 and 90 days compressive strength of normal geopolymer concrete was 22.62, 40.02 & 43.26 MPa and replacement of waste crushed glass compressive strength was 26.24, 42.37 & 47.37 MPa. The increasing strength was 16.0%, 5.87% & 9.5% receptively.
- The 7, 28 & 90 days spilt tensile strength of normal geopolymer concrete was 1.2, 3.2 & 3.42 MPa and replacement of waste crushed glass tensile strength was 2.3, 4.2 & 4.8 MPa.
- The Maximum loading carrying capacity of with waste crushed glass as fine aggregate beams higher than conventional geopolymer concrete.
- Increasing glass content was used in GPC increases the deflection of the beams.

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Chapter 46
A Performance Study on Lithium Based Admixture in the Properties of Concrete

S. Sathya and R. Manju

Abstract A great threat to the environment is posed by recycling of lithium-ion batteries. Electronic waste disposal is an environmental threat. One of the compounds in electronic waste that poses a challenge to the recycling of lithium-ion batteries is lithium. Lithium can be used in structural engineering if it is extracted properly. When lithium bases compounds are used in concrete, they help to control cracks due to alkali silica reaction (ASR), which improves the concrete's strength and durability. While adding the appropriate amount of lithium additives to the concrete, ASR suppression and the formation of ettringite is delayed. The performance of $LiNO_3$ on the properties of concrete, the formation of ASR gel, and the bending characteristics of concrete beams are investigated in this paper. Concrete properties were examined for mix ratios, of control mix, lithium nitrate with 0.6 molarity (M) $LiNO_3$, 0.65M$LiNO_3$, 0.7$LiNO_3$M, 0.75M$LiNO_3$, 0.8M$LiNO_3$. $LiNO_3$ prevents the formation of ASR gel, and also has an excellent influence on the properties of concrete. The 0.75M Lithium Nitrate has high strength, according to the findings. In order to investigate the microstructural characteristics of concrete, SEM analysis was performed on 0.75M and control mixes. When compared to concrete without lithium nitrate, the ASR gel formed in 0.75M was suppressed. Water permeability and absorption test, and Rapid chloride penetration test characteristics are investigated in concrete. The flexural behavior of the rectangular beams is studied and compared with the analytical study using ANSYS 16.0.

Keywords ASR gel (Alkali Silica Reactive gel) · Crack · $LiNO_3$ · Optimum Dosage · Concrete Properties · SEM Analysis

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46.1 Introduction

Concrete is a composite material which solidifies as time goes. Cracking in concrete could not be restrained. If its causes, are comprehended better, it can be eliminated easily. Cracks in the concrete is due to the factors such as drying, chemical action, creep & shrinkage, difference in temperature, elastic deformation, mobility of moisture, elastic deformation, foundation movements, defects in manufacturing and soil settlement. The cracks appear as a result of a chemical action, are predominantly due to alkali silica reaction. Reactive aggregates react with OH^- ions which are derived from alkali present in the cement, which leads to enormous swelling of alkali silicate gel, which disrupts the concrete, and eventually leads to structure failure. In structural world, ASR is known as "concrete cancer", in which the concrete swells since, highly alkaline cement paste reacts with reactive silica present in aggregates. Which, in turn leads to development of soluble adhesive gel called sodium silicate (Na_2SiO_3)gel.

This gel inflates and enlarges in its volume by absorbing water. The strength of the concrete gets reduced, since the gel formed exerts pressure inside the siliceous aggregate. Alkali Silica Reaction leads to severe cracks, which may finally destructs the structure. Lithium admixtures, if added in concrete, retaliates with silica, before the OH^- ions, developing lithium sulphate. ASR will be prevented by the formation of Lithium sulphate, which acts as a diffusion barrier, resulting in the prevention of cracks.

The observations from the literature are as follows. Alkali Silica reaction is mitigated when fly ash is made to react with lithium Nitrate and, the early heat formation is also reduced (Millard and Kurtis 2008). The incorporation of Li_2NO_3 decreases the solubility of silica and dissolution rate, when it combines with caustic soda (Leemann et al. 2014). The addition of lithium salts influences the initial and final setting time. Earth strength development is enhanced by incorporation of Lithium sulphate. Li^+ ion hinders the ettringite formation and reduces the solubility of calcium ion but allowing the products of hydration (Deng et al. 2014). Not only based on silica content, the reactive nature of aggregate depends upon the size and mineral distribution. The developed ASR gel is based on the presence of calcium ions. Among all lithium-based admixtures, lithium nitrate is the most effective in controlling ASR (Rajabipour et al. 2015). Lithium salt required to inhibit ASR is determined by the reactivity of the aggregate mineralogy and the test duration. Li_2NO_3 is effective in prevention of ASR gel, if reactive type of aggregate are used (Islam and Ghafoori 2016). Investigations were done to study the effect of lithium ion composition of ASR gel. As the amount of lithium salts added, increases the average CaO/SiO_2 ratio decreases. With the cement containing high alkali content of 1.1% Na_2O_e, the reduction of ASR gel was at 0.75M incorporating LiOH and $LiNO_3$. At high dosage levels of CaO, ASR gel becomes an analogous compound (Kawamura and Fuwa 2003). Alkali Silica reactivity in concrete was investigated using LiF, LiBr, LiCl, LiOH, $LiOH.2H_2O$, $LiHNO_3$, $LiNO_3$, $LiCO_3$, Li_2SO_4, Li_2HPO_4, which suppresses ASR. $LiNO_3$ shows better efficiency in mitigating ASR. For other lithium salts, Li/Na_2Oe ratio is 0.67 to 1.2 for obstructing ASR, while for $LiNO_3$, it ranges between 0.72 and 0.93 (Feng et al. 2005). Alkali silica reaction mechanism aluminium containing metakaolin and $LiNO_3$ was investigated. The aluminium ions does not influences the product formed but the speed of the reaction is governed by aluminium ions. Metakaolin and $LiNO_3$ has an ability to suppress ASR formation. A layer around reactive aggregates is formed by addition of $LiNO_3$ which suppress the ASR by forming dense product. (Leemann et al. 2015). A paste made with cement, $LiNO_3$ and with lithium bearing glass and cement with lithium bearing glass was tested. The molar ratio of Li/Na_2O_e is maintained at 0.74. Three different types with pore solution was tested at 3, 7, 28, and 91 days which are subjected to temperatures of 23, 38, and 60 °C in a sealed container. $LiNO_3$ lowers hydrogen ion concentration by 0.1 and lithium glass raises hydrogen ion concentration by 0.2 (Bérubé et al. 2004).

46.2 Materials Used

OPC confirming to 43 grade with 34% consistency was used. The initial and final setting time of cement is 75 and 600 min. The specific gravity is 3.15. The specific gravity of sand & M – Sand is 2.4 & 2.67 that of water absorption is 1.3% & 1% for River sand& M- Sand. The aggregated were graded confirming to Zone II. There is no moisture content.

The specific gravity of coarse aggregates used is 2.76 and water absorption rate is 0.4%

Mix Proportion

The mix design had been done as per Indian Standards: 10262-2009. The mix proportion achieved was 1:1.8:3:0.5. The amount of $LiNO_3$ for 0.6M, 0.65M, 0.7M, 0.75M & 0.8M were 80, 86, 93, 100 & 106 g for 0.078 m^3 of concrete volume.

46.3 Experimental Programme

The reactivity of the aggregates has been tested as per ASTM C1260 standards i.e., Accelerated Mortar Bar Expansion test. The Compressive strength, tensile strength, bending strength has been studied on concrete. Also, durability tests viz., acid attack, sulphate attack, water absorption, water permeability, rapid chloride tests have been done as per Indian Standards.

SEM Analysis

Specimen's surface morphology and particle size is determined using SEM analysis. Images of various samples were taken at magnifications such as X500, X5000, and in order to identify the ASR gel and ettringite formation. SEM analyses is done for control mix concrete and then the concrete which 0.75M (optimal dose). The repression of alkali aggregate reaction and the development of ettringite were investigated.

46.4 Results and Discussions

46.4.1 Alkali Aggregate Reactivity Test

Sand is inert under highly caustic conditions of aggregate reactivity tests, whereas M Sand is reactive with an average length expansion of 0.45%.

46.4.2 Mechanical Properties

Compressive Strength

Table 46.1 shows the results of the compressive strength test. The compressive strength tests were done at 7th, 28th & 90th day. The maximum compressive strength at 28th & 90th day of 30.93 N/mm^2 and 34.95 N/mm^2 were achieved for 0.75M of $LiNO_3$ concrete. For, the concrete with 0.75M of $LiNO_3$, the strength varies by 14.30%. The optimum dosage of $LiNO_3$ to be added is found to be 0.75M in Concrete compared with other molar ratios of $LiNO_3$. Also, it can be proved with 90 day strength of concrete cubes. Figure 46.1 compares the 7th, 28th & 90th day compressive strength of concrete cubes. Hence in concrete containing $LiNO_3$ admixtures, the Alkali Silica gel formation will be suppressed due to formation of protective diffusion barrier $LiSO_4$, which acts as a shield against cracking.

Split Tensile Strength

The tensile strength characteristics of concrete is assessed. The split tensile strength of 0.75M concrete was 33.87% higher than that of control mix concrete. The split tension strength $LiNO_3$ additive concrete was shown in Table 46.2 (Fig. 46.2).

Flexural Strength

The bending strength of the 0M concrete is 3.85 N/mm^2. The bending strength for 0.75M $LiNO_3$ concrete is higher than other $LiNO_3$ additives. Table 46.3 indicates flexural strength test results (Fig. 46.3).

Table 46.1 Compressive strength test

Mix ID	Density of Concrete (kg/m^3)	7th day Compressive strength (N/mm^2)	28th day Compressive strength (N/mm^2)	90th day Compressive strength (N/mm^2)
CM	2488.8	15.18	27.06	30.77
0.8M	2533.3	17.26	28.98	34.22
0.75M	2571.8	18.49	30.93	34.95
0.7M	2518.5	16.48	27.78	33.78
0.65M	2497.7	16.08	27.21	32.36
0.6M	2494.8	15.49	27.16	31.66

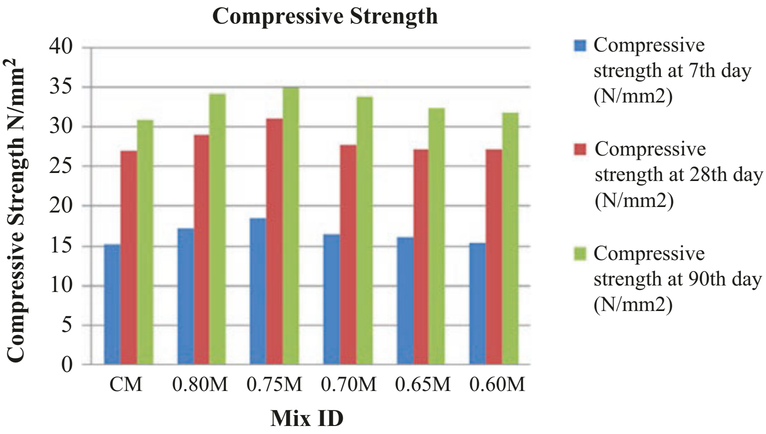

Fig. 46.1 Compressive strength tests results

Table 46.2 Split tensile strength test results

Mix ID	Split tensile strength (N/mm^2)	Percentage increase in strength (%)
CM	1.24	–
0.8M	1.52	22.58
0.75M	1.66	33.87
0.7M	1.48	19.35
0.65M	1.35	8.87
0.6M	1.29	4.03

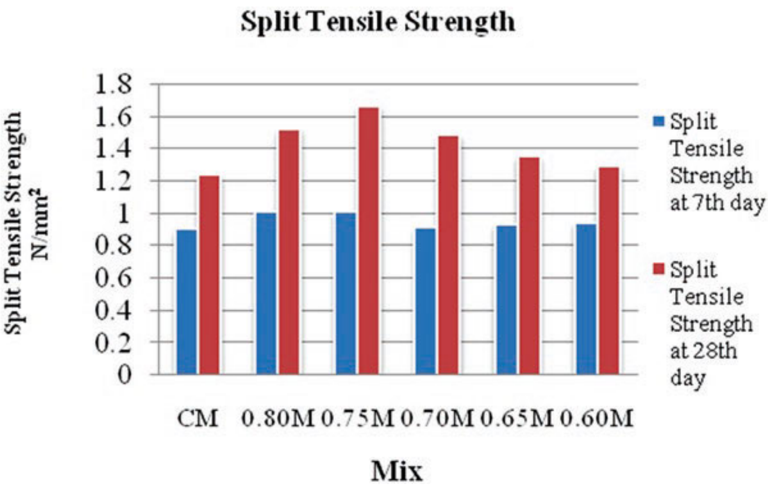

Fig. 46.2 Results of split tensile strength test

Table 46.3 Flexural strength test results

Mix ID	28 days Flexural strength N/mm^2	Percentage increase in strength (%)
CM	3.85	–
0.8M	4.367	13.42
0.75M	4.633	20.33
0.7M	4.222	9.66
0.65M	3.888	0.989
0.6M	3.877	0.701

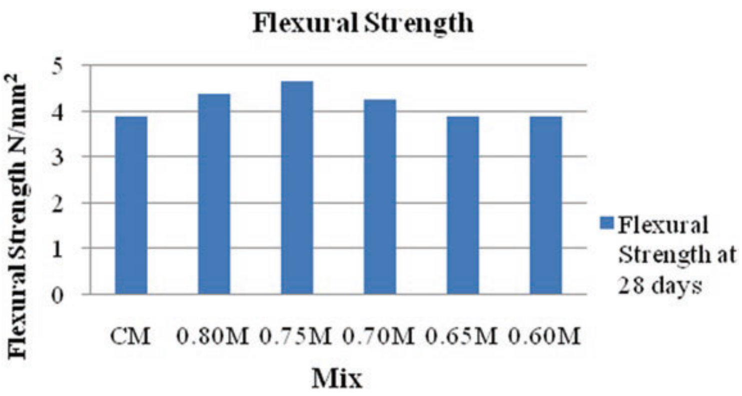

Fig. 46.3 Flexural strength test

SEM Analysis

The reaction of alkali aggregate in control mix concrete results in void formation and permeability, since amount of ASR gel formed is high. But, in concrete with LiNO, the amount of ASR gel formed is minimum and resulting in low permeability. And hence, ASR gel formed in 0.75M has been subdues and leading to less cracks. And also, the formation of ettringite is delayed (Fig. 46.4, 46.5, 46.6, and 46.7).

46.4.3 Durability Properties

To check concrete against weathering, chemical attack, and abrasion, the durability tests has to be performed. Water Permeability tests performed in accordance with IS 3085:1965 show that water penetration is reduced significantly in $LiNO_3$ added mixes, which in inturn increase the durability properties. Table 46.4 displays the results of the water permeability test. The incorporation of $LiNO_3$ also reduced water absorption in concrete specimens. Table 46.5 shows the results of water absorption tests. As per AASHTO T277 standard, Rapid chloride penetration test has been done. The permeability of chloride in concrete containing Lithium Nitrate as an admixture is extremely low. As a result, the risk of corrosion is low. Carbonation

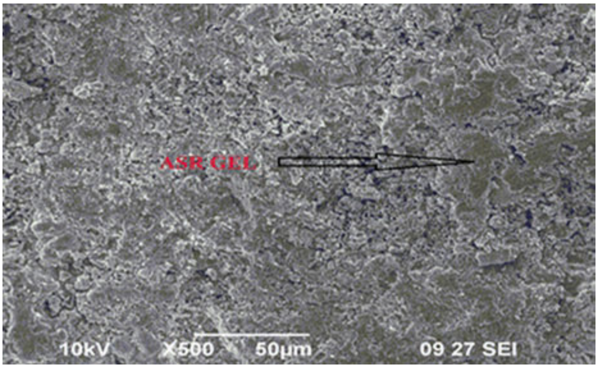

Fig 46.4 Image of 0M mix concrete with magnification X500 under SEM

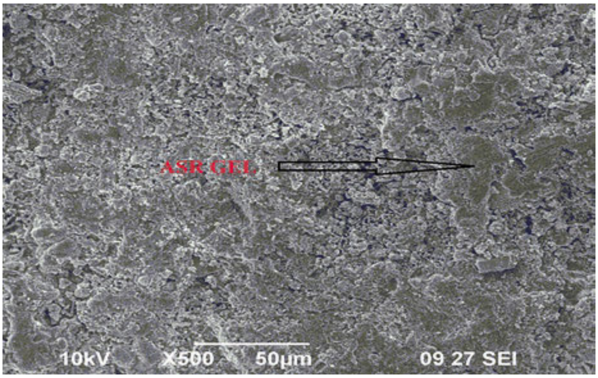

Fig 46.5 Image of 0.75M concrete of magnification X500 under SEM

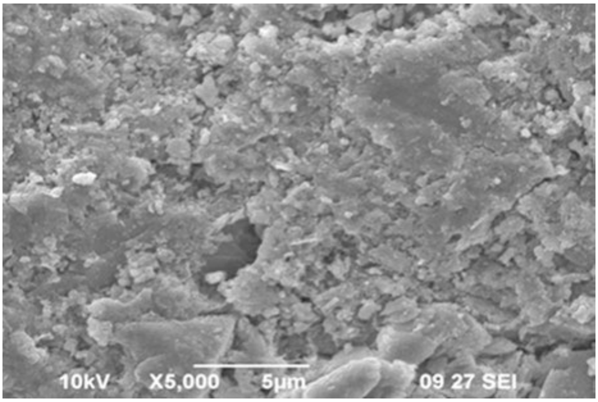

Fig 46.6 SEM image for 0M mix of magnification X5000

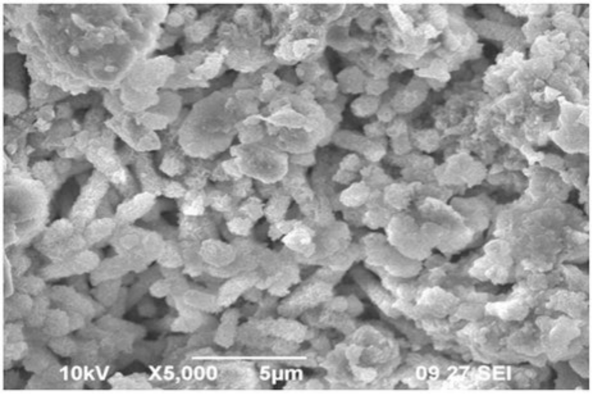

Fig 46.7 Image for 0.75M of magnification X5000 under SEM

Table 46.4 Results of water permeability test

Mix ID	Depth of penetration (cm)
CM	3.2
0.80M	2.5
0.75M	2.0
0.70M	2.8
0.65M	2.9
0.60M	3.0

Table 46.5 Water absorption test results

Mix ID	Absorption %	Average
CM	1.11	1.025
	0.95	
0.80M	0.78	0.785
	0.79	
0.75M	0.64	0.750
	0.86	
0.70M	0.98	0.865
	0.75	
0.65M	1.03	0.925
	0.82	
0.60M	0.95	0.945
	0.94	

did not occur in this lithium admixture concrete investigation. As a result, the chances of corrosion are extremely low. Figure 46.8 demonstrates that there is no carbonation in concrete.

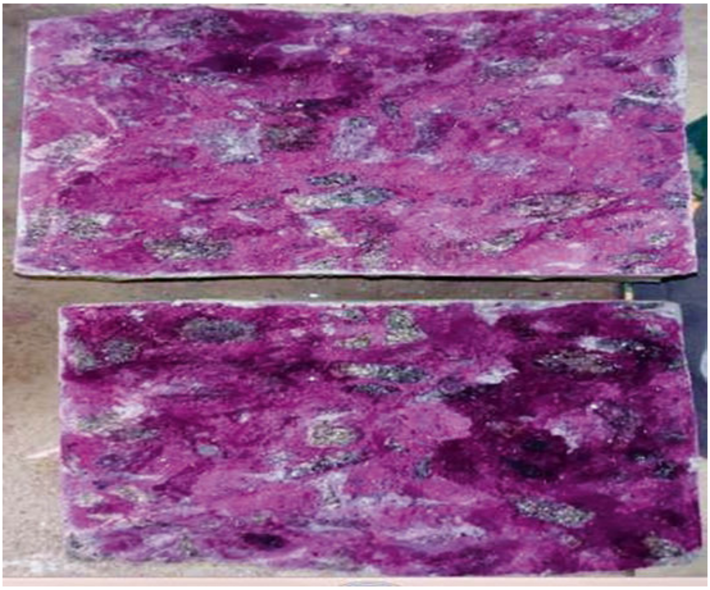

Fig. 46.8 Uncarbonated 0.75M concrete

46.5 Analysis of Flexural Behavior of RC Rectangular Beams

To investigate the flexural behavior of beams experimentally, reinforced concrete beams of size 1500 mm × 150 mm × 175 mm was casted for control mix and 0.75M lithium based admixture mix. 2 rods of 10 mm & 2 rods of 8 mm diameter of Fe500 grade steel reinforcement is provided as main reinforcement and as hanger bars. 2-legged 8 mm diameter rods at 100 mm c/c spacing are provided as stirrups. Load deflection plots at centre and one-third distance were shown in figure for control mix and 0.75M mix concrete (Table 46.6, Figs. 46.9 and 46.10).

Load at First Crack

The incorporation of lithium nitrate increased the first cracking load than the control mix beam.

Ultimate Load

The ultimate load corresponds to yield of steel and crushing of concrete. The yielding of steel is found to be more in the specimen incorporating $LiNO_3$ as an admixture.

Table 46.6 Experimental beam test results

Parameters	Beam results		% variation of 0.75 beam with
	CM beam	0.75M beam	CM beam
Initial stiffness (kN/mm)	26.32	30	14
Final stiffness (kN/mm)	9.94	10.125	1.86
First crack load (kN)	50	55	10
Ultimate load capacity (kN)	159	162	1.9
Maximum deflection at L/2 distance (mm)	16	14	12.5
Maximum deflection at L/3 distance (mm)	13	12	7.69
Crack width (mm)	2	1.5	25%
Crack pattern	Flexural Cracks	Flexural Cracks	

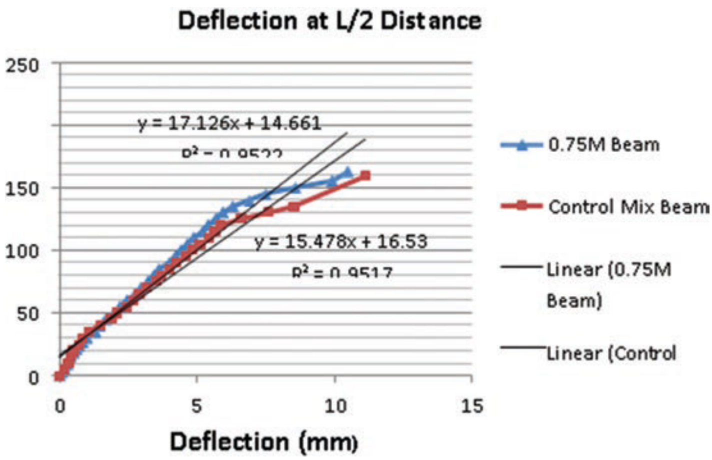

Fig. 46.9 Load deflection plot at L/2 distance for control mix concrete beam and 0.75M $LiNO_3$ mix beam

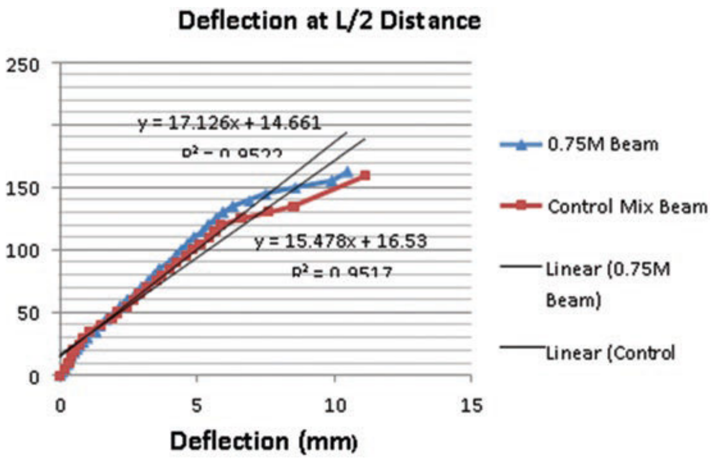

Fig. 46.10 Load deflection plot at L/3 distance for control mix concrete beam and 0.75M $LiNO_3$ mix beam

Fig. 46.11 Flexural cracks in the beam after testing

Crack Width
The crack width for the control mix beam and 0.75M Lithium Nitrate added concrete beam is 2 mm and 1.5 mm respectively. The crack width has been reduced in the later, because the addition of Lithium Nitrate forms a diffusion barrier against sodium silicate gel, which disrupts the formation of ASR gel and hence there is reduction in cracks.

Crack Pattern
The flexural cracks developed in both the beams are visible, if ultimate load is at 60–70% of its total capacity. The crack pattern observed is flexural cracks in both the beams. The tensile cracks are formed in both the beams and gets widen indicating higher strain in the steel. Up on further incrementing the load, the cracks gets propagated towards compression zone. The beams which exhibits tensile failure, is a ductile failure. Figure 46.11 shows the flexural cracks in the beam after testing.

46.6 Analytical Programme

ANSYS 16.0 Software is used to simulate the flexural characteristics of rectangular RC beams. The bending characteristics was studied for RC beams of 0M and 0.75M mix using ANSYS. Young's Modulus, strength characteristics and stress- strain behavior of experimental results of concrete is given as input. The beam is modeled in ANSYS and it is fine meshed. The deformation & stress characteristics were investigated. Figures 46.12 and 46.13 shows the Load – Deflection performance and stress intensity pattern of the beams (Fig. 46.14).

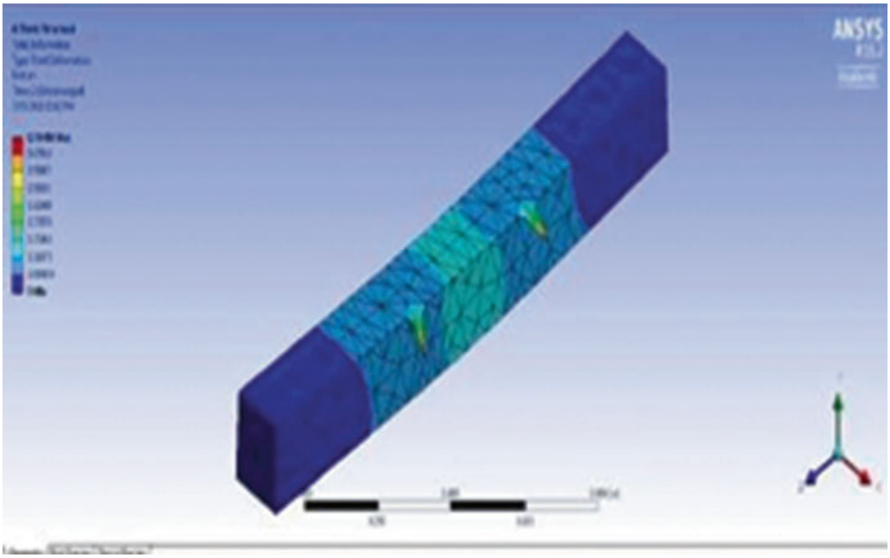

Fig. 46.12 ANSYS image for deformation pattern of 0.75M mix beam

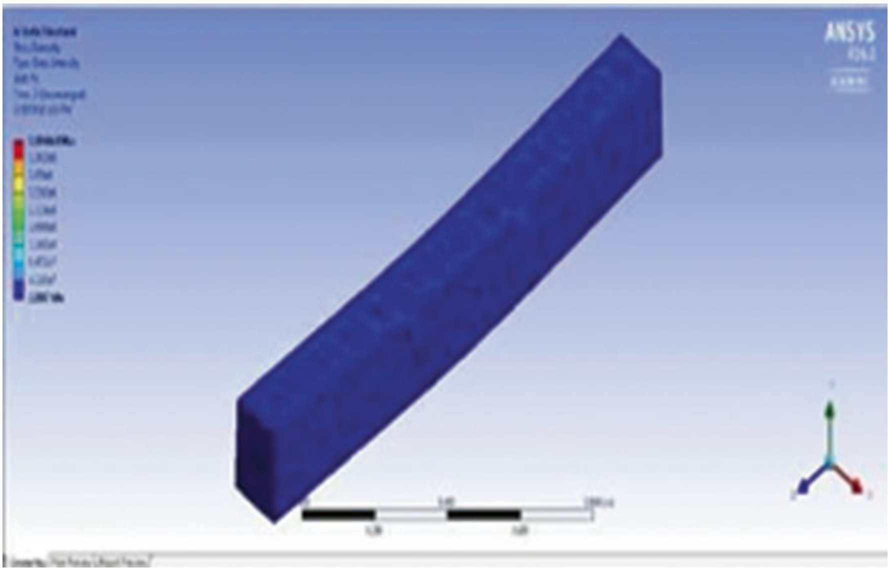

Fig. 46.13 ANSYS image for stress intensity pattern of 0.75M mix beam

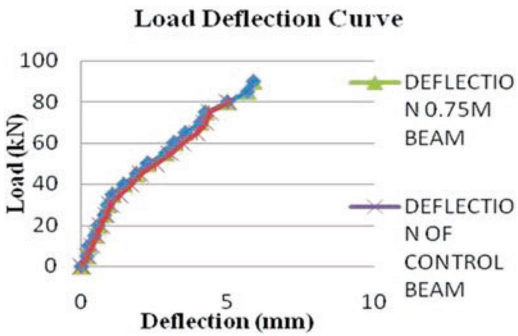

Fig. 46.14 Load deflection plot

46.7 Comparative Study on Analytical Results with Experimental Results

The analytical beam results are compared with experimental results. The ultimate load capacity of CM & 0.75M beam analytically is 11.165% & 8.27% lower than experimental results. The maximum displacement of CM & 0.75M beam analytically is 15.94% & 0.36% lower than experimental results. The percentage variation is 3% for analytical and experimental studies. The crack width due to ASR gel formation is reduced when concrete is added with Lithium Nitrate (Table 46.7, Figs. 46.15 and 46.16).

46.8 Conclusions

- At 28 days, the compressive strength for the mix containing 0.75M of $LiNO_3$ was 30.93 N/mm^2 and it is 14.30% greater than control mix concrete.
- The strength to resist tension for 0.75M concrete was 33.87% greater than 0M concrete, resulting in a split tensile strength of 1.66 N/mm^2
- The optimal Li/Na_2O_e dosage for alkali suppression was 0.75.
- The SEM image clearly shows that the ettringite formation in the 0.75M mix is minimal. However, a large amount of ettringite formation is indicated in the reference mix. As a result, ettringite formation is delayed in lithium nitrate additive concrete.
- The water permeability and absorption of 0.75M concrete is 37.5% & 26.83% lower than control mix concrete.
- The chloride penetration is very low for all mixes.
- Alkali silica reaction is minimum in concrete which contains 0.75M $LiNO_3$ such that voids are minimum and permeability is less.

Table 46.7 Comparative study on analytical results with experimental results

Parameters	Experimental beam results		Analytical beam results		% variation of analytical results with experimental results	
	CM beam	0.75M beam	CM beam	0.75M beam	CM beam	0.75M beam
Ultimate load capacity (kN)	159	162	141.25	148.6	11.16	8.27
Displacement at L/2 distance (mm)	16	14	13.45	13.95	15.94	0.36

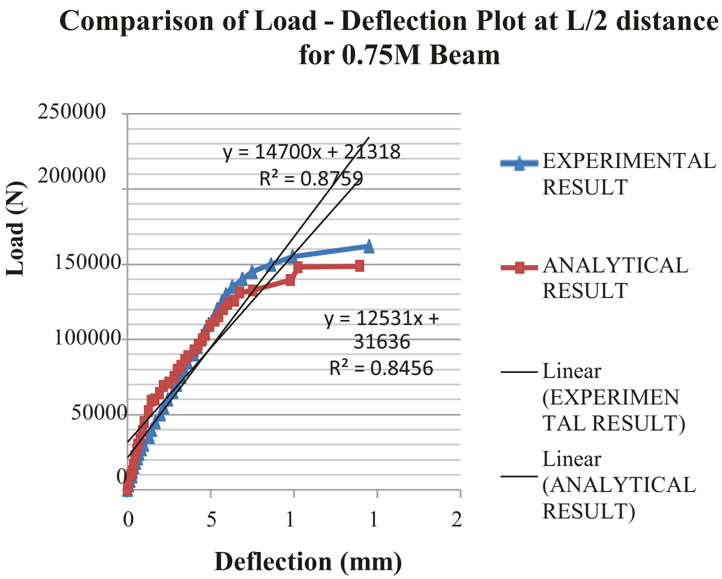

Fig 46.15 Comparison of load deflection plot at L/2 distance for CM beam

- Experimental results states ultimate load capacity of 0.75M beam is 1.9% higher than CM beam. The crack width of the 0.75M beam is 25% lower than the control mix beam.
- The ultimate load capacity of CM & 0.75M beam analytically is 11.165% & 8.27% lower than experimental results. The maximum displacement of CM & 0.75M beam analytically is 15.94% & 0.36% lower than experimental results.
- The load capacity of the CM & 0.75M beams analytically are 11.16% & 8.27% lesser than experimental load capacity.
- The cost for Lithium Nitrate added concrete is 60.78% higher than control mix concrete. But, if Lithium is extracted from e-waste, the cost can be much reduced.

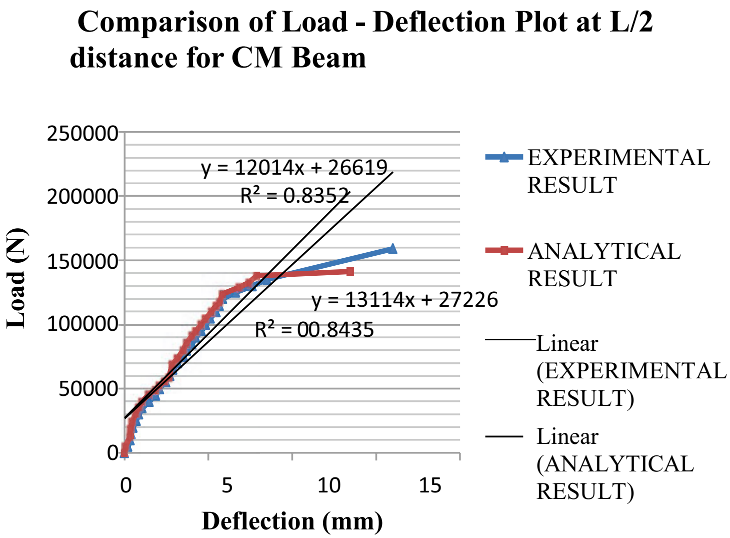

Fig 46.16 Comparison of load deflection plot at L/2 distance for 0.75M beam

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Chapter 47
Self-Curing Concrete Made By Using Hemp: A Review

Ankush Tanta, Varinder S. Kanwar, and Manvi Kanwar

Abstract In today's world, global warming is at its peak and the materials are being excessively used by the industry leading to an adverse effect on the environment. This made leaders all over the globe to work on halting global warming, and thus invention led to the rehabilitation of building materials made of agro-waste concrete, which has the additional benefits of carbon restoration, renewability and low embedded energy. Concrete mixes consist of agro-wastes, such as rice husk, coconut shell, wheat straw, sugarcane bagasse, maize cob, bamboo leaf, Hemp etc. In India, research on Hemp concrete has not been done so far on large scale therefore this surface new opportunity of different outcome on Hemp concrete. The purpose of this paper is to review the research on finding the self-curing properties (Hygrothermal properties), mechanical properties, and light weight properties of hemp concrete so that it can be used as a construction material, with the goal of recognizing research gaps that will guide the future research into its execution in the rapidly increasing green building industry. Several gaps were identified in the research regarding the strength, light weight and the self-curing properties of the Hemp concrete. The article closes with a discussion of the direction and necessity of upcoming research to enhance Hemp concrete's manufacturing methods and mechanical performance in order to expand its use in the construction sector.

Keywords Hemp · Self-curing concrete · Hygrothermal · Hemp concrete · Agro-waste · Light weight concrete

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47.1 Introduction

Agriculture plays an important role as a largest contributor to the economy. It also includes the raising of animals, plants, and other living things for food, fibre, biofuels, medicines, and other products that help people live longer (Arjun 2013). It also generates waste materials which are also called agro-waste. Agro-waste is usually generated through farming activities. It includes compost, bedding, plant stalks, hulls, leaves, forest waste and vegetables. In farming; agro-waste is often not in use and is being discarded. But it can be used in some other Industries (https://www.natthushrirame/agriculturalwaste-management-80609107).

For example, there are various types of agro-waste which are being used by the construction Industries. Some of them are rice husks, coconut shells, wheat straw, sugarcane bagasse, maize cob and Hemp. Figure 47.1 shows the types of agro-cycle and Fig. 47.2 shows Hemp plant.

Agro-wastes are used in the production of concrete which gives better durability, workability then normal concrete and reduces the emission of CO_2 from cement. Hemp, or industrial Hemp, is a type of species of the cannabis plant used specifically for the industrial use. It is one of the first plant which was harvested 10,000 years ago and is one of the fastest growing plant. It is also known as marijuana which is a psychoactive drug and that is used for medical purposes. Hemp has been utilised as a construction material in European nations for ages. Authorized

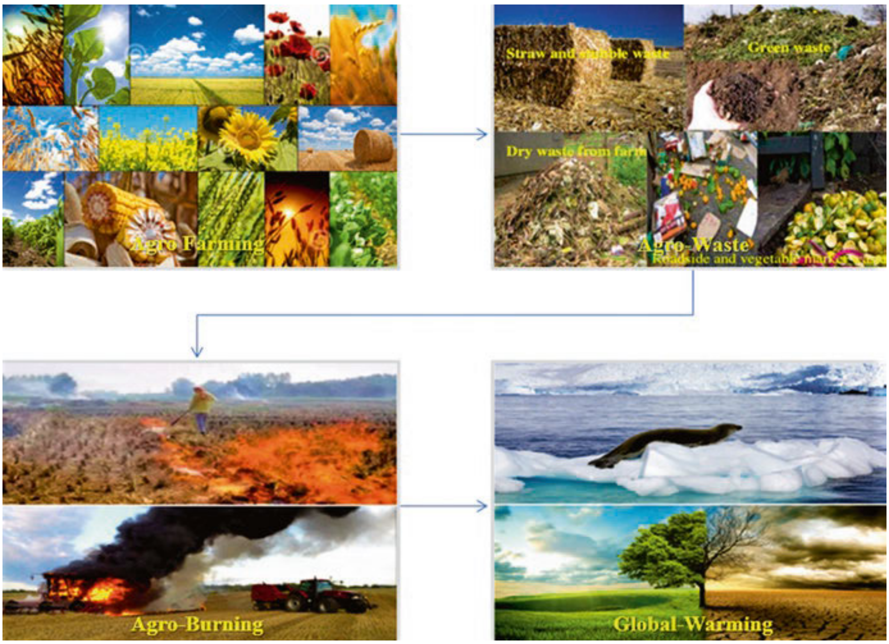

Fig. 47.1 Agro-cycle

Fig. 47.2 Hemp

commercial farmers are now growing industrial hemp as a modern construction material (Crini et al. 2020). Growing Hemp in many countries has been legalised from decades.

With less use of fertilizer and water, Hemp plant can grow up to 4mtrs in a period of three to four months and is one of the fastest growing plants which do not require pesticides or herbicides (Lawrence et al. 2012). Hemp plant and all its parts can be used for many purposes like seeds can be used as food, fibers around the stem can be used to make paper, clothing and reinforcement of resin and wood core of the stem can be used as bedding for animals and as aggregates in the concrete. Hemp is long-lasting and has a variety of other advantages. Hemp observes CO_2 from the atmosphere as similar to other natural plant (Ip and Miller 2012). Basically, Hempcrete is made up of Hemp hurd, cement and it can be combined with cement and water to make a Hempcrete. Hemp is one of the few natural fibres with a high silica concentration, making it one of the few (Sinka and Sahmenko 2013). Silica allows Hemp hurds to bind well with lime and cement. Its weight is very light and adding to cement makes it light weight cementitious insulating material. The weight of Hemp concrete is only one-seventh to one-eighth than that of normal concrete (Evrard et al. 2006).

Hempcrete is a bio-composite material that may be used as an alternative to concrete and conventional insulation in building. It has a negative carbon waste, with significant potential for sustainable construction (Pavla and Walker 2010). It naturally controls the building's humidity and temperature, reducing condensation and energy consumption while also improving thermal comfort. It provides breathable and flexible natural insulation which is free of toxins, mold-resistant, and fire-resistant (Evrard 2006). It is a low-density material that resists cracking when moving, it is ideal for locations at risk of seismic activity. Textile fibres can also be made from the outer part of the plant stem (Kostic et al. 2008). Hemp is the only construction material capable of removing carbon dioxide from the atmosphere. Because of the high volume of hemp used, the block became lighter and had a lower density (Tronet et al. 2014). Figure 47.3 shows the various uses of different parts of Hemp. Figure 47.4 shows the cube of Hemp concrete (Jackpattison 2020; Burkey 2016). It

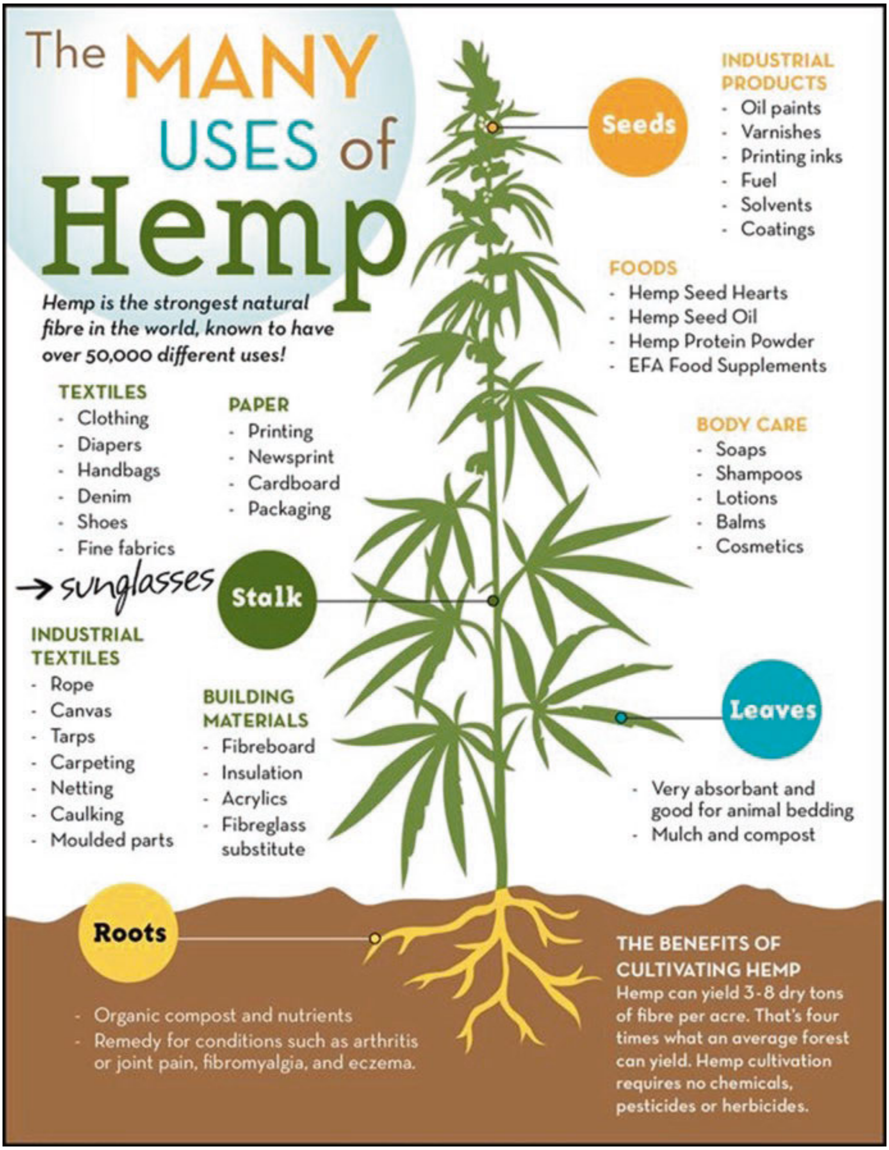

Fig. 47.3 Uses of Hemp

Fig. 47.4 Hempcrete

also demonstrates the several advantages of using Hempcrete block as a construction material.

47.2 Literature Based on Previous Work

In different regions of the globe, a lot of research has been done on the varied characteristics of Hempcrete. The findings of several researchers are presented in the next section.

Pochwała et al. (2020) calculated the thermal conductivity of Hemp–lime composites used in construction. The material was found to be a great alternative to other commonly used construction materials when combined with supporting beams made of other biodegradable materials. Scrucca et al. (2020) represented an environmental and energy assessment of cultivation of Hemp crop in France. It was discovered that the overall carbon footprint is less than the CO_2 uptake because to the biogenic carbon gathered and stored throughout Hemp growth. Delannoy et al. (2020) analysed the variability in extract composition of three types of Hemp shiv and their effect on the cement hydration. It has been found that certain kinds of shiv cause cement to take a long time to set. (Haik et al. 2020) studied the consequence of lime-Hemp concrete (LHC) on thermal performance by replacing lime with different unfired binders, compared it with conventional building materials. It was found that temperature and relative humidity behaviour were correlated across all LHC cells. Awwad et al. (2020) reported research on blocks of green concrete formed with industrial Hemp hurds and fibers. According to the research, raw hemp fibre mixed into masonry blocks has been shown to produce lighter blocks with higher thermal insulation properties. (Novakova and Sal 2019) added technical hemp to concrete to increase the concrete's thermal characteristics at the expense of its strength. Hemp concrete has been discovered to be a good filler, binder, and carrier material for nickel.

Jami et al. (2019) presented an overview of state-of-the-art research on Hemp concrete in order to identify gaps in future research leading to its application in the green building industry. It was found that Hemp concrete has minimal embodied carbon and energy, making it perfect for green building uses. Jothilingam and Paul (2019) studied different ratio of binder mixture to discover the optimal mix ratio of binder mixture to make Hempcrete with use of Hemp fibre. The result showed better outcomes in CO_2 sequestration and compression strength containing Hemp fiber with lime and meta-kaolin. Nováková (2018) described different products, their characteristics, and purposes, with a focus on the usage of technical hemp in the construction sector. This led to the conclusion that using cannabis for ecologically friendly construction materials, our health, and great properties is a viable choice. Jami et al. (2018) addressed the mechanical performance and durability of hemp and hemp concrete, as well as its carbon sequestration and carbon negativity. It was concluded that the traditional material has just gained futuristic status.

Kremensas et al. (2017) researched both types of composites made from Hemp shives, Hemp fibers and biodegradable binders. Experiments on thermal conductivity revealed that composites made of PLA binders and Hemp fibre shave superior thermal insulation characteristics than composites made of Hemp shives and starch binders. Jami et al. (2016) presented a review of the literature on the various studies conducted on Hemp concrete to recognize its properties, disadvantages and advantages in construction. It was noted that more study on LHC is needed to develop mix design principles, enhance LHC's compressive and flexural strengths, and its usage as a load-bearing structural material for high structures. K et al. (2016) evaluated the possibility of employing both Hemp shives and fibres in Hemp concrete to see if an optimal combination of various binding agents, as well as the addition of cement binder, will increase the material's mechanical strength. The evaluation showed that Hempcrete has a low elastic modulus and compressive strength, making it unsuitable for supporting direct bearing loads in structures.

Mikulica and Hela (2015) discussed the use of hemp as a natural organic filler for construction materials, particularly concrete used as a heat-insulating filler around

Table 47.1 Summarization of Different Findings of Hempcrete

Author	Paper year	Principle	Findings	Research gaps
Pochwała	2020	Calculated the thermal conductivity of Hemp–lime composites used in construction.	When combined with supporting beams constructed of other biodegradable materials, the material can be a great alternative to other conventional building materials.	Construction business does not require further development of traditional building materials since nature provides the finest options to make the best use of them.
Scrucca	2020	Represented an environmental and energy impact of growing crop of Hemp in France, found both good and negative effects.	The total CF is lower than the CO_2 absorption due to the biogenic carbon gathered and stored throughout Hemp development.	It may be more effective if no pesticides are used in the cultivation of Hemp.
Delannoy	2020	Analysed the influence of extract composition diversity in three varieties of Hemp shiv on cement hydration.	Certain kinds of shiv have been shown to cause a substantial delay in cement hardening.	Hemp shiv can be pre-treated to speed up the cement curing time.
Haik	2020	Studied the impact of conventional construction materials on the thermal performance of Lime-Hemp Concrete (LHC).	All LHC cells behaved in the same way in terms of relative humidity and temperature.	Cement can be used in place of lime to enhance compressive strength.
Awwad	2020	Reported an investigation on blocks of green concrete manufactured from industrial hemp fibres and hurds.	According to an ongoing investigation, raw hemp fibre was mixed into masonry blocks to produce lighter blocks with higher thermal insulation qualities.	The insertion of Hemp material reduced the thermal conductivity of blocks of Hemp masonry by around 20%, depending on the density of the Hemp mix.
Novakova	2019	Worked on addition of technical Hemp to concrete for improvement of its thermal characteristics.	Hemp concrete may be utilized as a filler, and nickels can be used as a carrier.	Hydraulic lime can be used to improve binding.
Jami	2019	Identified Hemp concrete research gaps for its use in green building construction.	Hemp concrete has been shown to have lower levels of embodied carbon and energy.	To increase its characteristics, the manufacturing method can be upgraded.

(continued)

Table 47.1 (continued)

Author	Paper year	Principle	Findings	Research gaps
Jothilingam	2019	Measured the effect of mineral additions at various amounts on the strength of Hempcrete.	Hemp fibres combined with lime and meta-kaolin produced better outcomes.	For increased strength, lime might be replaced with cement.
Novakova	2018	Worked on the use of technical Hemp for construction purpose.	It is a construction material having both environment friendly and has great properties.	The use of admixtures can boost the strength.
Jami	2018	Examined the uses and characteristics of Hemp and Hemp concrete.	The traditional material acquired a futuristic status.	Further research on creep and elasticity can be done.
Kremensas	2017	Investigated the mechanical and physical characteristics of efficient thermal insulation materials made of Hemp fibre.	In comparison to Hemp shives and starch binder, Hemp fibre and PLA binder provides better thermal insulation.	Compressive stress may be insignificant and to be determined.
Piot	2017	Studied the effects of coating on Hempcrete wall opened to climate.	Humidity on wall can occur due to poor coating.	By decreasing Hemp density, humidity can be dropped.
Manohari	2016	Worked on the mechanical strength of Hemp shiv and fiber by adding cement binder.	Water content influenced density; therefore, strength was higher with lower density.	Adding admixtures can improve compressive strength.
Jami	2016	Studied properties, drawbacks and advantages of Hemp concrete in construction.	More research on LHC is needed to build up mix design and increase compressive and flexural strength.	Hemp concrete's self-load bearing ability may be investigated.
Mikulica	2015	Utilized Hemp boon as heat-insulating and load-bearing filler material in wooden buildings.	It accelerated the construction process.	Mineralization can be used to prepare Hemp boon.
Walker	2014	Compared Hemp-lime concretes to hydraulic lime and cement.	The use of a water retainer and a lime–pozzolan binder has improved the early strength and resistance to thaw.	To achieve early compressive strength, admixtures can be added to cement.

(continued)

Table 47.1 (continued)

Author	Paper year	Principle	Findings	Research gaps
Sinka	2014	Studied the effect of pre-compressed Hemp-lime mixture before it getting cured.	Compressive and flexural strength was directly affected by compaction.	More binder can be used to obtain a higher density.

the load-bearing framework of timber structures. It was found that the most significant benefit was the construction speed, as Hemp concrete hardens quickly. Walker et al. (2014) investigated the consequence of binder type on durability and mechanical strength (freeze-thaw resistance, biodiesel and salt exposure). It has been discovered that concrete with lime-pozzolanic binders is more vulnerable to freezing and thawing than with multiple hydraulic binders. Sinka et al. (2014) worked on the effect of a pre-compressed Hemp-lime mixture before it cured. The result showed that both compression and flexural strength are both directly affected by compaction, thermal conductivity was also negatively affected by increased density.

47.3 Research Gaps

Various studies on the usage of Hempcrete in building have been conducted in recent years. Table 47.1 shows the study that has been done on Hempcrete and its applications in building, as well as the research gaps.

47.4 Discussion

We live in an era where we are attempting to minimise carbon dioxide emissions, which includes the manufacture of building insulation. Hemp can eliminate carbon from the atmosphere and as a building material, it requires no labour to develop, as well as no irrigation or fertilisers (Nguyen et al. 2010). To minimise CO_2 emissions, new forms of construction materials are emerging that combine natural fibres (biomass) with zero or low emission pozzolans (Walker and Pavia 2011).

Lime Hemp Concrete (LHC) and Cement Lime Concrete (CLC) is a construction material and is a carbon-free and environmentally friendly construction material (Mukherjee and MacDougall 2013). In recent years, the use of hemp fibre as a strengthening agent in composite materials has increased in response to the growing need for recyclable, biodegradable and sustainable materials. Extensive study has shown that it has excellent acoustic and thermal insulation characteristics, as well as the ability to manage humidity in the built environment. It is having good property of Self-curing as it requires very less amount of water for curing (Collet et al. 2008).

Because of its low modulus of elasticity and compressive strength, it cannot be utilised as a load bearing material, but it may be used as a filler (Awwad et al. 2012). Hempcrete is utilised across Europe and other nations, with the exception of India (Nguyen et al. 2009). Based on past study on Hempcrete, it has been determined that Hempcrete may be used as a building material in the construction sector. In India, Hemp production and usage are prohibited, although certain states have lately allowed commercial growing of Hemp crops, which are a rich source of high-quality fibre and a variety of medical and nutritional goods (Hautala et al. 2004; Khan et al. 2010; Benfratello et al. 2013).

47.5 Conclusion and Future Scope

Hemp may be used as a construction material in concrete for wall partitioning. Also, the possibility of utilising cement instead of lime, which may produce greater outcomes than lime, may be investigated. The physical and mechanical characteristics of Hempcrete, as well as its hygrothermal behaviour, must be determined in order for it to be used more effectively in India. Because the characteristics of Hemp found in India may vary, several tests on different types of Hemp must be conducted in order to make it usable in the building industry.

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Chapter 48
Research Progress of India in Waste Management at Global Level: A Bibliometric Evaluation

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Abstract Rapid urbanization and increase in population with changing lifestyle and consumption pattern have led to generation of huge amounts of solid waste. The management of municipal solid waste is very important to cope up with the human health and environmental impacts of its disposal. This paper presents the bibliometric analysis of research publications of India with a global scenario in waste management and disposal during 1996–2020. The SCOPUS linked with electronic database SCImago is used to extract publication related data. To compare the progresses made globally and in India particularly, different bibliometric indicators such as total research publications, citable documents, and number of citations per document have been computed and evaluated. Out of the total publications (n = 367895) produced worldwide in waste management during 1996–2020, the contribution of India was 4.35% with n = 15999 documents & follows exponential trend. Further, this rising trend in research publications will help us to ensure the environmental sustainability along with achieving some of the sustainable development goals by 2030.

Keywords Municipal solid waste management · Bibliometric assessment · Per capita waste generation · Total publication · Number of citations

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48.1 Introduction

Across the globe, management of waste materials have become one of the great challenges for the human society. Rapid urban sprawl, huge population, along with heavy industrialization are the major factors which are responsible for it (Srivastav and Kumar 2020). Solid waste generation is directly related with the human life style and it cannot be avoided (Paul et al. 2019). Apart from Brazil and USA, in Asian region China, India and Japan are the countries in which huge amounts of solid wastes are being generated (Pujara et al. 2019). Therefore, waste management has become a prime need of human societies in order to protect their health and environment because these wastes can promote several environmental problems such as water & soil contamination, communicable diseases etc. (Ahsan et al. 2014; Babaei et al. 2015). To ensure the effective management of solid wastes, research is very important as it can help in the development of cost-effective methods for the same along with generating energy from them (Sołowski et al. 2020). Hence, authors have evaluated the status of research progresses in India vs world through bibliometric study in the field of waste management & disposal. Moreover, scientific growth of nation can be judged by bibliometric studies as it includes quantities of the research papers published annually (Sweileh et al. 2018; Srivastav et al. 2019; Dutt 2020). Growth of a particular subject is also possible through such types of studies (Li et al. 2011) and further help the policy makers to draft the relevant policy documents (Wambu and Ho 2016). Therefore, in the present study we have made efforts to compare the research contribution of India against the world in the field waste management & disposal discipline through bibliometric assessment on the basis of statistics available on SCImago electronic database.

48.2 Methodology

During this study, research publication data was collected from the freely available portal of SCImago (https://www.scimagojr.com) during August, 2021 (SCImago 2021). This database has wide collections of the various subjects (and sub-subjects too) at world level, continent level, country level etc. Moreover, it can provide us data journal wise too. For waste management, we have selected Environmental Science as main subject and then waste manage & disposal as a sub-field out of total twelve sub-fields available. Published data was downloaded year wise for India and world against important bibliometric indicators such as documents, their citations, citations per document etc. For the purpose, total research documents published by the India & their citations were computed along with same for rest of the world from the years 1996–2020. Hence, it is expected that the present study span over the period of 25 years will facilitate the Indian policy makers for the designing of new policies to promote research and development in the study area.

48.3 Results and Discussion

In this section, a bibliometric analysis on the research potential of India against the global arena in waste management and disposal is performed and the results are presented. The management of solid waste is becoming crucial with the large growing population, rapid commercialization, urbanization, rural to urban migration, changing eating habits and modern living standards. Across the globe, the research community is working towards the aim of proper management of waste so as to extract maximum energy from waste. The research inclination of India in waste management & disposal is compared with the global waste management research through a bibliometric study. The bibliometric indicators evaluated in this study includes total publications, total citations, external citations, self-citations, external citation per document and self-citation per document.

Figure 48.1 shows the total research publications produced globally in waste management & disposal during 1996–2020 against that of India. The research growth in waste management at global level and in India particularly, has been exponential over the years which are clearly visible from the Fig. 48.1. The solid area (in Fig. 48.1) represents the total research documentations produced globally while the line represents the Indian counterpart. During the span of last 25 years, total 367895 documents were published at the global level, whereas, India contributed only 15999 (4.35%) documents. On an average, the number of research

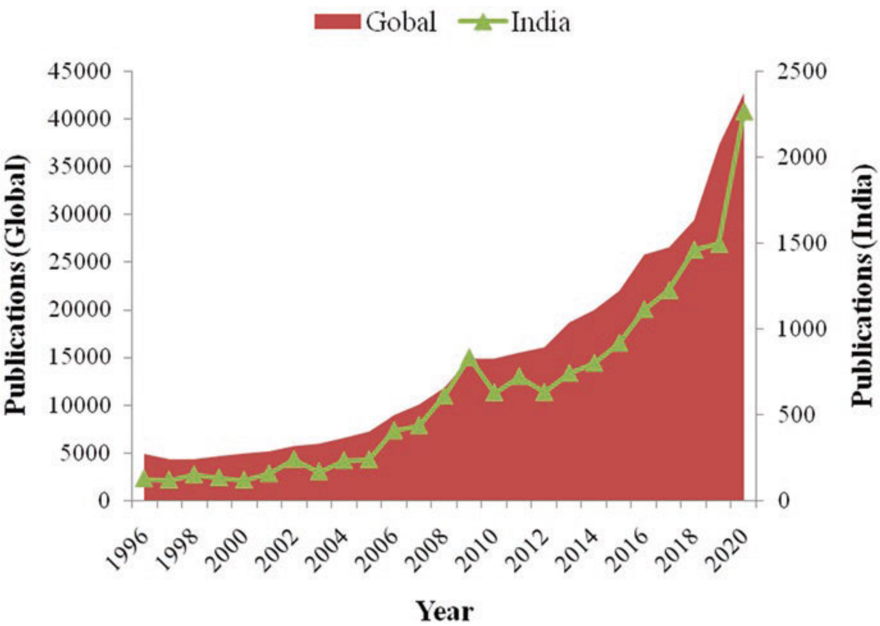

Fig. 48.1 Total publications, globally and in India in the field of waste management & disposal during 1996–2020

publications increase by 14716 documents globally and by 640 documents in India annually. This is owing to the large population size globally against India. Also, the rising research trend towards managing waste and extracting resources from waste aims at promoting the sustainable development goals for the future generations to come (Zhu et al. 2021).

The total citations of a research document is another bibliometric indicator that determines its research potential and impact on the research community. The number of citations of any research document is dependent on number of factors which include the quality of research findings, interest in the research topic, journal type and its popularity, access to journal is open or not etc. (Bernius 2010). The external citations of research document is an effective tool used for evaluating the impact of one's findings on others, while self-citations is a measure to promote one's own research (Costas et al. 2010). The total citations of the published research documents in waste management & disposal during 1996–2020 worldwide are plotted in Fig. 48.2 along with the total citations of research documents produced in India during the same time span. The global external citations and the self-citations are shown with solid area while the external and self-citations of the documents published in India are shown with line graph. In case of external citations, global citation magnitude monotonically increases up to year 2009 and thereafter decreases till 2019 and further rise in the year 2020. India follows the similar pattern with slight fluctuations and contributes only 4.8% to total global external citation output. On

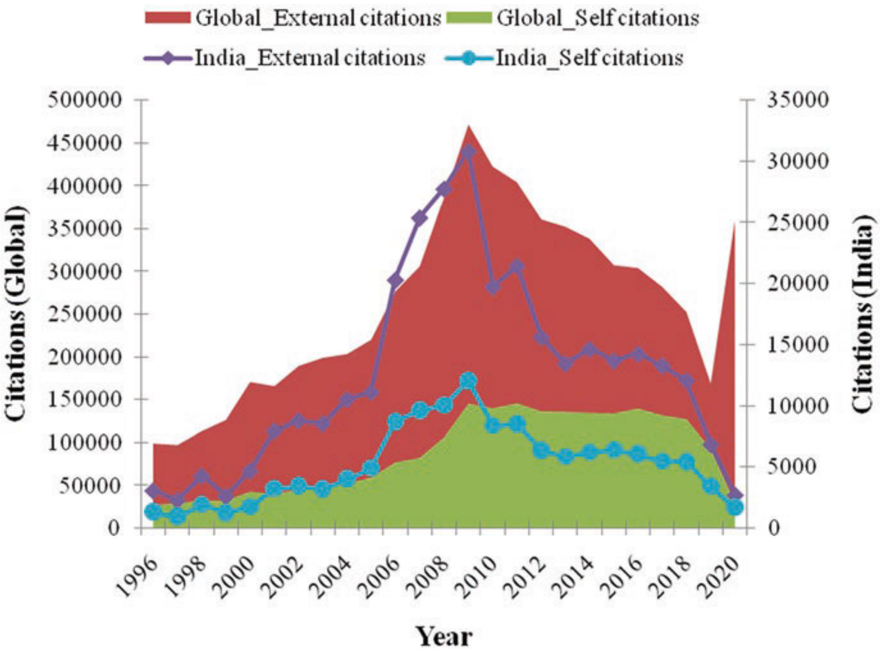

Fig. 48.2 Citations (external/self) of published documents in waste management & disposal globally and in India particularly, during 1996–2020

the other hands, the self-citations of documents published worldwide and particularly in India follow more or less similar variation with maximum magnitude in the year 2009. In 2009, the total self-citations of the published documents in India stands at 12076 against 145880 total self-citations of the research articles published globally. The more number of external citations than self-citations at global level and in India particularly, suggests the rising trend towards promotion of a researcher's findings by the research community rather than using it as a tool for publicizing one's research (Szomszor et al. 2020; Sugimoto and Larivière 2018).

The citation count per document of the published documents in waste management & disposal during 1996 to 2020 is shown in Fig. 48.3 in terms of the performance indicators, namely external citations per document and self-citations per document. In this figure, external and self-citations per document are plotted year wise for research publications produced worldwide against the publications produced in India. It depicts that external citation magnitude per document at global level fluctuates till year 2008. From 2009 onwards, steep downfall is observed till 2019 and increases thereafter. In case of India, external citation per document magnitude fluctuates till year 2007 with maximum value (58.0) and thereafter decreases and reaches a minimum in year 2020 (1.2). On the other hand, the self-citations per document in India is relatively more than the corresponding global value which is attributed to the research trend in which a researcher back his own findings in order to strengthen his research. This changing dynamics in the citation count per document over the years is known as citations dynamics (Mori and Nakayama 2013).

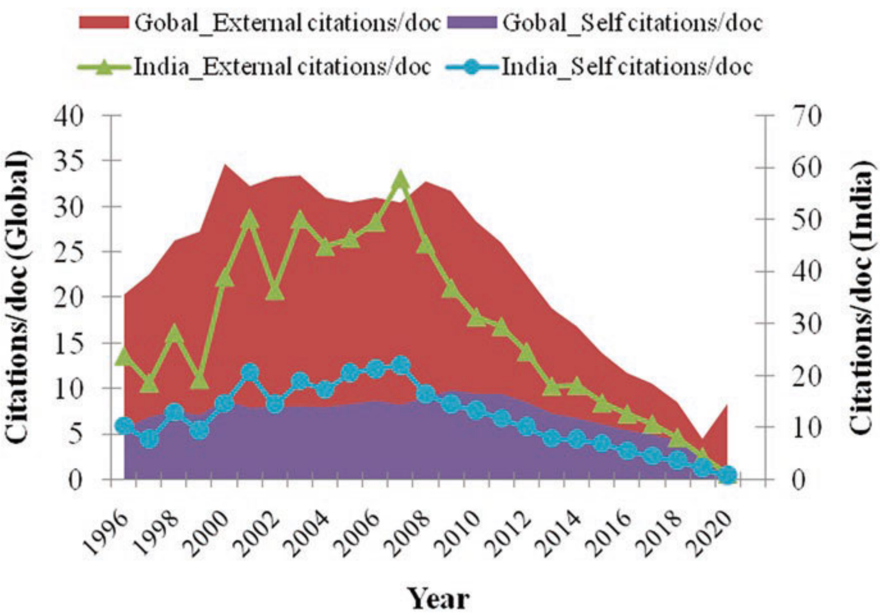

Fig. 48.3 Citations (external/self) per document at global level along with India's contribution in the field waste management & disposal during 1996–2020

48.4 Conclusion

In the present bibliometric study, India's contribution in the field waste management & disposal at global level is studied using important bibliometric indicators namely, documents published, their external/self citations and external/self citations per document over the span of last 25 years. Globally, 367895 research documents were published & followed exponential trend similar to India but with quite less output of 15999 (4.35%). Rank wise India occupied 3rd position in document publications whereas USA and China are respectively as first and second position. In citations again only 4.8% contribution of India was observed at global level. In case of citations per document, the magnitude observed in the year 2020 (1.2) is quite alarming. Therefore, consistent efforts are required at the national level to promote quality research in the field of waste management & disposal through more sophisticated techniques available globally.

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Chapter 49
Performance Evaluation of Acrylic Based Coating on Carbonation Depth on Different Grades of Concrete

Abhishek Thakur, Sanjay K. Sharma, and Amit Goyal

Abstract The world is currently focusing largely on overall sustainable development. In order to achieve this goal, each country knows that environment friendly infrastructure development is quite quintessential. The reinforced concrete structures are deteriorating with the passage of time. The deterioration of concrete is due to moisture or high humidity, growth of biological or organic agents and chemical ingression through the pores of the concrete, via diffusion's process, which initiates the corrosion process and hence corrodes the steel reinforcement. The present research work aims at protecting the concrete from the ingression of carbonation and water to increase the serviceability of reinforced concrete structures. The M25, M35, M50 and M60 concrete cubes were cast in laboratory and then curing for 28 days was done. Permeability and accelerated carbonation test were carried out on concrete specimens without coating and with 100% aliphatic acrylic anti- carbonation coating. The samples were kept in carbonation chamber for 84 days to investigate the depth of carbonation and the water permeability test was conducted for 72 h to analyze the ingression of water in the concrete cubes. The test results showed decrease in CO_2 and water ingression in concrete with increase in the compressive strength of concrete. The 100% aliphatic acrylic anti- carbonation coating (JAYGARUD) is giving 95% protection against ingression of CO_2 and 86% against water ingression as compared to reference concrete cubes samples.

Keywords JAYGARUD coating · Carbonation · Concrete · Deterioration · Ingression · Corrosion process

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49.1 Introduction

With time, concrete structure gets deteriorated and this process expedite under extreme environmental conditions such as increase in CO_2 percentage in the atmosphere and high humidity. Ingression of moisture and some deleterious substances like CO_2 and other chemicalsoccur through the pores of concrete by the process called diffusion and it starts the corrosion of reinforcement eventually damaging the reinforced concrete structures. Preservation of reinforced structures by a suitable protective coating is a capable method for increasing the durability in extreme environments. The degradation of reinforced concrete structures becomes quicker due to corrosion of steel reinforcement in the absence of protective coating. Construction of infrastructure for example flyovers, bridges, underpass and parking garage are inclined to ingression of CO_2. In extreme environmental conditions, concrete with chemical admixtures and less water cement ratio alone cannot protect the steel from corrosion. Therefore, supplementary protection measures for instance protective coating, corrosion inhibitors of calcium nitrate for new constructions and corrosion inhibitors for old constructions, also corrosion resistant steel or anti-corrosive painting of steel is vital for increasing the structure longevity. The most recent technology of cathodic protection is popular for supplementary protection in constructions like flyovers and bridges.

49.1.1 Carbonation

Carbonation is an indigenous process in which calcium hydroxide $Ca(OH)_2$ in the hydrated Portland cement reacts with the carbon dioxide (CO_2) when exposed to the moisture to produce as depicted in the following chemical reaction equations below:

Dissolution of CO_2 in the pore solution of cement paste:

$$CO_2 + 2\,OH = CO_3^{\;2-} + H_2O$$

Dissolution of Ca $(OH)_2$

$$Ca\left(OH\right)_2 = Ca^{2+} + 2\,OH^-$$

Decomposition of hydrated silicate and aluminate phases, viz:

$$X\,CaO.SiO_2\left(aq\right) + z\,H_2O = y\,Ca^{2+} + 2y\,OH^- + \left(x-y\right)CaO.SiO_2\left(aq\right)$$

Reaction to form carbonate:

$$Ca^{2+} + CO_3^{\;2-} = Ca\,CO_3$$

With the breakdown of inactivation layer around steel due to carbonation, moisture increases and it starts acting as low-resistance electrolyte to provide adequate oxygen for the cathodic corrosion reaction. It's worth noting that the rate of carbonation is more affected by the depth of concrete cover, permeability, concrete strength, relative humidity and exposure condition. Therefore, in order to prevent the carbonation exterior coatings like acrylic based, bituminous based, epoxy and polyurethane based may be used.

49.2 Experimental Details

49.2.1 Cement

Ordinary Portland Cement (OPC) by Ultratech (IS: 269-2015) was used in present study.

The physical characteristics of the OPC are below in Table 49.1.

49.2.2 Water

Water used in this study, was taken from the domestic water supply Chandigarh. Prior to mixing, the water samples were tested for dissolved oxygen, limits of alkalinity, parameters of pH, total dissolved solids (TDS), percentage of solids, chlorides, organic solids, suspended matter, sulphates and inorganic solids.

Table 49.1 OPC physical characteristics

Test parameters	Units	Results
Fineness	m^2/kg	265
Nominal consistency	%	28.9
Soundness	mm	0.6
Setting time		
Initial Final	Minutes	130 225
Compressive strength–		
After 72 h	Mpa	29.10
After 168 h	Mpa	39.40
After 672 h	Mpa	57.20

49.2.3 Fine Aggregate (FA)

Fine aggregates were brought from Yamunanagar having silt content 2.8%, specific gravity 2.63 used and fine modulus was 2.85 to confirm with IS 383: 2016 Zone II Table 49.2.

49.2.4 Coarse Aggregate (CA)

Coarse aggregate available locally were used in this study and its different physical properties were tested including gravity and grading as per IS 383:2016. The grading of course aggregate was used in the ratio 1:1.2 to form of 20 mm well graded aggregate size with specific gravity of 2.65. Sieve analysis results in 20 mm and 10 mm aggregate is shown in Table 49.3.

49.2.5 Chemical Admixture

MasterGlenium SKY 8632 has been used as plasticizer in the present study. It helps in water reduction without compromising the workability and compressive strength.

49.3 Mix Design

In this experimental study, proportion for concrete mix design of M25, M40, M50 and M60 has been carried out according to IS 10262: 2019 recommendations. The mix proportion are presented in Table 49.4.

Table 49.2 Sieve analysis for fine aggregate

Sieve size	10 mm	4.75 mm	2.36 mm	1.18 mm	600 mic.	300 mic	150 mic
Passing %	0	92.46	81.65	66.86	45.76	23.21	5.08

Table 49.3 Sieve analysis for coarse aggregate

20 mm nominal size				
Sieve size	40 mm	20 mm	10 mm	4.75 mm
Passing %	100	99.15	4.64	0.84
10 mm nominal size				
Sieve size	12.5 mm	10 mm	4.75 mm	2.36 mm
Passing %	99.12	88.67	7.45	1.35

Table 49.4 Proportion of concrete mixes and ratio

Concreate mix.	Cement (Kg/m^3)	Water (Kg/m^3)	Sand (Kg/m^3)	Coarse aggregate (Kg/m^3) (20 mm)	Coarse aggregate (Kg/m^3) (10 mm)	Superplasticizer (litters/m^3)	Mineral admixture (Kg)
M-60	470	140	730	610	497	3.5	30
M-50	442	135	741	619	504	4.5	–
M-40	412	160	642	736	492	4.12	–
M-25	340	175	747	732	488	2.7	–

Slump test and compaction factor test with the prescribed water/cement ratio can all be used to determine the workability of fresh concrete. The cubes were casted on the standard specimen of size 15 cm × 15 cm × 15 cm. After 24 h, the cube specimens are demolded.

49.4 Acrylic Based Coating

In this study, JAYGAURD has been used as a coating material. It is recently developed by Jayanti Lal Chemicals Panchkula with 100% aliphatic acrylic anti- carbonation coating. It is widely used to provide protection to the concrete surfaces against carbonation and other environmental attacks, it also provides durable and long-lasting finishing to concrete surface.

49.4.1 Method of Application

For the application of anti-carbonation coating,

- The surface should be smooth, dry and clean.
- Primer needs to be applied by the brush in order to turn out the better bonding and surface finishing.
- Coating must be done 4 h prior to the final coat on concrete surface.
- Where the final coat be applied once after primer or pre coat and the temperature should be more than 20 °C.

49.5 Results & Discussion

49.5.1 Compressive Strength Test

Test is performed on Compressive Testing Machine as per IS 14858:2000 under the applied gradually load of 140 kg/cm^2 per minute till the sample specimen do not fail. The compressive strength can be calculated by load where specimen get fails divided by area of specimen (Table 49.5).

49.5.2 Water Permeability Test

Permeability defined as the property governs the rate of flow of water into a porous solid and it is important when dealing with durability of concrete. The test was conducted as per IS 516 (Part 2/Sec 1): 2018. Water ingression were measured for both before coating concrete samples and after coating concrete samples at 7, 14, 28, 56 and 84 days respectively as shown in Tables 49.6 and 49.7.

From above Fig. 49.1 and Table 49.6, it can be seen that the higher grade of uncoated concrete samples subject to less water ingression as compared to the lower grade of concrete samples. Also, the permeability decreases with the increase in time period.

The Table 49.7 and Fig. 49.2 shows that coated concrete samples follow same trend as before coating concrete samples with respect to grade concrete and time period i.e. the water ingression decreases with the increase in the grade of concrete and time period. However, when compared as shown in Fig. 49.2 below it can clearly be observed that the water ingression for coated concrete samples is less as compared to before coating concrete samples for each grade of concrete tested at 7, 14, 28, 56 and 84 days (Fig. 49.3).

Significant changes in the value of permeability can be seen in the graphs shown above notable drop down in the permeability can be observed after the application of 100% aliphatic acrylic anti- carbonation coating.

Table 49.5 The results of compressive strength for M-25, M-40. M-50 and M-60

Concreate grade	Compressive strength (MPa) 7 days	Compressive strength (MPa) 28 days
M-60	51.80	72.40
M-50	42.65	61.95
M-40	35.70	50.70
M-25	22.25	33.80

Table 49.6 Results of Ingress of water before coating for M-25, M-40. M-50 and M-60

Permeability	7 days	14 days	28 days	56 days	84 days
M-25	8.91	7.96	7.23	6.25	5.15
M-40	6.75	6.02	5.45	4.98	4.25
M-50	4.58	3.99	3.45	3.15	2.94
M-60	3.62	3.02	2.65	2.08	1.75

Table 49.7 Results of Ingress of water after coating for M-25, M-40. M-50 and M-60

Permeability	7 days	14 days	28 days	56 days	84 days
M-25	1.43	1.11	1.01	1	0.77
M-40	1.08	0.84	0.76	0.80	0.64
M-50	0.73	0.56	0.48	0.50	0.44
M-60	0.58	0.42	0.37	0.33	0.26

49.5.3 Carbonation Test

The chamber was used having 5% CO_2 concentration and 27 °C temperature and relative humidity 75%. Samples specimens were taken out after designed time and checked for ingression of CO_2 with the help of phenolphthalein based rainbow indicatoras shown in Table 49.8.

From above Fig. 49.4 and Table 49.9, it can be seen that as grade of concrete is increasing, depth of carbonation is decreasing and with the passage of time carbonation is increasing.

From above Fig. 49.5 and Table 49.9, it can be seen that as after coating there is negligible amount of carbonation depth (Fig. 49.6).

As we can see that clearly in graph representation, Depth of Carbonation is increased with the duration of time and decrease with the increasing order of concrete grade. Whereas, after coating it shows same depth of carbonation with respect to time.

49.6 Conclusions

100% aliphatic acrylic anti- carbonation coating provides an excellent barrier to penetration & attack of moisture along with CO_2.

An aliphatic acrylic based coating increases the impermeability with the concrete surface and reduces the pores in concrete that increases serviceability and durability even in the case of extreme environmental conditions.

The study result shows, the 100% aliphatic acrylic anti- carbonation coating provides protection upto 95% of ingression on CO_2 and upto 86% in water permeability as compared to reference concrete samples.

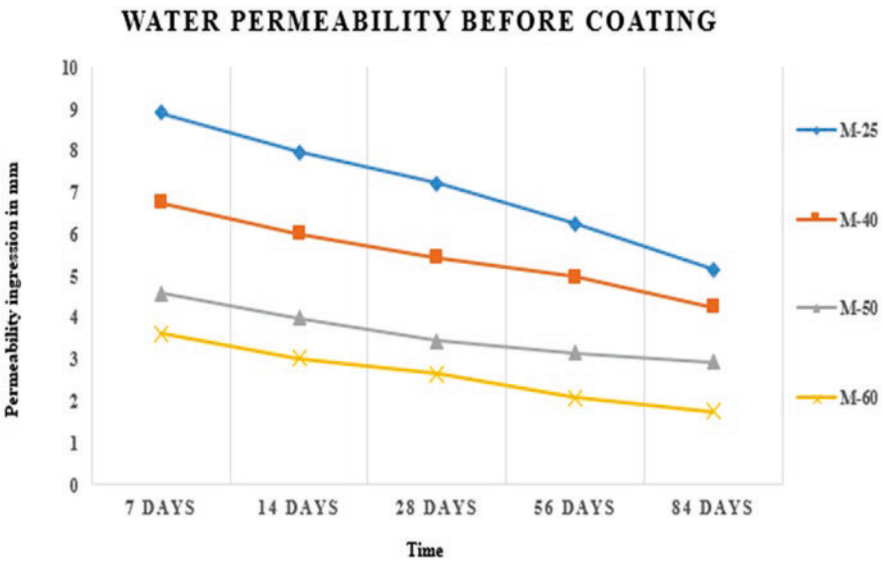

Fig. 49.1 Graphical representation of results of Ingress of water before coating for M-25, M-40. M-50 and M-60

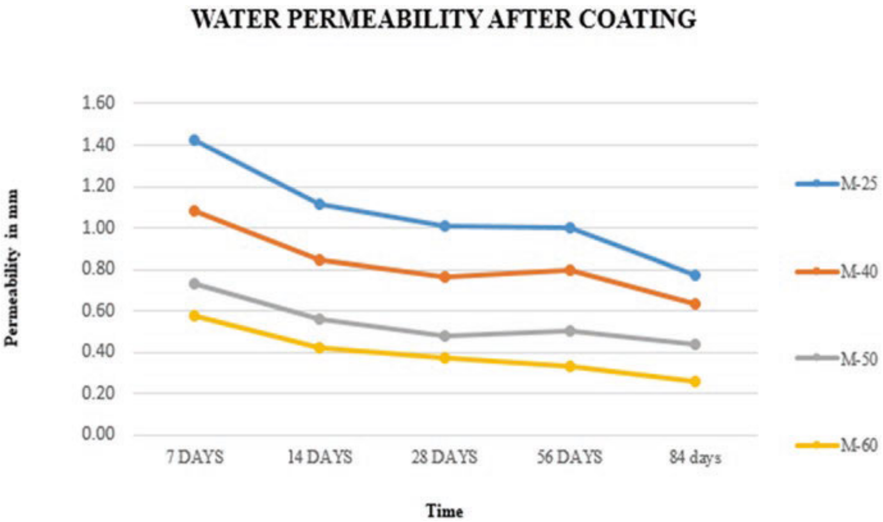

Fig. 49.2 Graphical representation of results of Ingress of water after coating for M-25, M-40. M-50 and M-60

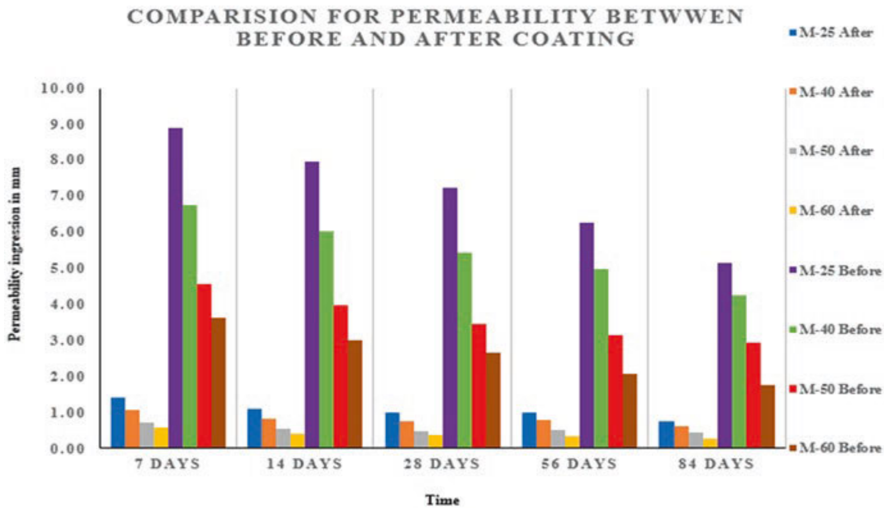

Fig. 49.3 Graphical representation of results of Ingress of water before-after coating for M-25, M-40. M-50 and M-60

Table 49.8 Results of Accelerated Carbonation depth before coating for M-25, M-40, M-50 and M-60

Carbonation depth	7 days (mm)	14 days (mm)	28 days (mm)	56 days (mm)	84 days (mm)
M-25	6.12	10.05	12.05	14.56	16.55
M-40	4.55	8.23	10.65	12.40	13.95
M-50	3.80	6.84	8.95	10.42	11.50
M-60	2.80	4.52	5.85	7.82	10.45

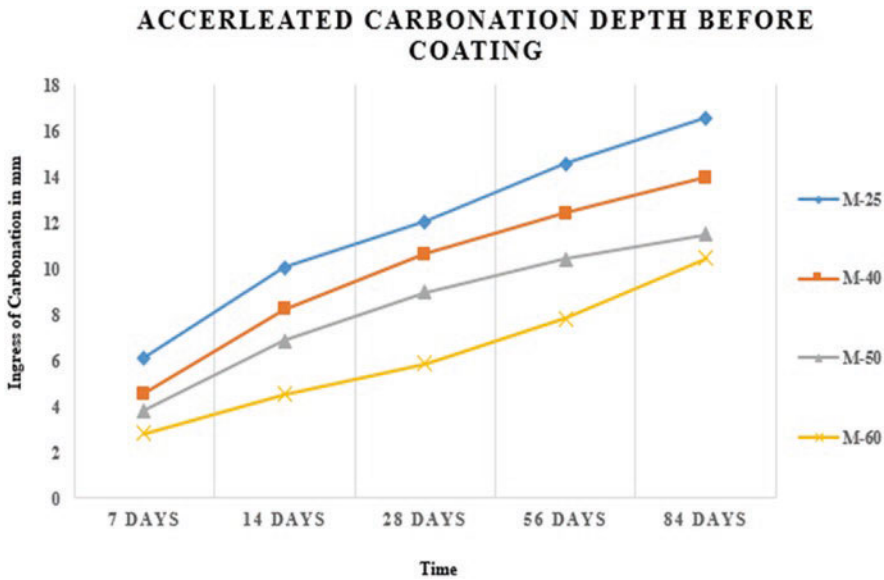

Fig. 49.4 Graphical representation of results of Accelerated Carbonation depth before coating for M-25, M-40, M-50 and M-60

Table 49.9 Results of Accelerated Carbonation depth after coating for M-25, M-40. M-50 and M-60

Carbonation depth	7 days	14 days	28 days	56 days	84 days
M-25	0.6	0.10	0.12	0.03	0.05
M-40	0.5	0.08	0.11	0.02	0.04
M-50	0.4	0.07	0.09	0.02	0.03
M-60	0.3	0.05	0.06	0.02	0.03

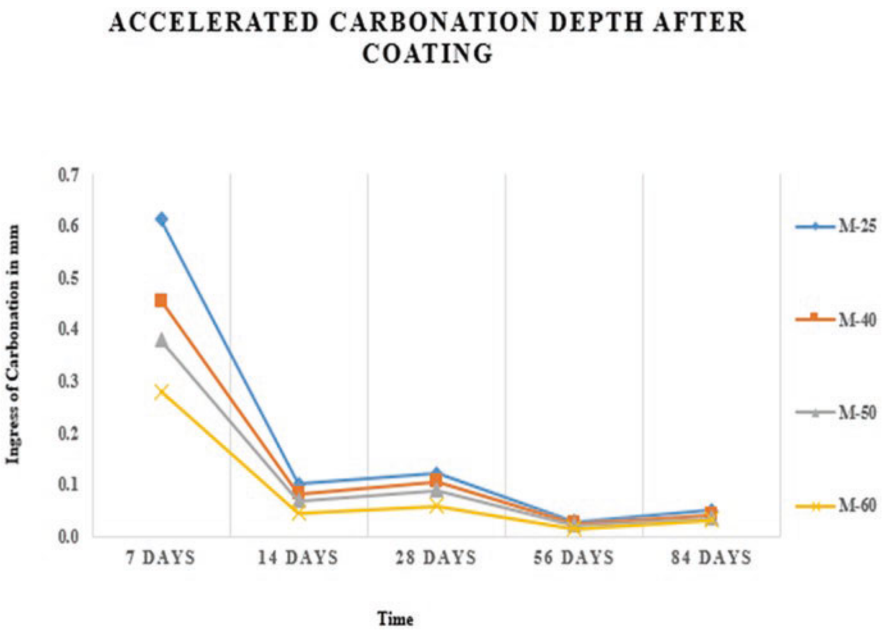

Fig. 49.5 Graphical representation of results of Accelerated Carbonation depth after coating for M-25, M-40. M-50 and M-60

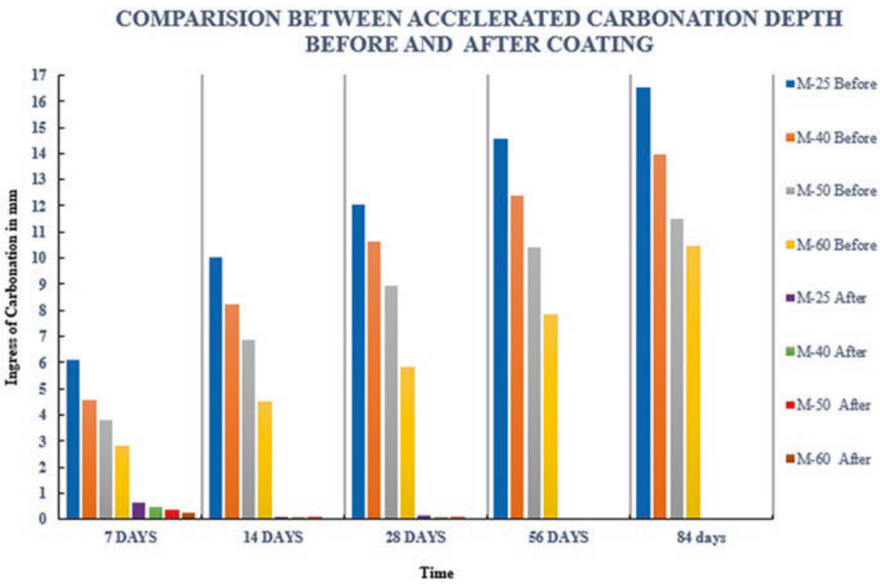

Fig. 49.6 Graphical representation of results of Accelerated Carbonation depth before-after coating for M-25, M-40. M-50 and M-60

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Chapter 50
Cost Benefit Analysis of Retrofitting for Existing Building as Net Zero Energy Building: A Case Study in Composite Climate Zone

Aditya Punia, Sanjay K. Sharma, and Poonam Syal

Abstract In response to the sustainable development goals and climate change, this paper presents a case study of an existing institutional building located in composite climate zone at Chandigarh, India, for retrofitting it as a Net Zero Energy Building (NZEB). Its cost benefit analysis and payback period has been carried out. This analysis determines whether the benefits outweigh the cost of implementation of NZEB. The before and after energy demands of the building has been simulated on eQUEST and validated with actual energy bills. The results of energy simulation has been used to arrive at the potential energy savings. A 250 kWp onsite grid interactive solar PV system on rooftops of existing buildings is recommended to meet the energy demand of the building, after implementation of retrofitting measures. Simulation results indicated that annual reduction in energy demand by retrofitting of building envelope components is 28.82 MWh, by retrofitting electrical appliances is 191.87 MWh, and by retrofitting Heating Ventilation and Air Conditioning is 90.46 MWh. An encouraging reduction of 53.6% in annual energy demand by deploying various energy efficiency measures is projected.

Keywords Energy efficiency measures · Renewable energy · Energy simulation · eQUEST · Net Zero Energy Building · Composite climate zone

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50.1 Introduction

Presently, as a result of the growing urban population and technology-intensive lifestyles, energy demand has increased in recent decades. Rapid economic development, urbanization, and population increase have put a strain on conventional energy supply resources. Buildings utilize approximately a third of the country's total annual electrical energy consumption and are one of the major contributors to Green House Gas emissions, second only to the industrial sector. Higher energy costs, increased risks of global climate change, and adverse environmental and health effects occur from increased usage of fossil fuels. Moreover with growing energy demands, there is a need to utilize alternate energy sources.

Furthermore, from a sustainability perspective, fossil fuels are non-renewable energy resources that will deplete over time (Meier et al. 2013). The United Nations Agenda 2030 for Sustainable Development, adopted in 2015 (United Nations 2021), emphasizes the importance of smart, green, and sustainable cities and utilizing renewable energy sources.

India has pledged to lower the emissions intensity of its national GDP by 33–35% by 2030, compared to 2005 levels (Government of India 2018). The building sector can create a significant impact on any efforts to reduce GHG emissions (United Nations Environment Program 2018). For these goals to be met, the building sector must be transformed to the most advanced standards of building energy efficiency, such as Net Zero Energy Buildings (NZEBs).

At the international level, a 1% improvement in HVAC system energy efficiency adds up to millions of dollars in annual savings (Shoureshi 1993). The guide to good practises in operating Information Communication Technology equipment (Kamilaris et al. 2014) and actionable input from occupants (Kamilaris et al. 2015) both revealed massive energy-saving possibilities of about 130,000 kWh and 311 kWh yearly.

NZEBs use a combination of renewable energy and energy efficiency enhancement to produce as much energy as being consumed over a time period of one year. By onsite energy generation from renewable sources, NZEBs have low operating and maintenance costs, while helping the environment and increased resiliency during power outages (Rupal et al. 2016). However, the initial cost of such NZEBs maybe higher, which will be paid back over course of limited time as energy savings (Singh et al. 2021).

An energy simulation software is a computation engine that accepts inputs such as building geometry, operation schedules, and system parameters and produces outputs such as graphical performance comparisons and compliance reports. Energy modelling is an iterative process in which fundamental design parameters are addressed in initial models and feedback on the performance of building form and orientation and how they will affect the buildings energy efficiency is provided. This energy simulation is useful in energy efficient building design.

Over time, variety of software for energy modelling of building are available, each with its own set of advantages and disadvantages. A software tool's applicability changes depending on the needs and circumstances.

DOE-2 (engine), EnergyPro, Green Building Studio (GBS), eQUEST, Energy Plus (engine), and DesignBuilder, are some of the software tools frequently used for various applications in energy modelling (Punia et al. 2021). DOE-2 is a calculation engine for Building Energy Modelling that has developed by Lawrence Berkeley National Laboratory. It calculates life cycle costs and energy performance of whole building project.

50.2 Methodology

The method used in this study for the calculation of energy savings and payback period is energy simulation and the tool used for it is eQUEST Version 3.65 (Hirsch 2018). In line with the requirements outlined in ECBC, the software is a program based on DOE-2.2 simulation engine and is capable to model 8760 h per year, hourly variations in occupancy, interior loads, HVAC equipment's and controls, defined separately for weekdays, holidays and weekends, multiple thermal zones, part load performance for mechanical equipment, air side economizers, using a representative weather file specific to a location.

A baseline model of the institutional building under consideration, as shown in Fig. 50.1, has been generated using the schematic design wizard of eQUEST. Energy simulation has been performed in the software eQUEST by inputting different parameters in wizards of the software. The simulated energy demand of the baseline model has been compared with the actual energy consumption of the building computed and analysed by energy bills. It has been found that the simulation results are in line with the EPI index of the building. The proposed retrofitting measures has

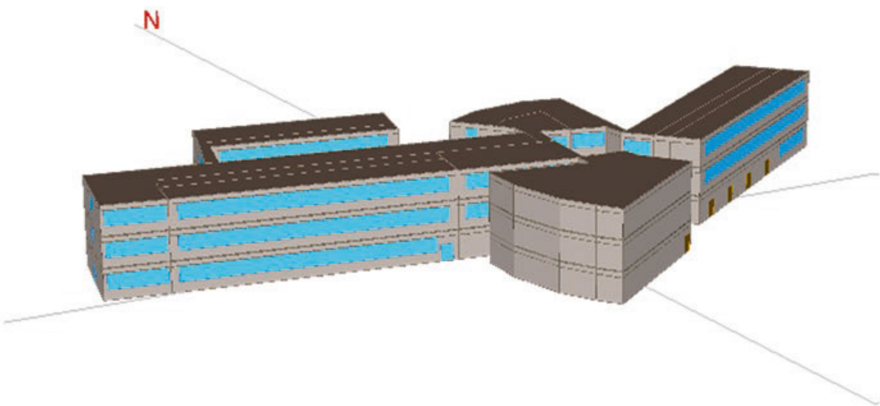


Fig. 50.1 3D baseline model

been applied to the baseline model as Energy Efficiency Measures (EEM) wizards in eQUEST. Various combination of EEM wizard simulations has been run to determine which retrofitting measure is the best for energy savings amongst the available alternatives. The cost benefit analysis has been carried out by considering the investment cost and cost of energy saved by respective retrofitting measures.

50.2.1 Building Details

The study is aimed at National Institute of Technical Teachers Training and Research (NITTTR) Chandigarh, India, located at Latitude 30°44′14″ N, Longitude 76°47′14″ E which is in composite climate zone. In composite climate zone, there are extreme summer and extreme winter conditions. NITTTR is a premier academic institute in Chandigarh, established in 1967 by Ministry of Education, Government of India. NITTTR, Chandigarh undertakes a wide spectrum of activities such as Education and Training Programs, Instructional Material Development, Curriculum Development, Consultancy in Technical Education and Technology areas as well as Research and Development. The buildings of this institute under consideration in this study are Homi Bhabha Academic Block, S.S. Bhatnagar Auditorium, Visvesvarya Lecture Hall Complex and Chandrasekhar Hall. These buildings are considered since heavy load testing equipment and laboratories are present in these building and constitute a large part of the total energy demand of the institute. The combined total area of buildings under consideration i.e., Homi Bhabha Academic Block, Visvesvaraya Lecture Hall Complex, and Chandrashekhar Hall is 7239.86 m^2. Table 50.1 gives the area details of various buildings under consideration.

The floor-to-floor height in the buildings is 12 ft and the floor to ceiling height in the buildings is 10 ft. The building envelope consists of brick walls of 9-inch thickness, with 15 mm thickness plaster on both faces and white paint finish. The U-value (Thermal Transmittance) of wall is 0.32 Btu/h ft2 °F. The RCC slab of 6-inch thickness, overlaid with 3-inch-thick sand filling, a bitumen coating and 4-inch-thick brick tiles is provided in the buildings. National Fenestration Rating Council, NFRC website has been referred for technical details of material used in buildings.

The technical details of glazing used in buildings are Solar Heat Gain Coefficient (SHGC) of value 0.86, Thermal Transmittance (U-value) is 1.07 Btu/h ft2 °F, Visual Light transmittance (VLT) having value of 0.76, and Emissivity (e) of 0.90.

Table 50.1 Area details of buildings

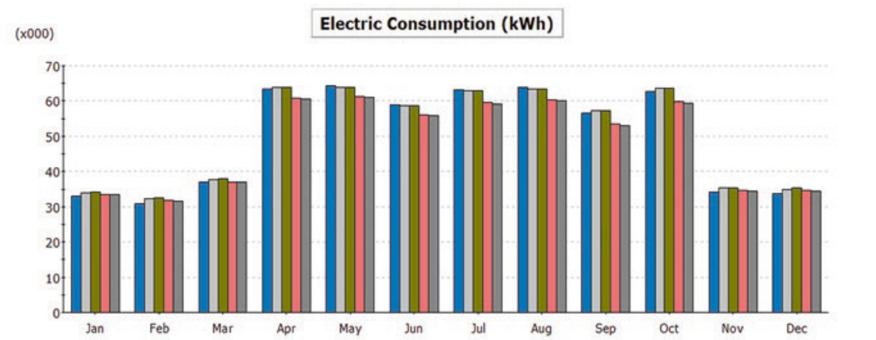
S. No.	Name of buildings	Area (m^2)	Area (ft^2)
1.	Homi Bhabha Academic Block	3971.49	42733.23
2.	Chandrashekhar Hall	2456.24	26430.22
3.	Visvesvaraya Lecture Hall Complex	812.13	8738.51

50.3 Retrofitting and Energy Efficiency Measures Wizards

The various retrofitting provisions for energy efficiency measures (EEM) has been grouped into six major components, namely, building envelope EEM, internal loads EEM, HVAC EEM, water efficiency EEM, efficient transformer EEM and renewable energy EEM. These are discussed as follows.

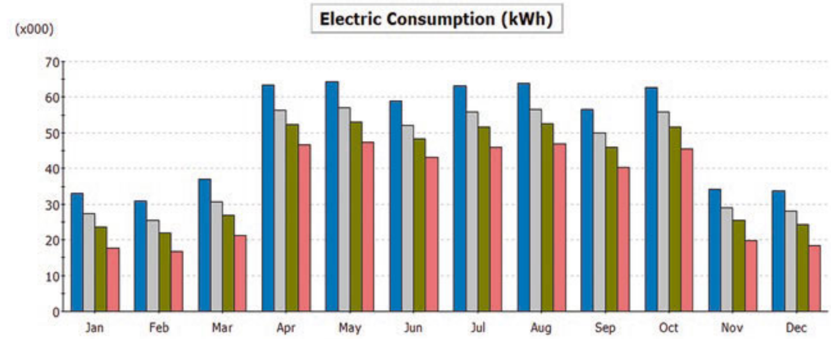
50.3.1 Building Envelope EEM

In building envelope EEM, the retrofitting measures considered are – roof and exterior wall insulations of 3 inches thick insulation of polystyrene, double reflective glass of 6 mm thickness and 12 mm air insulation, for 1845 m^2 combined window area and overhangs on all south and west facing windows. The results of building envelope EEM simulation are shown in Fig. 50.2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	33.04	30.93	36.96	63.46	64.29	58.91	63.20	63.76	56.51	62.70	34.21	33.62	601.58
Run 2.	34.02	32.28	37.83	63.89	63.77	58.78	62.99	63.30	57.19	63.69	35.36	34.96	608.06
Run 3.	34.27	32.48	37.89	63.89	63.91	58.80	63.00	63.33	57.22	63.63	35.46	35.24	609.11
Run 4.	33.47	31.73	37.04	60.78	61.33	56.07	59.61	60.41	53.56	59.95	34.60	34.56	583.12
Run 5.	33.37	31.63	36.94	60.49	61.09	55.81	59.27	60.12	53.13	59.51	34.48	34.45	580.29

Fig. 50.2 Building envelope EEM simulation on baseline model



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	33.04	30.93	36.96	63.46	64.29	58.91	63.20	63.76	56.51	62.70	34.21	33.62	601.58
Run 2.	27.31	25.36	30.69	56.39	57.12	52.10	55.92	56.65	49.92	55.87	28.89	28.02	524.24
Run 3.	23.51	21.91	26.86	52.30	53.06	48.26	51.72	52.50	45.98	51.60	25.35	24.22	477.27
Run 4.	17.63	16.78	21.27	46.67	47.47	43.03	45.98	46.83	40.40	45.47	19.88	18.28	409.71
Run 5.													

1. NITTTR - Baseline Design (02/03/21 @ 19:50)
2. NITTTR - Daylighting EEM (02/03/21 @ 19:50)
3. NITTTR - Equipment Power EEM (02/03/21 @ 19:50)
4. NITTTR - Lighting Power EEM (02/03/21 @ 19:50)

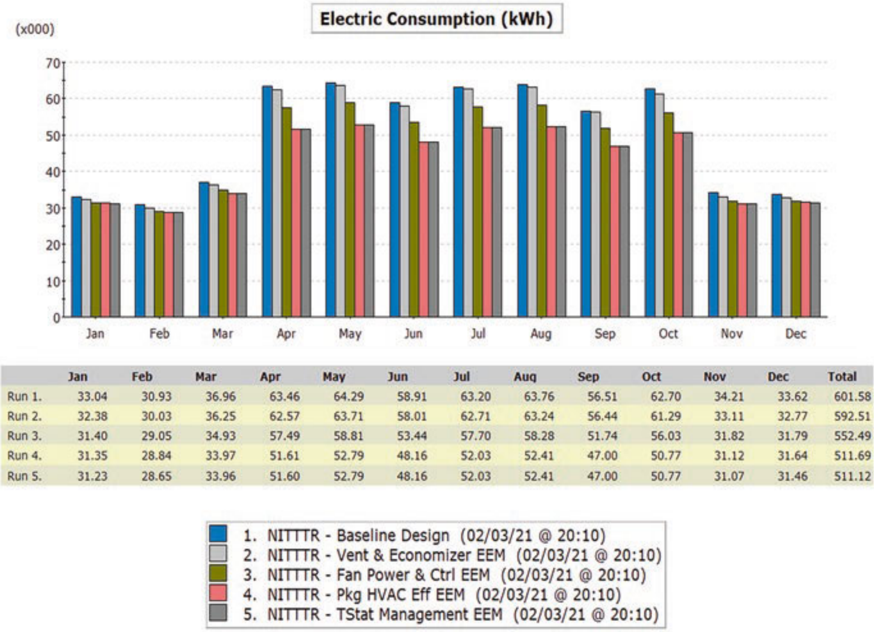
Fig. 50.3 Internal loads EEM simulation on baseline model

50.3.2 Internal Loads EEM

In internal loads EEM, retrofitting measures considered are – installation of 150 number photo sensors, each controlling 30 lights according to the level of natural luminance available, replacement of lighting with energy efficient LED lights, a total number of 262 T-8 lights of 36W each, 146 CFL lights of 14W each and 4235 T-5 lights of 14W each has been suggested to be replaced with energy efficient LED lights while maintaining the lux required as per super ECBC standards, for equipment loads, a total number of 425 conventional fans of 75W each has been suggested to be replaced with 5 star rated brush less direct current (BLDC) technology fans of 28W each, 122 window type and 106 split type single star rated air conditioners has been suggested to be replaced with 5 star rated split inverter technology air conditioners. The result of internal loads EEM simulation is shown in Fig. 50.3.

50.3.3 HVAC EEM

In heating, ventilation and air conditioning (HVAC) EEM, the retrofitting measures considered are - thermostat management, the cooling setpoint for occupied condition i.e., 74 °F and for unoccupied condition i.e., 78 °F have been selected keeping in view the thermal losses involved for an indoor operative temperature of 27 °C,



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	33.04	30.93	36.96	63.46	64.29	58.91	63.20	63.76	56.51	62.70	34.21	33.62	601.58
Run 2.	32.38	30.03	36.25	62.57	63.71	58.01	62.71	63.24	56.44	61.29	33.11	32.77	592.51
Run 3.	31.40	29.05	34.93	57.49	58.81	53.44	57.70	58.28	51.74	56.03	31.82	31.79	552.49
Run 4.	31.35	28.84	33.97	51.61	52.79	48.16	52.03	52.41	47.00	50.77	31.12	31.64	511.69
Run 5.	31.23	28.65	33.96	51.60	52.79	48.16	52.03	52.41	47.00	50.77	31.07	31.46	511.12

Fig. 50.4 HVAC EEM simulation on baseline model

i.e., 80.6 °F for summer months for mixed mode buildings as per ECBC standards,installation of outside air multiplier with multiplication factor of 0.5 and an economizer of dry bulb type temperature with high limit of 80 °F capable of running with compressor has been suggested, replacement of HVAC system with a new Variable Refringent Flow(VRF) technology system with high Energy Efficiency Ratio (EER) of 11.8 has been suggested. Replacement of fan motorswith variable speed motors of 10.6 BHP with premium energy efficiency and installation of 35 number variable frequency drives to control the motors has been recommended. Applying these retrofitting, the results of HVAC EEM simulation are shown in Fig. 50.4.

50.3.4 Water Efficiency EEM

The energy savings by water efficiency has been calculated manually as the same is not supported by eQUEST. A total of 36 numbers of water closet (WC), 72 numbers of taps and 18 urinals has been suggested to be replaced with low flow water efficient fixtures to save 9980 KL of water and 1.35 MWh of energy annually.

50.3.5 Efficient Transformer EEM

The energy savings by efficient transformer has been also calculated manually as the same is not featured on eQUEST. It has been suggested to replace the existing non star rated transformer with a five-star rated transformer with lower losses, resulting in annual energy saving of 10.07 MWh.

50.3.6 Renewable Energy EEM

To meet the energy demand of building after implementation of retrofitting provisions, a grid interactive solar PV renewable energy generation based system of 250 kWp capacity has been recommended over the rooftop of buildings.

50.4 Cost Benefit Analysis

For carrying out cost benefit analysis, salvage value of existing equipment has been deducted from the cost of new equipment and energy cost of Rs. 6 per kWh of energy saved is considered.

- Using daylighting photo sensors to determine the intensity of natural lighting available in the building and operate the lights according to the desired luminance intensity results in substantial annual energy reduction of 77.34 MWh. The investment required for this EEM to be implemented is Rs. 4.5 Lakhs.
- Reduction in lighting power density while retaining the lux as per standards can be achieved by using energy efficient LED lighting fixtures. The annual energy reduction with LED's is 67.56 MWh. The investment required for replacing existing lights with LED lights is Rs. 23.35 Lakhs.
- Reduction in equipment power density can be achieved by using energy efficient and star rated appliances which amounts to annual energy reduction of 46.97 MWh. The investment required for replacement of fans and air conditioners is Rs. 40.25 Lakhs.
- Using energy efficient Heating Ventilation and Air Conditioning system with Variable Refrigerant Flow system with higher Energy Efficiency Ratio, variable speed and energy efficient fans and motors, and proper setting of thermostat temperatures amounts to annual energy reduction of 90.46 MWh. The investment required for retrofitting HVAC components is Rs. 41.22 Lakhs.
- Double reflective glazing is recommended to replace the existing single clear glazing, this has two purposes first to reduce the ventilation load by reducing the solar heat gain and second to reduce the lighting load by providing higher Visual Light Transmittance (VLT). The annual energy reduction with energy efficient

glazing is 25.99 MWh. The investment required for this retrofit along with providing exterior shading for south and west facing windows is Rs. 14 Lakhs.

- Window exterior shading is recommended for south and west facing windows, as the maximum higher summer sun stays in this direction, to avoid heat gain yet still allowing some amount of heat gain because of lower winter sun because of composite climate. This results in annual energy savings of 2.83 MWh.
- Energy savings of 11.43 MWh can be achieved by using water efficient fixtures and 5 star rated energy efficient transformer. The investment required is Rs. 9.37 Lakhs.
- Renewable energy generation to meet the annual energy demand of 280 MWh after retrofitting can be achieved by installing grid interactive solar PV power plant of capacity 250 kWp on rooftop of buildings. The investment required is Rs. 82.5 Lakhs.
- Insulation in composite climate is not effective if applied as a simple add on layer. Changing the structural composition of the roof and wall surfaces will be required in order to get the desired results from insulation. This is neither practical nor recommended for retrofitting of an existing building. However, for new buildings, which are still in planning stage, building envelope insulation can play a major role in deciding the energy consumption of the building and thus, needs to be assessed further.

The total investment of Rs. 2.16 crores is required with net payback period of 5.9 years. The summary of recommended EEM's is presented in Table 50.2.

Table 50.2 Summary of EEM and payback period

S. No.	Energy efficiency measure	Potential annual energy savings (kWh)	Investment required (Rs.)	Payback period (years)
1	Renewable energy generation system	281,250	8,250,000	4.8
2	Daylighting	77,340	450,000	0.9
3	Lighting power	67,560	2,335,000	5.7
4	Equipment power	46,970	4,025,000	14.2
5	Package HVAC efficiency	40,800	3,400,000	13.8
6	Fan & power control	40,020	637,000	2.6
7	Window glass type	25,990	1,400,000	8.1
8	Window exterior shading	2830		
9	Energy efficient transformer	10,074	615,000	9.1
10	Ventilation and economizer	9070	85,000	1.5
11	Water conservation	1358	322,000	2.5
12	Thermostat management	570	Nil	–
	Total	**603,832**	**21,619,000**	**5.9**

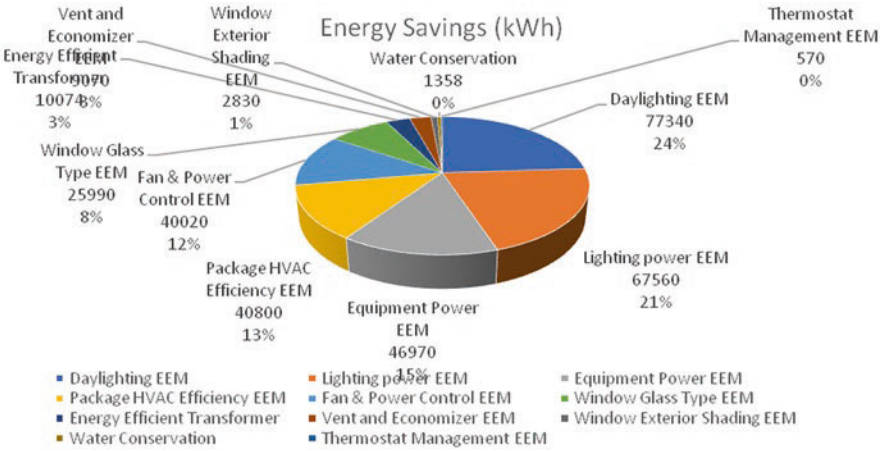


Fig. 50.5 Percentage reduction in energy consumption from EEMs

The percentage contribution of various EEMs in energy reduction along with the amount of energy units reduced in kWh is shown in Fig. 50.5.

Considering the lifetime of the retrofitting measures adopted to be 20 years, after completion of net payback period of 5.9 years, energy savings amounting to Rs. 5.1 crores is estimated for the remaining life of the suggested retrofitting.

50.5 Conclusion

A study has been conducted to carry out the cost benefit analysis of retrofitting of an existing institutional building i.e., National Institute of Technical Teachers Training and Research, Chandigarh, India, as a NZEB. The buildings of the institute under consideration are Homi Bhabha Academic Block, Visvesvaraya Lecture Hall Complex, S.S Bhatnagar Auditorium and Chandrashekhar Hall. The location of institute comes under the composite climate zone. From the simulation-based study, it has been concluded that existing institutional buildings can be successfully retrofitted as NZEB. Total investment of Rs. 2.16 crores is required with net payback period of 5.9 years for the buildings under consideration to be retrofitted as NZEB. Converting existing buildings as NZEB is necessary to achieve the sustainable development targets. Such buildings will consume less energy and power generated by renewable sources. This will result in causing less strain on our limited natural resources and will help preserve the environment. The carbon footprint and greenhouse gas emissions associated with the operation and maintenance of a building will be thereby reduced.

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Chapter 51
Advances in Building Materials Industry by Annexation of Nano Materials

Ashmita Rupal, Sanjay K. Sharma, and G. D. Tyagi

Abstract With the advances in the field of nanotechnology different aspects are being explored time to time to a significant extent to take up the problems in both stages of design and construction. Amongst others, the nanotechnology sciences are the utmost dynamic research areas with great exploration potential. Its application in multidisciplinary fields has been delved into a number of other fields and disciplines for example in development of composite materials for civil, mechanical, electrical engineering and many others. This paper represents the various studies and researches carried out related to the sustainable utilization of different nano materials such as nano fibers, carbon nanotube, titanium dioxide, nano based coatings, nano silica and many others which provide significant utility in improving strength characteristics in cement and concrete materials along with other enhancements such as insulation, UV ray absorption, lighting, waterproofing, potential reinforcement, fire protection, corrosion resistance and many more when used as building materials. Also, this paper highlights the utilization of nano based structural and functional materials which are used during construction, manufacturing of building materials and also for repair and protection of structures. Hence will aid researchers about the most recent progress of using nanotechnology in field.

Keyword Nano materials · Nano technology · Sustainability · Building materials

51.1 Introduction

Nanotechnology and nanomaterials are now being used in civil engineering at the turn of the century. The recognition of nanomaterials' enhanced strength and lower density had already solved numerous building and construction constraints. The

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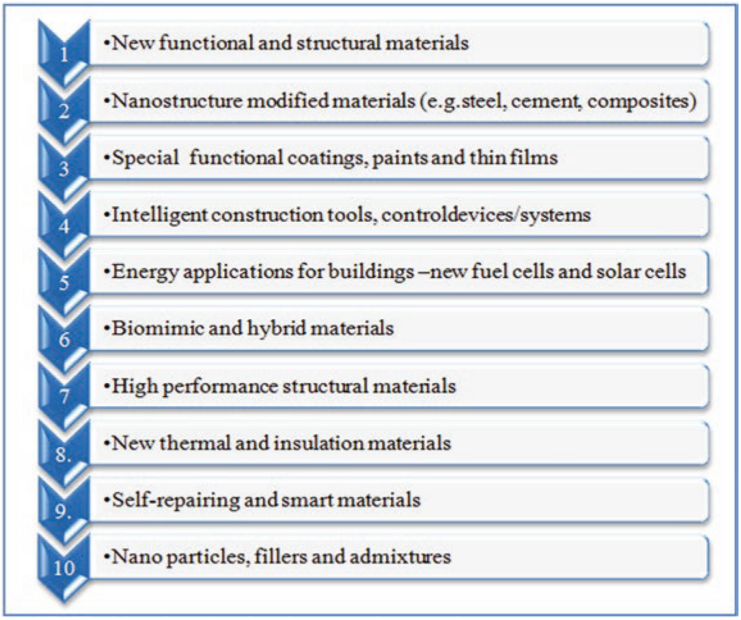
study of handling materials at the nanometre scale and then using the characteristics and properties of this dimension in different techniques, materials, and systems is known as nano science and nanotechnology. Nanotechnology is involved with particles whose size range between 1 and 100 nanometres (1 × 10 m = 1–9 nanometres). In analytics related to nanotechnology science, there is requirement of advanced imaging tools and different tools for optimization related to different composite material fabrication as well as their engineering from the raw base nanomaterials in form of solids, fluids, liquids or in molten form, fine powders with particle sizes ranging from 1 to 100 nanometres (Saurav 2012). Nanotechnology enables the development of matrixes with high sensitivity, high-density, specific catalytic and high strain resistance, wider coverage area, and catalytic effects (Syed 2014). However, the potential for nanotechnology to be used in the field of construction engineering is continuing to expand. According to recent researches it has been found that (Mann 2006) new nanotechnology-based goods will have a significant impact on people's quality of life, the environment, and defence capabilities. The paper reviews the application of nanotechnology in building construction material. This paper introduces and emphasizes the use of nanomaterials in construction. The purpose is to report the scientific reference of the various requisites associated with the scope of nanotechnology and hence providing an allied reference to correspond these nanotechnology science issues to various relevant stakeholders and dealers.

51.2 Importance of Nanotechnology in Building Materials

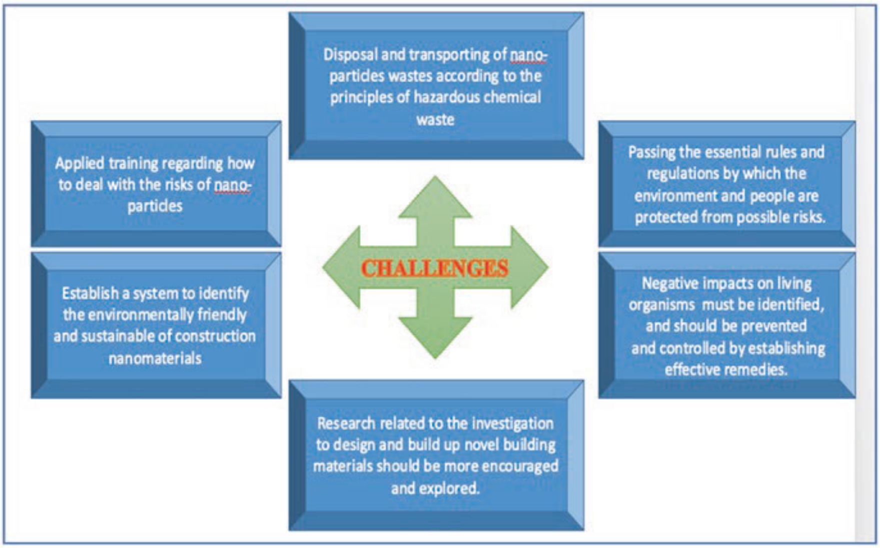
Building materials play the major role in construction industry being the main constituting material of the infrastructures. Most significant structural, economic and aesthetic aspects are associated with the building materials. Cement, bricks, concrete, timber, stones, steel, glass, polymers and a variety of metals have been among the most construction materials (Bigley and Greenwood 2003). Humans used stone and timber to build shelters against natural calamities, animals, and other calamities in the past, since these are the ancient materials. Building materials, like all other things, have continued to evolve, including concrete and steel presently dominating in the building and construction industry. New smart materials are being designed and developed by researchers and engineers across the world as a result of technological advancements, and this process is indeed maintain track.

51.3 Application of Nanotechnology in Building Materials

A brief overview of different domains of nanotechnology science in the construction and building materials is shown in the Flow Chart 51.1 below. Important environmentally safe nanomaterials with potential use in construction industry are discussed here in Table 51.1 below.



Flow Chart 51.1 Overview of use of nanotechnology in building materials



Flow Chart 51.2 Challenges faced in using nano particles and nanotechnology in construction industry

Table 51.1 Environmentally safe nanomaterials with potential use in construction

S.No	Application/ potential use area in construction industry	Nano based materials	Detail
1.	Cement and Concrete	Nano-Silica (SiO_2) Carbon Nano Tubes(CNTs)/ Multiwalled Nanotubes(MWCNTs, Titanium dioxide (TiO_2).	The adjunction of nano-silica (SiO_2) and other substances to the cement based raw material scan limit the calcium silicate hydrate (C-S-H) reaction minimizing the penetration of water and strengthening durability. The physico-mechanical properties of fabricated samples developed increase exponentially when relatively small amounts (1 percent) of carbon nanotubes are added. When compared to the reference samples, oxidised multiwalled nanotubes (MWCNTs) exhibit the significant improvements in compressive and flexural strength (Ge and Gao 2008). Addition of titanium Dioxide Nano-powder to the concrete can breakdown the grime or pollutants, enabling it to be completely removed by rainwater on everything from concrete to glass, and it can also be utilised as a reflective coating. TiO_2 uses significant catalytic end results to splitting down of the organic contaminants, VOCs (volatile organic compounds) and also presence of different bacterial membranes. It gives applied surfaces self-cleaning positive attributes (Worrell et al. 2001). The resulting concrete, which has already been utilised in projects all over the world, has a white colour that material's early stages holds its whiteness exceptionally well. In addition, concrete fibre wrapping is widely used nowadays to improve the potency of strength of different RCC structural parts. The utilization of a fibre sheet made up from composite matrix (encompassing nano-silica particles and suitable resin-hardeners has revolutionized the method. These nanoparticles infiltrate and repair the disruptions, minor cracks producing a resilient link among the substrates such as concrete surface and the fibre reinforcement making it robust for the strengthening applications (Raval et al. 2013).

(continued)

Table 51.1 (continued)

S.No	Application/ potential use area in construction industry	Nano based materials	Detail
2.	Wood	Carbon Nano Tubes (CNTs)/Multiwalled Nanotubes (MWCNTs); Silica and Alumina Nanoparticles	Wood often made by nanotube or "nanofibrils". Internal self-repair and self-sterilizing surfaces could be facilitated by lignocellulosic surfaces at the nanoscale. Wood is coated with substantially engineered water resistant coatings which hydrophobic polymers in its structure along with silica and alumina (Adams 2009).
3.	Steel	Copper Nanoparticles, Vanadium and Molybdenum Nanoparticles, Magnesium and Calcium Nanoparticles	Copper nanoparticles minimize steel's surface unevenness, which lessens fatigue cracking and results to an even more efficient material with better protection that necessitates less monitoring. By enhancing the steel microstructure, the nanoparticles of vanadium and molybdenum solve the issue of deferred fracture difficulties related to use of high strength bolts. And the weld toughness is improved by adding Magnesium and Calcium nanoparticles (Freitag and Stoye 2008). Two noval products are also available today named MMFX2 steel and SandvikNanoflex. These are manufactured as a result of different applications of nano technology making them corrosion resistant with significant mechanical properties.
4.	Glass	Titanium dioxide (TiO_2), Nano-Silica (SiO_2)	Self-cleaning technology is accomplished by coating glasses with TiO_2 nanoparticles. Because of its hydrophobic qualities, TiO_2 coatings are used in antifogging coatings and self-cleaning windows to absorb and break down different organic as well as inorganic air pollutants along with the bacterial membranes through a photo-catalytic reaction process. Nano-TiO_2 can also be used in coatings fabricated for the building facades which avert the pollutants from adhering to them, lowering maintenance expenses (Das and Mitra 2014). Fumed silica (SiO_2) nanoparticles are used as an interlayer placed between the two glass panels to create fire-resistant glass, which when heated becomes a rigid and opaque fire shield.

(continued)

Table 51.1 (continued)

S.No	Application/ potential use area in construction industry	Nano based materials	Detail
5.	Waterproofing Building Materials	Silicon, nano based polyurethane mix, polymer composites	The current advancements in science and technology have enabled the use of cutting-edge nanotechnology to create eco-friendly Organo-Silicon solutions that waterproof virtually all types of building materials. For the past 50 years, a lot of science and product development has gone into various waterproofing goods, particularly with polymeric main components and a range of other materials (Hossain and Rameeja 2015). Another important issue that waterproofing addresses is the deficit of concrete structural strength, especially as a result of ASR (alkali silica reaction), acid rain, and sulphate damage.
6.	Coating Paints and Isolation Materials	Silica aero gel particles, TiO_2 nanoparticles, C6 Nanotechnology	Coatings usually provide required protecting as well as functional properties. Usage of C6 Nanotechnology is quite useful for paints, membranes or coating for providing properties such as waterproofing property, thermal and sound insulating properties which is achieved by the addition of nano particles. Being hydrophobic, such coatings provide metal the protection from acid/saline water ingress. Nanoparticle based composite materials or matrixes with certain polymers provide enhanced adhesion, elongation and strength properties. Silica aero gel particles in blend proportioning amid reinforcing materials in various application of paints and different coatings and usually delivers insulating properties. Because of properties of TiO_2 nanoparticles, its coatings are also used for glazing and now a days research is going on to use it as an overlay material in road and highway construction (Bigley and Greenwood 2003).

(continued)

Table 51.1 (continued)

S.No	Application/ potential use area in construction industry	Nano based materials	Detail
7.	Nano technology in Fire Protection	Carbon Nanotubes (CNT's)	Steel constructions are basically made fire resistant with a spray-on cementitious coatings. Also the nano-cement comprises of nanosized particles which have the capability to boost toughness, durability and help in achievement of elevated temperature resistant coatings. Such composition is achieved by integrating carbon nanotubes in cement to develop fibre composites with multiple functionalities such as enhanced strength.
8.	Nanotechnologies for Water Purification	Carbon Nanotubes, Alumina Fibers, titanium oxide nanowires or palladium nanoparticles	Carbon nanotubes and alumina fibers are used water purification purpose also called as nanofiltration. The use of small perforations in zeolite filtration membranes, nano catalysts, and magnetic nanoparticles is its working principle. For analytical monitoring of pollutants in water samples, titanium oxide nanowires and palladium nanoparticles are employed. Charged particles, chemical effluents, sediments, bacteria, and other pathogens can all be eliminated with it.

51.5 Drawbacks and Future Challenges

Despite all the numerous advantages of Nano based materials, vast amount of confronts and challenges exist which are associated with the practical implementation and use of nano particles. Health issues is one of the main concerns associated with the use of nanoparticles and nanotechnology. As nanoscale particles are credibly extra responsive in comparison to that of the same material present in majority i.e in bulk volume. So the repercussions and effects should be potentially recognized and proper prevention and eradication methods and techniques should be employed. The main challenges which are faced in using nanoparticles and nano technology in construction industry are shown in Flow Chart 51.2 below.

51.6 Conclusions

Although the overall market segment of nanoparticle-based composite materials and products in the construction sector is not such significant and regarded as a part in only niche markets, but it is anticipated to expand in the upcoming times. Because nanoparticles are clearly imperative in providing an innovative and effective framework for the processing, designing, fabricating and manufacturing of materials in the building and construction industry. It is concluded that the usage of nanomaterials and application nano technology in construction industry is feasible and workable in four main domains of expansion: cement and concrete manufacturing; coatings and paintings; sound and thermal insulations, additive in word, glass, steel etc. Hence the application of nano based structural and functional materials during design, development, construction, manufacturing of building materials and also for repair and protection of structures should be more emphasized and research in this domain should be encouraged for attaining the desirable usage.

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Chapter 52
Experimental Investigations on Utilization of Electroplating Waste Sludge in Manufacturing of Polymer Based Checkered Tiles

Sivasankara Rao Meda, Sanjay K. Sharma, G. D. Tyagi, and Ishan Tank

Abstract Electroplating sludge is considered as a hazardous waste as it contains Cu, Ni, Zn, Cd, Cr, Pb, Fe, ammonia, etc. One of the problems faced by cities throughout the world is toxic waste management and sludge disposal as it causes grave ecological influence. The main objective of this investigation is to reuse the electroplating waste sludge in production of checkered tiles of size 250 mm × 250 mm × 25 mm by using polymers as a binder. Five different tile samples (A, B, C, D and E) containing waste sludge @ 30%, 35%, 40%, 45% and 50% of total weight of mix were prepared. This method of making tiles does not require any energy for heating and burning, does not consume any natural virgin materials like water, sand etc. To check the suitability of these produced tiles to be used as a construction material, various tests such as wet transverse strength, water absorption test and resistance to wear tests were carried out. The leaching test is also performed as per JSCE-G 575–2005. The experimental result confirmed a new possibility of utilization of electroplating waste sludge i.e. up to 50% in production of checkered tiles without compromising any strength requirements.

Keywords Electroplating waste sludge · Epoxy · Checkered tiles · Leaching test · Wet transverse strength test · Surface abrasion test

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52.1 Introduction

The Electroplating industries grew significantly and in the late 1970s and the first automated plant was started in Mumbai and now there are 750 automatic plants throughout India. The industry has grown from the Rs. 10 cr business to Rs. 12,000 cr. Currently 300,000 smaller units are running and meeting the various electroplating needs of industry as per the statics of the conference organized by CII in the year 2015. Electroplating process is considered a major pollutant because it emits toxic substances and heavy metals through wastewater (waste), air emissions and solid waste pollutants in the environment.

The main problem confronted by the manufacturing units that generate toxic waste comprising unjustified quantity of heavy metals is leaching of these harmful metals and recovery of heavy metals from a waste is neither feasible nor possible (Faustina 2018, Gordon 2019). The rainwater liquifies toxins and conveys them into nearby water streams, lakes, ponds and even into the groundwater (Mao Linqiang 2017).

Consequently, numerous techniques have been developed to convert hazardous waste into a non-toxic waste. The popular method used to convert unsafe waste into an environmentally feasible product is stabilization and solidification (Zhang Yu 2018). Due to rapid industrialization and urbanization, the generation of unsafe waste increases day by day, this can depressingly disturb the environment and well-being of community. Due to insufficient landfill sites, costs and stern environmental requirements, the waste management and dumping has become a primary concern for many Indian industries (Velumani 2017).

The landfill method of waste disposal and management is a cheapest method, but in future finding the correct location for landfill will be a foremost challenge due to urbanization (Liew Abdul 2004). In developing countries, the burning of toxic waste in landfill sites is the common means of waste disposal, causing grave health problems as well as environmental damage (Johnson et al. 2014). Many coastal metropolises and cities are even piped the harmful waste to the seabed. Number of cities resolve their problems of waste management by burning after water reduction methods. Due to lack of appropriate set-up for efficient disposal and recycling of dangerous waste, results in unscientific waste management and disposal in India. Strict environmental rules and rapid industrial development have amplified the waste management and dumping requirements (Faustina et al. 2018). Sewage discharging in water bodies is prohibited in several countries.

As per recent study conducted by ASSOCHAM and PwC, about 75 lakh tons of harmful waste is generated in India per year. This much enormous quantity of manufacturing waste requires massive area for landfill disposal. However, due to scarcity land filling area, there is a pressing need for alternate disposal systems and methods (Kanwar 2017).

Today's construction engineering is probing for superior materials which are strong, durable, light in weight, easy to install, last for a long time, but also adjustable and adoptable (Iftode V-I 2019, Udawattha 2017). With its exceptional relation of strength to weight, protecting properties, durability, flexibility and elasticity, polymers are extensively utilized in modern construction engineering (Gonzalo 2016). There is a pressing need to recognize and study the use of appropriate alternative binders like polymers for sludge stabilization. This maximizes reuse of harmful sludge and more 50% replacement can be attained in making construction materials, without further consumption of natural materials like sand, aggregates, water etc. and causing any additional contamination to the atmosphere.

52.2 Materials

52.2.1 Electroplating Waste Sludge

The waste sludge is collected from drying beds of Effluent Treatment Plant (ETP) of metal casting and forging industry. The different chemical and physical tests are conducted to determine various properties. The result of different tests conducted on waste sludge generated from of electroplating industry are given below in Table 52.1. Figs. 52.1 and 52.2 shows the photo of electroplating sludge collected from metal industry and photo of electroplating sludge after pulverization respectively.

The chemical analysis of waste sludge is done by XRF method. The result of XRF testis given below in Table 52.2.

52.2.2 Epoxy Resin

The best suitable resin for stabilization and solidification of electroplating sludge was selected after conducting different hit and trail experiments. The most suitable resin is “Casting Grade Epoxy Resin” with Epoxide value of 181–192. The various properties of Epoxy Resin weredetermined by conducting different tests namely Appearance, Epoxy value Eq/kg, Epoxy Equivalent Weight (EEW) g/eq, Viscosity (cps) at 25 °C and Density (g/cm^3). The test results of suitable epoxy resin for stabilization and solidification of electroplating sludge is given below in Table 52.3.

Table 52.1 Properties of electroplating waste sludge

S. No.	Name of test	Effluent Treatment Plant (ETP) sludge
1	PH value	5.0
2	Specific gravity	2.30
3	Moisture content	43%

Fig. 52.1 Effluent Treatment Plant (ETP) sludge

Fig. 52.2 ETP sludge after pulverization

52.2.3 Epoxy Hardener

After selecting the suitable epoxy resin, accordingly the hardener was selected by conduction different tests. The test results of hardener is given below in Table 52.4.

52.3 Methodology

The flow chart for methodology is shown in Fig. 52.3.

Five checkered tiles of each sample (A, B, C, D and E) were produced with different mixing ratios of waste sludge @ 30%, 35%, 40%, 45% and 50%. The mixing ratios of sludge and polymers are given below in Table 52.5.

Table 52.2 XRF (X ray fluorescence) report of electroplating sludge samples

S.No.	Element	Effluent Treatment Plant (ETP) sludge
1	O (Oxygen)	42.64%
2	Fe (Iron)	16.53%
3	C (Carbon)	08.72%
4	Ca (Calcium)	08.70%
5	Si (Silicon)	05.34%
6	Cr (Chromium)	02.72%
7	S (Sulfur)	02.69%
8	Ni (Nickel)	02.62%
9	Na (Sodium)	02.09%
10	Mg (Magnesium)	01.98%
11	Al (Aluminum)	01.73%
12	Cl (Chlorine)	01.62%
13	Zn (Zinc)	00.97%
14	P (Phosphorus)	00.65%
15	Cu (Copper)	00.39%
16	K (Potassium)	00.24%
17	Ti (Titanium)	00.11%
18	Mn (Manganese)	00.11%
19	Pb (Lead)	00.05%
20	Ba (Barium)	00.03%
21	V (vanadium)	00.03%
22	Sr (Strontium)	00.01%
23	Zr (Zirconium)	75 PPM
24	Mo (Molybdenum)	22 PPM
25	Tb (Terbium)	01 PPM
26	Co (Cobalt)	01 PPM

Table 52.3 Epoxy resin properties

S No	Name of property	Value
1	Appearance	Clear liquid
2	Epoxy value Eq/k (ASTM D1652)	5.2–5.5
3	Epoxy Equivalent Weight (EEW) g/eq	181–192
4	Viscosity (cps) at 25 °C (ASTM D 2196)	450–650
5	Density (g/cm^3) (DIN 53217)	0.96–0.98

Table 52.4 Epoxy hardener

S No	Name of property	Value
1	Appearance	Yellow brown
2	Amine value mg KOH/g (ASTM D2073)	350–400
3	AHEW g/eq	95
4	Viscosity (cps) at 25 °C (ASTM D 2196)	12,000–18,000
5	Density (g/cm^3) (DIN 53217)	0.96–0.98

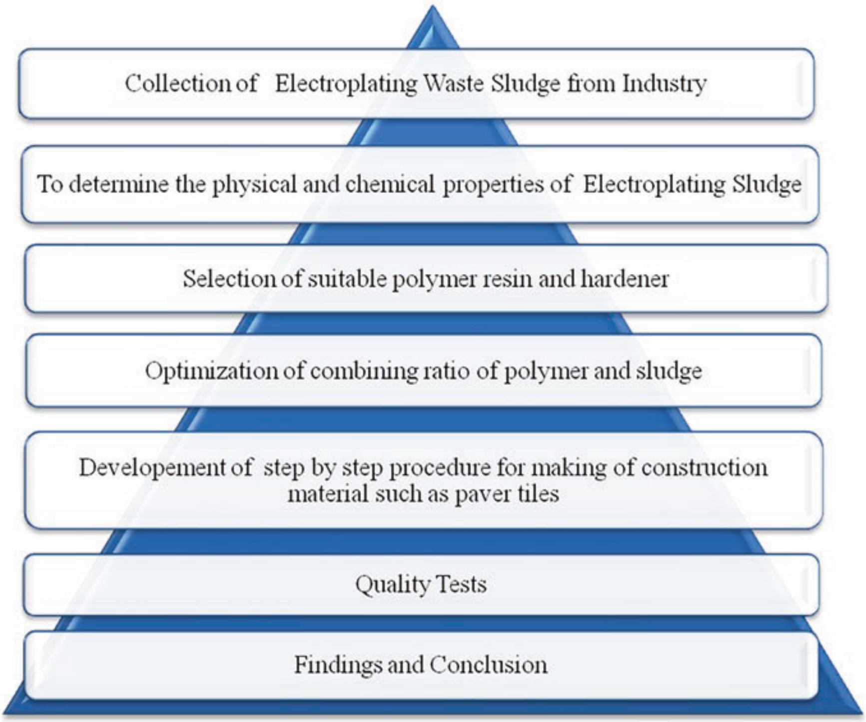


Fig. 52.3 Flow chart

Table 52.5 Different mix ratios

S No	Name of item	A (sample)	B (sample)	C (sample)	D (sample)	E (sample)
1	Waste sludge %	30	35	40	45	50
2	Polymers %	70	65	60	55	50

52.3.1 Manufacturing Process

A step by step procedure for production of checkered tiles is also developed. The step by step procedure followed in production of checkered tiles is given below.

52.3.1.1 Preparation of Waste Sludge

The waste sludge collected from Effluent Treatment Plant (ETP) of electroplating industry contains a moisture more than 40%. To reduce the moisture content below 5%, the waste sludge is required to be sun dried for 3–4 days. The collected sludge from industry contains many lumps and does not have uniform particle size. Therefore, it requires pulverization and sieving by using 600 microns sieve to get uniform particle size.

52.3.1.2 Selection of Epoxy Resin and Hardener

In market there are variety of epoxy resins and hardeners are available, but many of the resins does not react with the waste sludge. The different tests are required to be conducted for selecting suitable epoxy resin and hardener. To determine the properties of Epoxy Resin and Hardener, the list of tests are required to be carried are given in Table 52.6.

52.3.1.3 Mixing

Take required quantity of epoxy resin as per Table 52.7, in container and add sludge up to 25% of required quantity. Then start mixing of contents with a stirrer for 5 min at a speed of 2000 rpm. Add another 25% of sludge and mix the contents for five more minutes at a speed of 4000 rpm. Add another batch of 25% of sludge and mix them at a speed of 6000 rpm for five more minutes. Finally add remaining 25% of sludge and mix the contents for 2 min @ 8000 rpm. After proper mixing, finally add hardener and keep on mixing for 1 min @ 8000 rpm.

Table 52.6 Tests on epoxy resin and epoxy hardener

S. No	Tests on epoxy resin and epoxy hardener
1	Colour (ASTM D1544)
2	Epoxy value Eq/kg (ASTM D1652)
3	Viscosity (mpas) 25 °C (ASTM D2196)
4	Epoxy Equivalent Weight (EEW) g/eq (ASTM D1652)
5	Amine value mg KOH/g (ASTM D2073)
6	Pot life 25 °C (ASTM D2471)

Table 52.7 Mixing ratios of waste sludge and polymers

S No	Name of item	A (sample)	B (sample)	C (sample)	D (sample)	E (sample)
1	Epoxy resin	1166.67 gm	1083.33 gm	1000 gm	916.67 gm	833.33 gm
2	Electroplating waste sludge	600.00 gm	700.00 gm	800.00 gm	900.00 gm	1000.00 gm
3	Hardener	233.33 gm	216.67 gm	200.00 gm	183.33 gm	166.67 gm
	Total weight	2000 gm	2000 gm	2000 gm	2000 gm	2000 gm

52.3.1.4 Preparation of Mould

The mould should be properly cleaned, so that it is free from any dust, foreign particles and moisture. The wax coating is applied properly inside the mould so that it will be easier to remove the tiles after curing.

52.3.1.5 Placing

Pour the mixture into the mould slowly. Use blower to remove entrapped air if any.

52.3.1.6 Curing

Allow the mould to cure at temperature of 27 °C for 1 day. Remove the mould and cure the checkered tiles at a temperature of 27 °C for 07 days. After 7 days of curing the checkered are ready for use. The size of checkered tiles is 250 mm × 250 mm × 25 mm (Figs. 52.4, 52.5, 52.6, 52.7, 52.8, 52.9, 52.10, 52.11, 52.12 and 52.13).

52.4 Testing

Various tests were performed on 05 number tiles of each sample to check the suitability to be used as a construction material as per IS code provisions and specifications.

52.4.1 Wet Transverse Strength

The test was performed as per IS 13801 (2013). The wet transverse strength

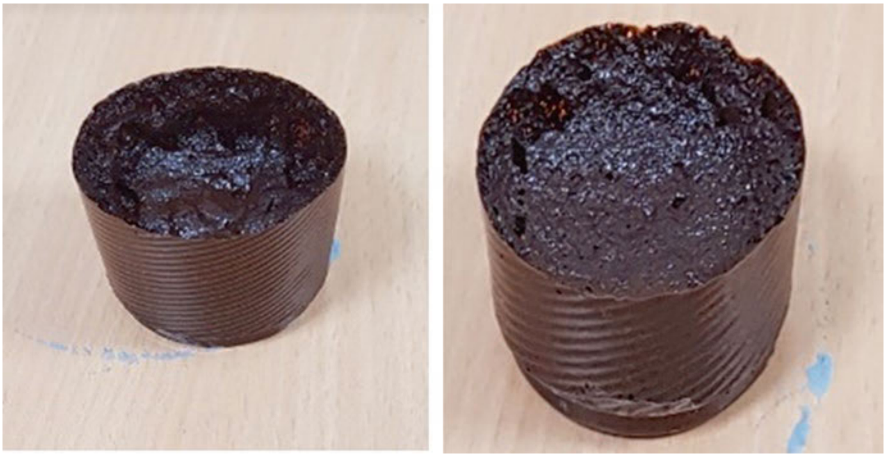


Fig. 52.4 Trail 1 (polymers does not react with sludge)

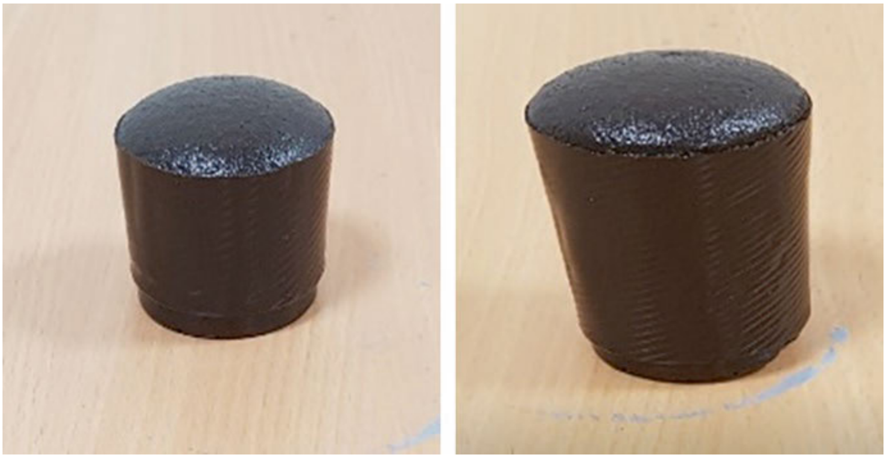


Fig. 52.5 Trail 2 (foaming problem)

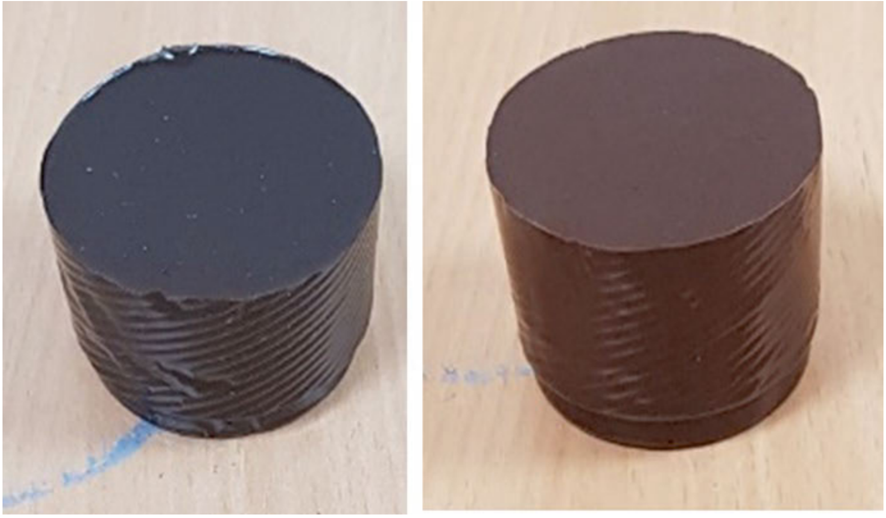


Fig. 52.6 Trail 3 (polymers successfully react with sludge)

Fig. 52.7 Mould

Fig. 52.8 Manufacturing of checkered tiles

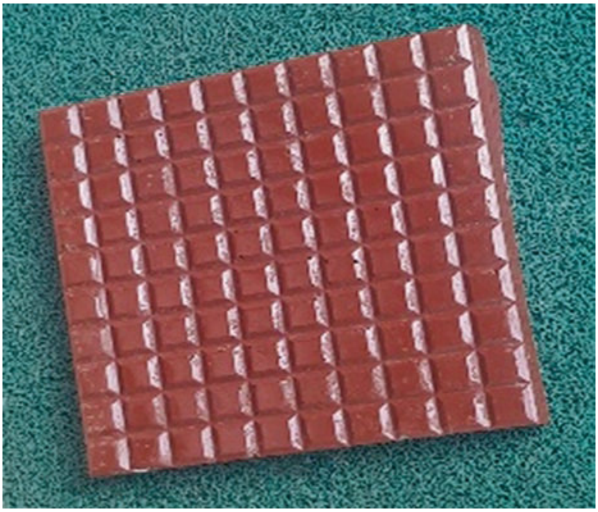


Fig. 52.9 Sample A

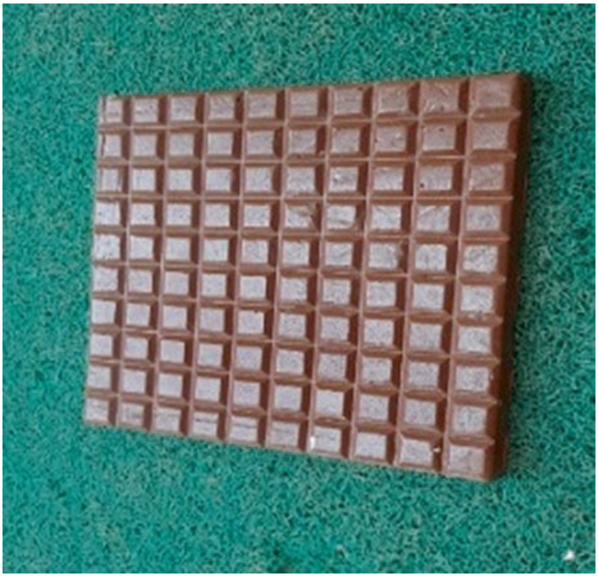


Fig. 52.10 Sample B

Fig. 52.11 Sample C

Fig. 52.12 Sample D

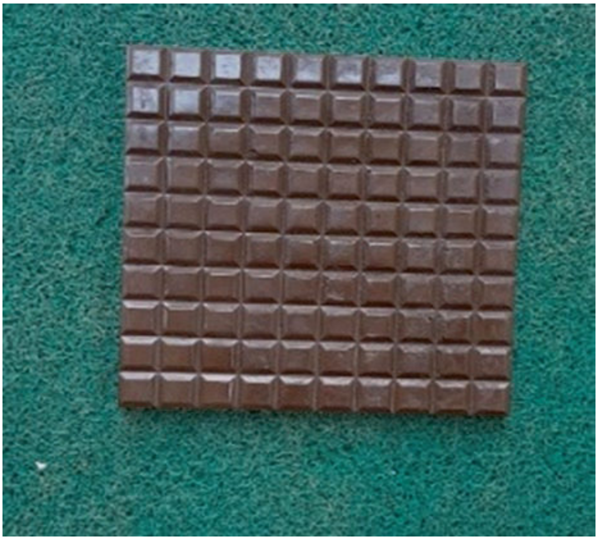
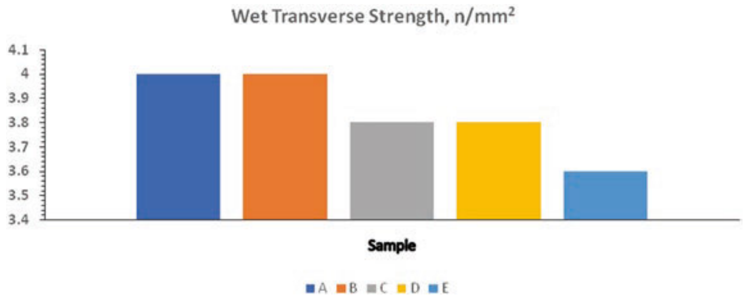


Fig. 52.13 Sample E

Table 52.8 Wet transverse strength test result

S. No.	Name of test	A (sample)	B (sample)	C (sample)	D (sample)	E (sample)	Min value as per code
1	Wet transverse strength (N/mm^2)	4.0	4.0	3.8	3.8	3.6	3.0



Graph 52.1 Wet transverse strength test result

Fig. 52.14 Test arrangement

Fig. 52.15 Photo of tiles after testing

$$f = 3PI / 2bt^2 N / mm^2$$
$$P = \text{Final Load(breaking) in N}$$
$$I = \text{Distance between supports (span) in mm}$$
$$B = \text{Width of Tile in mm}$$
$$t = \text{Thickness of the fracture line in mm}$$

The test results are shown in Table 52.8 and plotted in Graph 52.1 (Figs. 52.14, 52.15).

Results and Discussion

It can be noticed from results that with increase in addition of sludge, there is a decrease in wet transverse strength. It can be concluded that with increase of sludge addition from 30% to 50% (66.67%), there is a decrease of wet transverse strength from 4 N/mm^2 to 3.6 N/mm^2 (10%). Therefore, the sludge percentage can be further increased if possible without effecting the strength much.

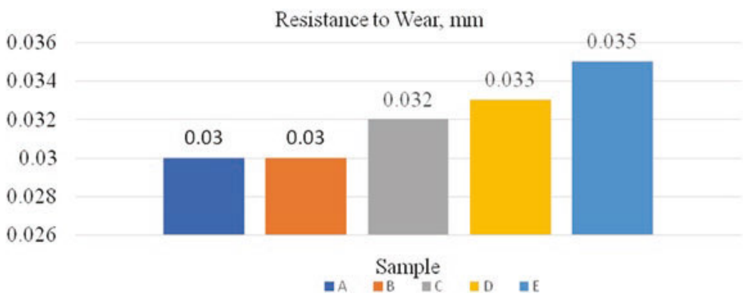
52.4.2 Resistance to Wear Test

The test was performed as per IS 13801 (2013). The shape of test specimen is square and size is 70.6 mm × 70.6 mm (500 mm^2 in area).

The test results are shown in Table 52.9 and plotted in Graph 52.2 (Fig. 52.16, 52.17 and 52.18).

Table 52.9 Resistance to wear test result

S No	Name of test	A (sample)	B (sample)	C (sample)	D (sample)	E (sample)	Max value as per code
1	Resistance to wear (mm)	0.03	0.03	0.032	0.033	0.035	3.50



Graph 52.2 Resistance to wear test result

Fig. 52.16 Specimen before test

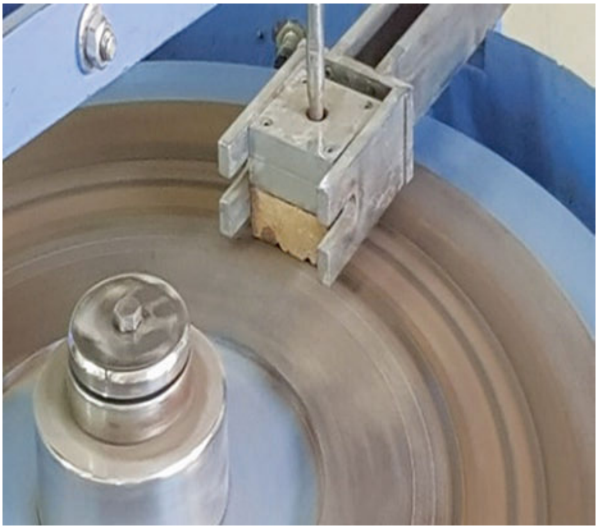


Fig. 52.17 Specimen during test

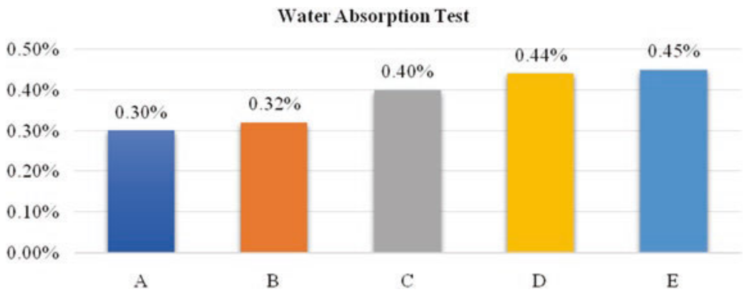
Results and Discussion

The results indicates that with increase in addition of sludge, there is a decrease in wearing resistance of tiles. It can be decided that with increase of sludge from 30% to 50% (66.67%), there is a decrease of wearing resistance from 0.03 mm to 0.035 mm (16.67%). Therefore, there is a scope for further increasing the sludge percentage without compromising the resistance to wear requirements.

Fig. 52.18 Specimen after test

Table 52.10 Water absorption test result

S. No.	Name of test	A (sample)	B (sample)	C (sample)	D (sample)	E (sample)	Max value as per code
1	Water absorption	0.3%	0.32%	0.4%	0.44%	0.45%	10%



Graph 52.3 Water absorption test

52.4.3 *Water Absorption Test*

The test is carried out as per IS 13801 (2013). The test specimen is kept in water for 24 h, then it is taken out and wiped dry.

$$\text{Water absorption, percent by mass} = \left[\left(\text{M1} - \text{M2}\right) / \text{M1}\right] \times 100$$
$$\text{M1} = \text{mass of saturated specimen, in g}$$
$$\text{M2} = \text{mass of oven dried specimen, in g}$$

The test results are shown in Table 52.10 and plotted in Graph 52.3.

Results and Discussion
As per results it can be decided that with increase in addition of sludge from 30% to 50%, there is a negligible effect on water absorption of tiles. It can be decided that with increase of sludge addition from 30% to 50% (66.67%), there is an increase of water absorption from 0.3% to 0.4% (16.67%). Hence, increasing the sludge percentage further will not affect the water absorption percentage of tiles much.

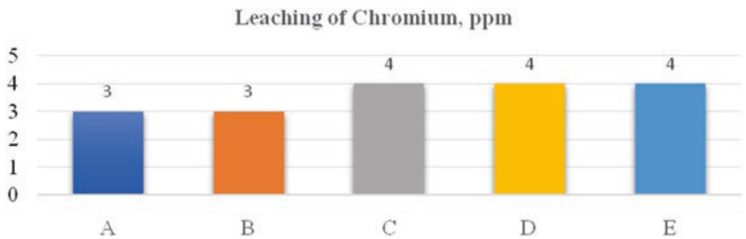
52.4.4 Leaching Test

The leaching tests were conducted as per Japan Society of Civil Engineers Code i. e (JSCE) – G 575–2005, to find out leaching of heavy metals. The test results are given in the Table 52.11 and plotted in Graph 52.4.

Results and Discussion
From the test results it can be concluded that there is no leaching of heavy metals like Nickel (Ni), Zinc (Zn), Iron (Fe), Copper (Cu) and Lead (Pb). The leaching of chromium (Cr) is also under permissible limits. It is also observed that with increase in addition of sludge from 30% to 50% (66.67%), there is an increase of leaching of chromium (Cr) from 3 ppm to 4 ppm (33.33%) and after that, the leaching remains constant. Therefore, increasing the sludge percentage more than 50% will not affect the leaching of chromium (Cr).

Table 52.11 Leaching test result

S No	Name of heavy metal	A (sample) (ppm)	B (sample) (ppm)	C (sample) (ppm)	D (sample) (ppm)	E (sample) (ppm)
1	Chromium (Cr)	03	03	04	04	04
2	Nickel (Ni)	00	00	00	00	00
3	Zinc (Zn)	00	00	00	00	00
4	Iron (Fe)	00	00	00	00	00
5	Copper (Cu)	00	00	00	00	00
6	Lead (Pb)	00	00	00	00	00



Graph 52.4 Leaching test result

52.5 Conclusions

- Various tests such as wet transverse strength test, resistance to wear test and water absorption tests were conducted on checkered tiles, to assess their suitability to be utilized as construction material. From the experimental results it can be observed that the electroplating sludge can be safely used up to 50% of total volume in manufacturing of checkered tiles.
- The heavy metals can be effectively and safely immobilized by using polymer as binder. The leaching of heavy metals is within the permissible limits. This will solve the waste disposal problem and also protects the environment for further pollution.
- This method of making checkered tiles does not require energy for heating/burning of tiles and no water, sand, aggerates etc. are consumed. Therefore, it helps in achieving the concept of sustainable development by conserving natural virgin materials. To promote the utilization of different waste sludge in construction industry, considerablebacking is also need from government for strategy preparation and public awareness.
- The developed polymer based checkered tiles have following unique properties: –

  (a) Light in weight by 50% as compared to conventional tiles
  (b) Better finish and appearance
  (c) Acid resistance properties
  (d) Better Electrical Resistance

- This study also suggest that there is a possibility of using polymers as binder for solidification and stabilization of other hazards waste sludges containing excess quantity of heavy metals and can produce different other construction material like Paver Blocks, Bricks, Precast slabs etc.

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Chapter 53
Alccofine as a Partial Substitute of Cement with Scrap Iron Slag as a Coarser Material in High Strength Non-conventional Concrete as an Experimentational Representation

Naveen Hooda, Rinku Walia, Devinder Sharma, and Abhishek Gupta

Abstract With the historical evolution of concrete, while using by UAE in constructing floors, underground cisterns and housing aspects structures in 6500 BC to making the skyscrapers like Burj Khalifa in Dubai in modern day, concrete and its technologically events come so far with using smart sensors for testing concrete maturity and its temperature etc. In present scenario concrete is being used in an aggressive way that it only has to cross the limit of using water on the planet earth. So, it will soon affect the gravity system and a drastic decrease in speed of earth too. So, with huge demand of concrete by almost all nation we have to considerably thinking about the alternative of concrete. Also, we have to seriously take steps about reusing of waste material too so that we can settle down the unnecessary available waste material on earth in a fruitful way. For all this scenario we have a technical revolution in construction field known as supplementary cementitious material like Alccofine. Alccofine-1203 is the latest generation product, ultrafine having very low amount of calcium silicate and also manufactured in India with economic purpose too. Its distinct characteristics are to enhances the execution of concrete in well workable situations. The ultimate prospectus of using Alccofine-1203, because of its availability as a substitute material and economic scenario. For getting high strength we can use it as an alternate material of conven-

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tional cement and make the concrete workable as well as durable with adding some admixtures. The design mix considered in this work as M-60. The Alccofine was used as 12% replacement of cement and coarser materials were a substitute by scrap iron slag waste material with a percentage of 25%, 50%, 75%. The compressive strength results, flexural strength points as well as split tensile strength values were found out by different proportions of scrap iron slag at much likely curing periods of 7 days, 14 days, 28 days. Durability of concrete wise tests were also conducted after curing period of 28 days. The strength getting form these mixes were compared with conventional concrete.

Keywords SCM · Alccofine · Compression · Superplasticizer · HSC · Scrap iron slag · Durability · Workability

53.1 Introduction

With the introduction of high strength concrete we can imagine a non-conventional concrete having a relative high strength value comparative to normal strength concrete. There is not any specific precise value to differentiate these two types of concrete but as per American concrete institute high strength concrete (Gehlot and Singh 2021) having at least a compressive capacity of 6000 psi or 41.36 Mpa. High strength concrete generally combines with low water cement ratio with addition of some admixtures to get that particular grade of compressive strength. This type of concrete will fulfil all demand of future concrete too but with addition of steel, timber, plastic, fibres etc. when discussing about Alccofine-1203 (Venkatesan and Venuga 2020) type product, they chemically reacted in presence of water and behaves as a binding material (Chand and Kumar 2021) to form an immensely rigid mass.

This paper resulted the various aspects of strengths with using Alccofine-1203 (Reddy and Meena 2018) and scrap iron slag in different proportions and showing those demanded properties. Alccofine works as high-water reducer and super aid to flow as their workability conditions (Antony and Rossen 2012). It also invades fast settings with no hazardous components to environment (Maria and Varela 2019). Durability (Narasimbha and Venkata 2020) is also a much suitable quality of this product and can be considered as a more economical alternative. Finally specifying the enhancement of ultimate strength (Elavarasan and Priya 2020) of concrete. Figures 53.1, 53.2, 53.3, and 53.4 represents the various strength characteristics of concrete.

While considering the scrap iron slag (Balamurugan and Ganesh 2021), it can easily be procured from industrial areas that are locally available anywhere in country parts. Scrap slag (Berndt 2009) consists of good bearing strength so increases overall capacity. Alkali aggregate reactions also can not affect the scrap iron slag;

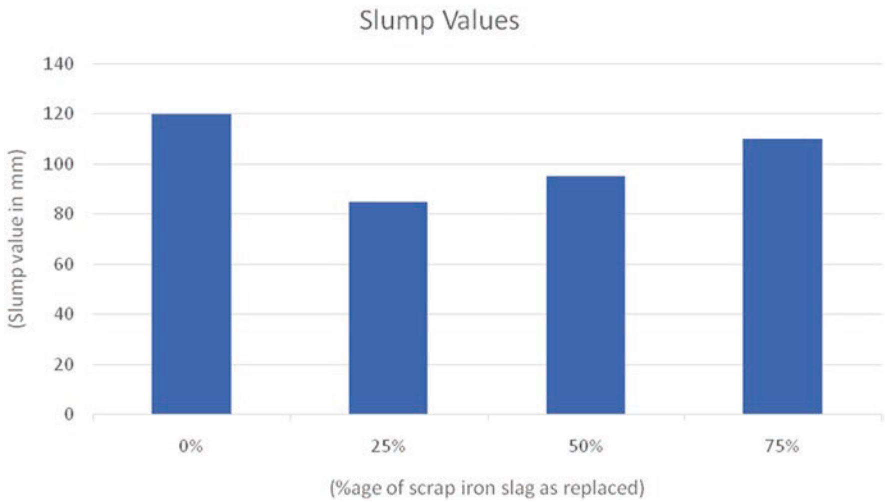

Fig. 53.1 Slump values

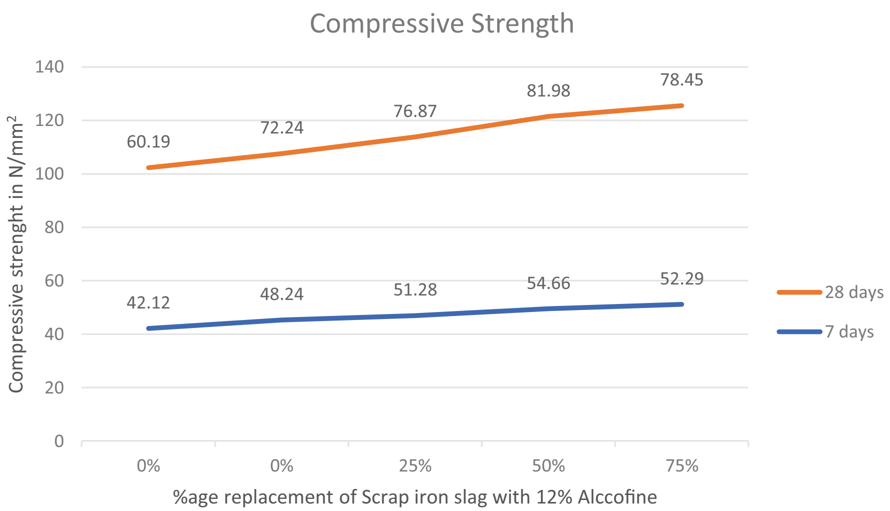

Fig. 53.2 Compressive stress variations

therefore, it may be considered as a merit of slag. Road base material can also be considered replaced by scrap slag. That is the main reason of familiar of using as a coarse material.

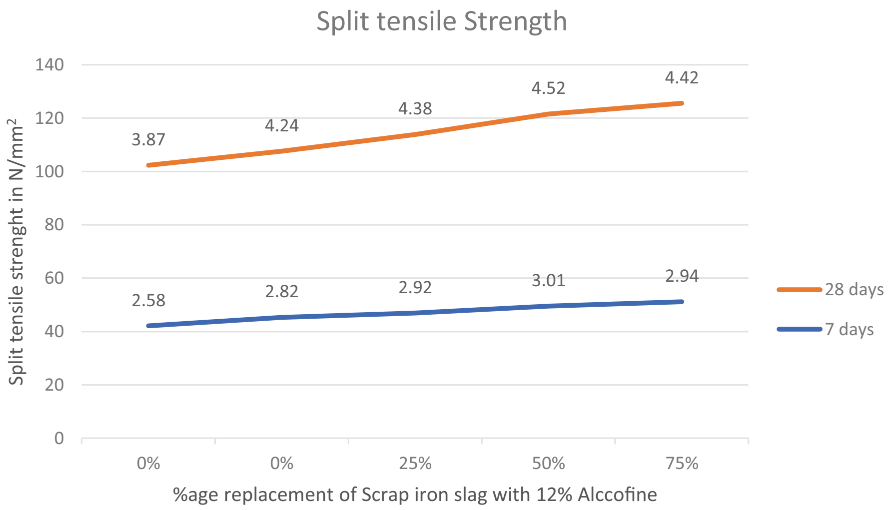

Fig. 53.3 Split tensile stress variations

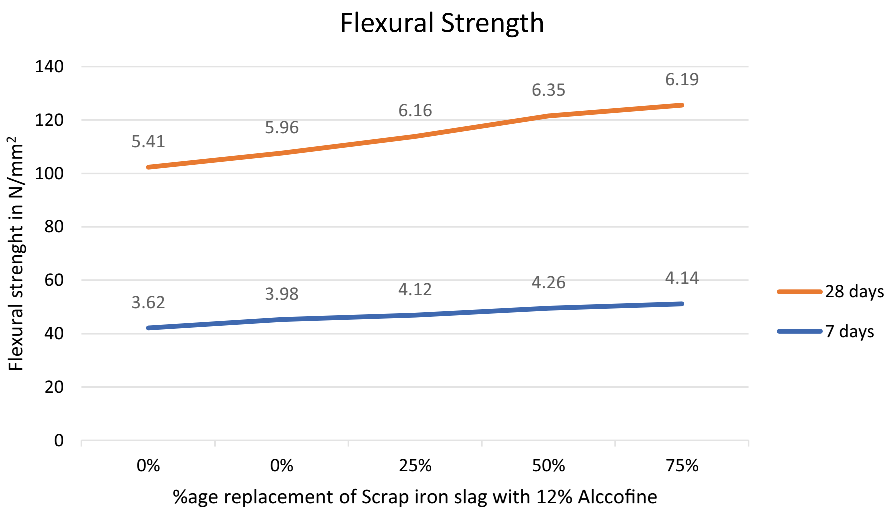

Fig. 53.4 flexural strength variations

53.2 Material

53.2.1 Cement

Normally available ordinary Portland cement with grade 53 is used in the observations and experiments. According to IS 12269:1989, all the physical parameters were examined as shown in Table 53.1 below.

Table 53.1 Various physical parameters of cement

Sr. no.	Characteristics	Results as per experiment done
1	Initial setting time	30 min
2	Fineness	3%
3	Specific gravity	3.14
4	Standard consistency	32%

Table 53.2 Various physical standard parameters of fine aggregates

Sr. no.	Specific properties	Values as per experiment done
1	Water absorption	1.1%
2	Specific gravity sp. Gr.	2.62
3	Fineness modulus value	4.12%

53.2.2 Fine Aggregate Availability

One of the main rivers i.e., Yamuna River sand was taken to considered as natural sand aggregates, which passed across 4.75 mm sieve verifying the Indian standard values IS 383-1970 was used. Physical parameters of such aggregates considered as value in Table 53.2 as shown below.

53.2.3 Coarse Aggregates

Again, Yamuna river's naturally available sand considered as aggregate which are satisfying the condition of 4.75 mm sieve not passing through it as per Indian standard values IS 383-1970 were used. Below given table states the various standard parameters of aggregates (Table 53.3).

53.2.4 Alccofine

Alccofine is ultrafine product having optimized particle size distribution which gives maximum workability conditions to concrete with enhancing its power and durability and can be categorised as Alccofine 1203 (Venkatesan and Venuga 2020) and Alccofine 1101. But Alccofine 12 series is slag-based product and more precisely result oriented as compare to 11 series, due to its high calcium oxide property (Saloni 2020) and low calcium silicate (Reddy and Meena 2018). Various properties are discussed in given below Table 53.4.

Table 53.3 Various physical properties of Coarser aggregates

Sr. no.	Characteristics	Values as per experiment done
1	Water absorption	0.5%
2	Specific gravity sp. Gr.	2.72
3	Fineness modulus values	4.11%

Table 53.4 Various physical standard values of Alccofine-1203

Sr. no.	Standards parameters	Values as per experiment done
1	Sp. Gr.	2.92
2	Colour	Black
3	F.M. as fineness modulus	3.60%

53.2.5 Scrap Iron Slag

For environmental safety purposes (Maria and Varela 2019) too, we have to minimise this type of waste with enhancing the uses of waste products by steel industries (Balamurugan and Ganesh 2021). It can be easily got by any steel industry (Berndt 2009) in nearby industries areas availability.it can result in soil contamination as well ground water impurities. So, we can broadly use it with its properties resulting in enhancing strength in concrete.

Some of the physical properties are here as (Table 53.5).

53.2.6 Water

Portable tap water is used here in all experiments that fulfil the minimum requirements of is 456-2000.

53.3 Mix Design

As per specification of IS 10262-2009 concrete mix was worked as for M-60 grade concrete. The W/C ratio as a value was taken as 0.29 for maintaining workability in a good sensible way. Given Table 53.6 provides the mixing standards of M-60 grade, while Table 53.7 shows the values of various mix proportions and combinations of Alccofine, scrap iron slag etc.

Table 53.5 Various physical standard values of scrap iron slag

Sr. no.	Standard parameters	Values as per experiment done
1	Sp. Gr.	2.72
2	Colour	Greyish black

Table 53.6 Mixing standards for M-60

Ingredients	Water availability	Cement used	Fine aggregates used	Coarse aggregates used	Super plasticizer used
Amount in Kg/m^3	141.68	504.21	683.24	1108.13	4.66
Ratio	0.29	1	1.35	2.19	0.8

Table 53.7 Percentage of mix and compositions of ingredients

Mixing values	Cement as in percentage used	Alccofine as in percentage used	Fine aggregate as in percentage used	Scrap iron slag as in percentage used	Coarse aggregate as in percentage used
M1	100	0	100	0	100
M2	88	12	100	0	100
M3	88	12	100	25	75
M4	88	12	100	50	50
M5	88	12	100	75	25

53.4 Experimentational Work

Cubes moulds of size 15 cm × 15 cm × 15 cm were used, while cylinder moulds having size 15 cm diameter with 30 cm height were used and beam specimen were used as of size 10 cm × 10 cm × 50 cm for the purpose of commanding the values of mechanical parameters standards of concrete as compressive strength, flexural strength along with split tensile test for duration of 7 days and 28 days. Along with Cubes moulds of size 15 cm × 15 cm × 15 cm were used for study of durability properties like acid resistance, salt resistance and sulphate resistance for duration of 56 days.

53.5 Results and Discussions

In this area we have discussed the various prepositions of results of fresh concrete parameters and hardened state parameters generally as slump value, compressive strength test results, split tensile strength results, flexural strength results.

Table 53.8 Slump fundamentals

Sr. no.	Compositions available	Slump concrete value (mm)
1	0% replacement i.e., controlled concrete	120
2	8% Substitution	90
3	12% Substitution	85
4	15% Substitution	110

53.5.1 Slump Values

Slump values has been verified as per Indian standard code 1199-1959. With the use of Alccofine 1203 the workability will be increased in a very well manner as comparing to normal concrete. As shown in the given below table with 12% replacement of Alccofine the workability is maximum while with others proportions, we have to make it more workable with addition of water. A non-linear relation between different mixes render hindrance to the workability so for avoiding it have to addition some more water because we are using superplasticizer as well scrap iron slag in mixes too (Table 53.8).

53.5.2 Compressive Strength

These tests were conducted on various stages of 7 days and 28 days of curing periods. Compressive strength was tested with 12% replacement of Alccofine and various proportions of replacement of coarse aggregates with scrap iron slag as shown in Table 53.9. All the mixes give the better compressive strength as compare to conventional concrete. For maximum results M-4 was responsible grade of mix, because with M-5 mix the compressive value is slightly low.

53.5.3 Split Tensile Strength Test

As the result shown in the table given below the minimum value of split tensile strength was observed as 3.87 with M-1 mix as conventional concrete, while maximum value can be obtained as 4.21 with grade M-4. All tests were carried out with Indian standard specification. To get great extent of resistance against tension, this type of test can be an evolution in modern civil field (Table 53.10).

Table 53.9 Compressive parameters of Alccofine with composition of Scrap iron slag

Mix	Percentage replacement of Alccofine	Percentage replacement of Scrap iron slag	Compressive strength data in N/mm² for 7 days	Compressive strength data in N/mm² for 28 days
M1	0	0	42.12	60.19
M2	12	0	48.24	72.24
M3	12	25	51.28	76.87
M4	12	50	54.66	81.98
M5	12	75	52.29	78.45

Table 53.10 Split tensile standards of Alccofine and Scrap iron slag with various proportions

Mix	Percentage replacement of Alccofine	Percentage replacement of Scrap iron slag	Split tensile strength values in N/mm² for 7 days	Split tensile strength values in N/mm² for 28 days
M1	0	0	2.58	3.87
M2	12	0	2.82	4.24
M3	12	25	2.92	4.38
M4	12	50	3.01	4.52
M5	12	75	2.94	4.42

53.5.4 Flexural Strength Test

The given test was conducted for getting the flexural strength of this non-conventional concrete. Various values sowing in the table shows again the initial increase as the M-4 mix having maximum values then a little decrease in strength. This results in the proximity of rate of flexural strength will be considered as more w.r.t. compression parameters (Table 53.11).

53.5.5 Acid Attack Durable Parameter

The standard cubes of having size 15 cm were immersed in 5% HCl solution for at least 28 days and got various results as shown in table below. Variations of compressive strength after the Na_2So_4 curing, HCI curing phenomenon and normal curing phenomenon while considering the temperature of environment is completed. That particular standard cube, which had iron powder on it, resists the acid attack when determining with comparison of conventional concrete (Table 53.12).

Table 53.11 Flexural value parameters for Alccofine and Scrap iron slag with various proportions

Mix	Percentage replacement of Alccofine	Percentage replacement of Scrap iron slag	Flexural parameter values in N/mm^2 for 7 days	Flexural parameters value in N/mm^2 for 28 days
M1	0	0	3.62	5.41
M2	12	0	3.98	5.96
M3	12	25	4.12	6.16
M4	12	50	4.26	6.35
M5	12	75	4.14	6.19

Table 53.12 Acid attack durability parameters

Mixing grade	Considered loss in weight in percentage	Considered Loss in compression strength in percentage
M1	9.61	11.81
M2	7.76	5.03
M5	4.92	3.89

Table 53.13 Sulphate attack observations

Mixing grade	Considered loss in weight in percentage	Considered Loss in compression strength in percentage
M1	7.01	4.92
M2	6.23	1.01
M5	4.29	1.98

Table 53.14 Salt attack observations

Mixing grade	Considered loss in weight in percentage	Considered loss in compression strength in percentage
M1	4.98	4.01
M2	4.16	2.03
M5	1.99	1.57

53.5.6 Sulphate Attack Durability Parameters

The cubes with size of 15 cm were immersed in 5% $MgSo_4$ at least 28 days and got various results as shown below in Table 53.13. It can be observed that Alccofine shows better results even with some loss of strength.

53.5.7 Salt Attack Durability Parameters

In this test cubes were in full watered condition with 5% Nacl providing for 28 days and after that providing the values as shows here in Table 53.14. Alccofine contained concrete shows better resistance to salt as compare to controlled conventional concrete.

53.6 Conclusions

The effects of partial substitute of Alccofine with cement and partial substitute of scrap iron slag with coarse aggregates were tested and concluded here as;

1. The desired mixing grade with involvement of 12% Alccofine as a substitute shows the pure workability up to a greater extent as compared to all others mixes while for avoiding hindrance, we can use more water.
2. The addition of 12% Alccofine in place of cement shows some good indication of increasing of compressive strength from 60.19 N/mm^2 to 72.24 N/mm^2 with approximately 20.01% increase in strength.
3. 12% Alccofine replacement of cement with 50% replacement of scrap iron slag with coarse aggregates gives best result as compare to other mixes and showing an increase of 60.19–81.98 with approximately 36% increase in strength.
4. Split tensile strength increases with a rate of 9.56% as 3.87–4.24 N/mm^2 while using 12% replacement of Alccofine with cement.
5. With addition of 12% Alccofine as replacing in cement with 50% replacement of coarse aggregates with scrap iron slag gives better result as comparing to the conventional concrete. The rate of strength increasing was found in range of 3.87–4.52 N/mm^2 as 16.79%.
6. While considering the flexural strength of concrete with providing Alccofine only as a substitution of cement the results were in a minimum range of 5.41 N/mm^2 to maximum range 5.96 N/mm^2 i.e., approximately 10.16% increase in this strength.
7. With 12% substitute of binding material opc with Alccofine and 50% substitutions of coarser material with scrap iron slag the flexural strength gives better results as an increase rate of 17.37% i.e., 5.41–6.35 N/mm^2.
8. In durability test like sulphate attack test, salt attack test and acid attack test the combination of 12% inclusion of cement with Alccofine and 50% inclusion of coarser aggregates with scrap iron slag gives better results and much more durable as compare with conventional concrete.
9. Finally, we can say that there is a huge scope of using substitute of cement and aggregates for future construction projects, which are both economic as well good sustainable.

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Chapter 54
Water Pollution: "Dal Lake a Case Study"

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Abstract Dal lake is one of the famous freshwater lakes of Jammu & Kashmir and is rightly called as "Liquid jewel "in the heart of capital city Srinagar.

Over the years the lake is under serious anthropogenic activities which has resulted in pollution of the lake threatening its health and ecology. Despite many consultancies were engaged for the conservation of this lake yet the trophic condition of the lake has not shown any significant progress nor the water quality has improved.

In this paper an attempt has been made to assess the measures taken for its conservation, study the current Ecological status of the lake and reasons for the failure of the Conservation of the lake coupled with suggestive measures.

Keywords Dal Lake · Houseboat · Settling basin · LAWDA · Water quality · Seasonal variation · Suggestive measures

54.1 Introduction

The Dal lake is unique freshwater lake of union territory of J&K and its uniqueness is because of about 90 thousand people living within the lake on islands or hamlets, presence of floating gardens (for vegetable cultivations) and presence of Houseboats which act as mobile hotels. Dal lake as such is divided into five main basins viz: Nehru park basin, Nishat Basin, Hazratbal basin and Nigeen basin and BrariNambal lagoon. All the basins differ in morphometry, ecological characters and in vegetational cover.

Due to the population explosion and expansion of the City of Srinagar, thousands of new settlements have come up in the immediate Catchment of the Dal lake and in absence of any drainage and sewerage system till 2002 entire raw sewage pours into the lake which resulted in drastic changes in the water quality, vegetation of the

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lake. According to Kundangar et al. (2003) About 12.30 × 10^6 m^3 load of liquid waste is received by Dal lake annually from point and nonpoint sources. The liquid wastes carry about 25 × 10^3 kg of inorganic Nitrogen and 18.7 × 10^3 kg of Phosphorus and which not only enrich the lake sediment but also increase the fertility rate of water and results in accelerated weed growth.

Another major problem faced by the Lake are the large areas of the lake have been reclaimed and converted into floating gardens and subsequently into permanent land masses, besides expansions of exotic Lily pads with ulterior motives and heavy siltation from its catchment resulting in shallowness of the lake.

54.2 Observations

As a result of various conservation plans the successes observed over a period of time in implementation of the project plans, include catchment area treatment under which an area of 375 km^2 has been divided into 12 micro-watersheds for treatment in order to control the Non-Point Source of Pollution and silt flowing into the lake from the catchment. The treatment includes Afforestation, Anti Soil Erosion works, Vegetative measures, Control of Soil erosion, arresting of the silt; commissioning of a Settling basin with a capacity to arrest 80000 tonnes per year of silt coming from catchment, dredging out 28 Lac Cumecs of solid mass within the lake which includes the area from Nishat to Habak with addition of water expanse of around 2 km^2 added to the lake water out of dredging operation. According to Lakes and water ways Development Authority, looking after the lake Conservation 75 floating aerators have been installed in the stagnant pockets of the lake to combat the triggering of Euglenoid and Algal blooms besides removal of lily patches an area of 2.9 km^2 area stand cleared. The additional measures taken for the conservation of the lake includes improvement of outflow channel of Nallah Amir Khan to enhance its carrying capacity from 150 to 1330 cusecs there by improving Hydraulic Management of Lake.

Commissioning of 468 m long Cut and Cover Conduit linking BrariNumbal Lagoon with River Jehlum with the aim of improving water circulation of the lake. To combat the problem of Sewages from point and nonpoint sources Five STPs stand commissioned.

Under the Sewerage scheme of Dal and Nigeen lake, total trunk sewers laid till date is 23.94 km. The Authority has laid lateral/secondary Sewers of a total length of 73.64 km so far leaving a balance 4.158 km which is in progress.

The problem of houseboat sanitation is being solved by mooring the house boats near the Dal Gate to shore line to enable the authority to connect these house boats with the main Sewer line.

Under the rehabilitation programme of Dal dwellers about 1300 families have been settled in the various colonies.

According to Shabina Masoodi et al. (2014) the Lake Authority In a bid of beautification of Dal lake Periphery 2340 m of parapet wall and toe wall from Kralsangri to Nishat has been completed, while as 4315 m of iron grill railing Nishat to Habak is also completed with 27 No. Ghats/viewing decks/weed unloading points. For arresting the invasive weed species like Azolla etc from the hinterlands Weir meshes at the mouth of Bout khul and PoshpavNallah were installed. In addition Shoreline development on left side of Nishat Pipe line bund of length 180 m were strengthened.

Despite all these measures taken for the conservation of Dal lake it has been observed that neither the Lake has shown any improvement nor its water Quality has improved.

The reasons of failures of the project are enumerated as under:

- Non community involvement, nonexistence of forage production through Silvipasture, pasture and farm development and farm fodder development which otherwise result in massive grazing by the sheep and goats in the upper Catchment.
- Despite the fact the Settling basin at the entry point of Dal lake has been commissioned decades back and since then large quantities of silt and sediment has accumulated in the basin due to failure of Authority to de silt it periodically as a result the Basin has lost 43% of its functional efficiency.
- The recent desilting and dredging of tail end of TelbalNallah (the perennial water source to the lake) without studying its environmental impacts have resulted in invasion of exotic weed Azolla which often engulfs the entire Hazratbal basin of the lake probably due to release of nutrients from the Nallah bed and their entry to the lake.
- In order to work for improvement of lake hydrology and hydraulics man made bunds have been removed to improve flow of waters yet there are many stagnant pockets in the various basins of the lake which continue to obstruct the flow of water in the lake. The constructed regulatory gates all along the Boulevard road meant for controlling the sediment inflow from the hinterlands along with nutrients are virtually non-functional and thereby there is no ground evidence to show that they are functioning for the purpose they have been constructed.
- The BrariNambal cover and conduit cut for draining the surplus water from the, agony to Jehlum river is also non-functional and such no flushing of the lake or lagoon takes place. The lagoon as such has turned into a cesspool.
- The Decades old deweeding practices through mechanical and manual methods is now a regular feature, the same remains confined to the peripheral areas of the lake only while the massive weed infestation continues to be a perpetual problem in the interiors of the lake.
- The unscientific deweeding practices have proved a temporary treatment without any relief to the ecology and health of the lake ecosystem.
- Failure of Authority to exploit the aquatic weeds for their medicinal, fodder and bio fertilizer values.
- The peripheral sewerage scheme from Konkhan to Ashiabagha long western shore line has been under construction for last 35 years under UEED. It's non completion contributes 30% of sewage ingress to Dal. 58 hamlets and 700 houseboats within Dal Lake continue to drain their sewage into Lake making another

10% of total. So even if 60% sewage ingress to lake stands capped 40% continues to flow day in and day out negating efforts.

- Rehabilitation project of lake dwellers has become a war against time even after shifting them in 8 colonies and a big program for shifting in 700 kanal colony at RakhArth. Still more than 5000 families remain yet to be shifted. The increase in population, land mafia and vote bank politics has encouraged encroachments and coming up of illegal constructions despite moratorium
- The western lake boundary still remains to be delineated which otherwise is wide open for encroachments.
- Pending completion of rehabilitation some of the conservation measures related to water budget of Lake, flushing, maintaining of optimum envisaged water levels cannot be done as they will flood the habitated hamlets within the lake.
- Since all the conservation measures are being taken to improve the Quality of water of the lake but unfortunately the lake water continues to be deteriorating day by day with increasing load of nutrients like Nitrogen and Phosphorus.
- Since wastewater treatment (FAB) technology is energy dependent so it is proven to be failure under Kashmir conditions. Kundangar and Abubakr (2021) reported32% increase was recorded in Nitrate-N while 90–98% increase was recorded in ortho-phosphate and total phosphorus respectively during winter months in so called Treated waters through STPs. The adoption of this technology for Dal Lake had been cautioned by the Author prior to its installation. There are number of reports and research studies which indicate and testify the malfunctioning of FAB based Sewerage Treatment plants which instead of solving the problem have aggregated the Dal lake pollution.

- The analytical report by LAWDA (research and monitoring division) in August 2006 shows concentration of some nutrients increased in the waste waterat the outflow stage in relation to inflow stage regardless of receiving treatment at STPs. The effectiveness of the two STPs ranged between 63.39% and (−)366.3%. In addition, the STPs did not match the imposed norms, specifically with respect to parameters of inorganic nutrients such as nitrogen and phosphorus. "It further added that for the effective treatment of sewage, measures were required to be taken to prevent detrimental impact on the lake ecology due to entry of raw sewage which was one of the major causes of its amplified eutrophy.

In October 2006 LAWDA disputed that the STPs were working efficiently which was therefore, not acceptable" (The Comptroller and Auditor General audit report for the year ended 31 March 2011: Jammu and Kashmir).

During the year 2008 (Table 54.1), the studies carried out regarding the functioning of FAB based STP, showed that the chemical parameters of incoming sewage could enhanced partially as against the claims put forward by the Dal lake authorities in April 2008 health bulletin. Surprisingly, there was an increase in nitrate nitrogen content by 44% of the treated sewage which indicates the malfunctioning of the installed STP commissioned by the Dal Lake authority against the desires of the considered scientific opinion.

Table 54.1 Effectiveness of nutrient elimination through FAB-STP(April, 2008)

Parameters	Raw sewage	Treated	% Removal
COD (mg/l)	190	108	43.1
PO_4 (µg/l)	620	390	37.0
T.P (µg/l)	1320	805	39.0
NH_4-N (µg/l)	2810	392	50.0
NO_3-N (µg/l)	680	1232	44.0

Table 54.2 Analytical Comparison of Water Quality at (a) Houseboat Sites and Treated Effluent Outfall Sites (b) of Dal and Nigeen Lakes respectively

Parameters	Unit	Dal Lake(a)	Dal Lake(b)	Nigeen Lake(a)	Nigeen Lake(b)
pH		7.8	7.7	7.8	7.8
Conductivity	µS (@, 25 °C)	301	383	333	276
Dissolved Oxygen	mg/l	5.9	5.1	5.6	4.5
Total Alkalinity	µg/l	224	316	240	244
NO_3 -N	µg/l	424	489	426	476
NH_4-N	µg/l	523	564	416	392
PO_4-P	µg/l	185	434	184	412
Total Phosphorous	µg/l	668	1210	661	1061

After Qazi Tanveer (2017)

As per the latest analysis report by a researcher (Qazi Tanveer 2017) (Table 54.2) the Nitrate-Nitrogen content at Hazratbal outfall of STP the so called Treated waste water still contained 322 µg/l, 924 µg/l, and 2550 µg/l. that of Phosphates while at Lam STP fall out the treated effluent still had 435 µg/l of Nitrates, and 1876 µg/l of Phosphates.

The authors opined that situation where the STPs are malfunctioning will not only exacerbate the problem of pollution of Dal Lake but shall have catastrophic consequences; as the non-point sources of pollution are being made the point source of pollution. This is also manifested by rise in the BOD, COD, the concentration of electrolytes and increase in the oxygen consumption in the lower layer of water (hypolimnion), furthermore the concentration of chlorides, sulphides, phosphorus and nitrogen. The increase in the concentration of P and the optimal ratio between P and N shall have important effect on the primary production and structure of plankton community and aquatic macrophytes in various parts of the lake and subsequent deterioration of water quality.

54.3 Conclusions

While reviewing the Action plan for Conservation of Dal lake it becomes fairly evident that the conservation plan has number of gaps and missing links. It has no mention of measures to conserve one of the most important basins of the Dal lake viz. BRARI-NUMBAL, which has turned into mere cesspool, similarly the treatment of outlet channel Chuntikhul is also missing.

The Consultants (AHE CROORKEE) are indecisive with regard to rehabilitation of Dal dwellers, the population to be removed and the population to be kept intact. It looks the consultants have not studied the carrying capacity of the lake. There is no mention with regard to the evacuated hamlets, land masses and their future use. Like wise in absence of Vegetational maps the existing quantum and density of aquatic weeds is unknown.

The waste management of Houseboat has still remained an unresolved job. In early nineties the so called floating septic tanks were installed in some Houseboats which proved to be only show pieces as the same have been abandoned without any reason and rhyme.

The proposal of shifting of houseboats to Dole Demb is yet another onslaught to the Dal Lake Conservation as it is unscientific and illogical proposal and has been rejected outrightly by the Enex Team way back in 70s (Kundangar and Abubakr 2021).

54.4 Suggestive Measures

The following measures should be taken for the rejuvenation of the Dal Lake:

(a) In order to control soil erosion and regulate flow regimes we need to identify, conserve and prioritize micro watersheds and catchment area.
(b) For improving the water holding capacity measures should be taken based on water and sediment balance; water lilies, vegetable gardens, area under willow plantation, and other encroachment and also take proper measures for improvisation of water quality.
(c) It is important to establish a method to reduce the productive growth of exotic and endemic aquatic plant species like Azolla, lemna and salvinia. Furthermore, by enhancing Biodiversity conservation in order to achieve self-sustaining native and endemic fish population.
(d) In maintaing the present trophic status of water body construction of treatment compartments for wastewater treatment in and around Dal Lake also in other lakes of Kashmir valley will have several advantages compared to conventional, secondary and advanced wastewater treatment systems. The root zone technology or treatment compartment for treatment of wastewater is a long term solution in our opinion to the problem in Kashmir valley where there is already energy crisis and severe winters. The root zone technology or Treatment com-

partments have been found to be efficient in eliminating the nutrients (nitrogen by 70% and phosphorus by 73%) besides other chemical entities.

(e) The realignment of Houseboats at the exit site of the Dal lake along Boulevard and that of Nigeen lake to lake peripheries to facilitate their connectivity with the main Trunk Sewer is the most viable option of House boat waste management.

Acknowledgement Words at our command are not adequate in spirit and form to meet the ends of justice in matter of expression of profound sense of gratitude and indebtedness to Er Shabeena Masoodi and especially Dr MRD Kundangar, Former Director, Lakes & Waterways Development Authority, J&K for encouraging, material guidance, valuable suggestions and objective approach towards work which enables us to accomplish this paper.

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Chapter 55
Durability Properties of Admixture of Fly Ash, Bottom Ash and GBFS

Anil Kumar, P. Jitendra Singh, K. Manish Jain, and K. Deependra Sinha

Abstract Fly ash, bottom ash and granulated blast furnace slag (GBFS) are industrial wastes materials. These are using as concrete admixture by geopolymer techniques. Utilization of the above raw materials minimize the transportation, disposal, environment cost and consumption of cement. Ordinary Portland cement produce large amount of CO_2 in atmosphere which is not eco-friendly material. This article especially focused on the utilization of raw materials as eco-friendly and check the effect of various chemical environments and exposure time on the compressive strength of products formed by geopolymer technique. The Compressive strength (C.S) changes with chemical environments and exposure durations.

Keywords Fly ash · GBFS · Bottom ash · Compressive strength and Geopolymer

55.1 Introduction

Fly ash (F.A) and bottom ash (B.A) were generated from thermal power plants and Granulated blast furnace slag from steel industry. About 43% fly ash is recycled (www.statista.com) as a pozzolan to produce hydraulic cement. Granulated blast-furnace slag (GBFS) is obtained by quenching molten iron slag in water. GBFS has a glassy and cementitious nature which is grounded into a fine powder. Cement is the important materials for concrete which is used as construction. The manufacturing of cement would be expected 4.83 billion metric tons up to 2030 (www.statista.com). Many researchers have reported that the manufacturing of each ton Portland cement emits one ton of CO_2 into the atmosphere (Davidovits 2015) which contributes approximately 65% in global warming. Hence, alternative material for cement

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is required. The large requirement of industrial and domestic energy fulfilled by power plant which generate billion tons of fly ash (Davidovits 2015, 1991; Dhadse et al. 2008). Sixty percentage fly ash were used in cement and forty percentage used as stuffing material (Davidovits 1994). Aluminosilicates and alkaline activators are responsible materials for preparation of alkali-activated materials generally known as geopolymer which is eco-friendly and having excellent properties such as high early compressive strength, alkali & acid resistance etc. (Juenger et al. 2011; Provis 2013; Provis et al. 2015; Puertas et al. 2000; Palomo et al. 1999; Singh et al. 2015).

The major aluminosilicates materials are GBFS (Rodríguez et al. 2008; Shi 1996) fly ash (Zhu et al. 2014) and metakaolin (Mobili et al. 2016) which are used as predecessor and Sodium hydroxide used as activators (Shi et al. 2006). Geopolymers contain mainly two types of gel system, one is high-calcium and other is low calcium system which is dominated by calcium alumina silicate hydrate gels and alkali aluminosilicate gels respectively. calcium alumina silicate hydrate gels and alkali aluminosilicate gels were coexisted in reaction products of alkali activated (Ismail et al. 2014; Yip et al. 2005) and interchange to each other with depending upon presence of calcium/ sodium content (Li et al. 2017; Provis 2018). The polymeric Si-O-Al-O bonds (Davidovits 1991) were present in three-dimension structure of geopolymer. The sufficiently change in mechanical thermal and deformation properties of fly ash based geopolymer concrete were observed at elevated temperature (Nath and Sarker 2012). The durability of concrete is a critical issue because it starts deteriorate after 20–30 years in urban and costal environment, though their life design was at least 50 years (Mehta 2001). Geopolymer concrete is more resistant to OPC concrete in SO_4 and Cl^- environment (Bakharev 2005). In sulphate environment it makes cross linked aluminosilicate polymer structure. In acid solution, geopolymer compressive strength is greater than Ordinary cement concrete (Zhang Yunsheng et al. 2007; Djwantoro Hardijito et al. 2004; Singh et al. 2021).

55.2 Experimental Details

55.2.1 Source of Resource Materials

The raw materials were collected from Usha martin, Ranchi and Tata Steel Tata, their chemical compositions were determined by conventional and spectroscopy method are given in Table 55.1.

55.2.2 Nature of Resources Materials

Particle size (Table 55.2) were determined from Sieve analysis and specific density (Table 55.3) were determined by Pycnometer.

Table 55.1 Ingredient of resource materials

Constituent	FA	B.A	GBFS slag
SiO_2 (%)	50.96	51.80	14.20
Al_2O_3 (%)	29.70	16.30	2.70
Fe_2O_3 (%)	9.65	13.75	25.35
CaO (%)	2.20	3.65	42.83
MgO (%)	0.80	1.60	5.05
Na_2O (%)	0.60	0.40	—
K_2O (%)	0.40	0.50	—

Table 55.2 Particle size distribution of resource materials

Sieve no.	Fly ash (retained wt. in %)	GBFS (retained wt. in %)	Bottom ash (retained wt. in %)
+229 μ	20	42	98
−229 μ, +149 μ	38	10	2
−149 μ, +74 μ	30	26	0
−74 μ, +44 μ	6	8	0
−44 μ	2	10	0

During Sieve analysis 6% fly ash and 4% GBFS were loosed

Table 55.3 Physical properties of resource materials

Physical property	F. A	B. A	GBFS
Color	Grayish	Grayish	Shed grayish
Visible shape	dust	Dust	Dust
Plastic property	Not plastic	Not plastic	Not plastic
Specific density	1.97	1.96	2.90

55.2.3 X Ray Diffraction Analysis

Mineralogical phase was determined by XRD analysis with 2°/min scanning rate between 10° and 80° using Kα radiation.

55.2.4 Scanning Electron Microscopy Analysis

Surface morphology and elemental analysis of microphase were determined by Scanning Electron Microscope (JSM-6390LV) with an EDAX attachment.

Table 55.4 Composition of F. A-B. A -GBFS (FBG) Geopolymers Sample

Sample Nomenclature	Sample compositions				
	F.A (gram)	B.A (gram)	GBFS (gram)	Molarity of NaOH	Silica/alumina ratio
2FBG6M	2400	800	800	6M	2
3FBG6M	2400	800	800	6M	3
4FBG6M	2400	800	800	6M	4
2FBG10M	2400	800	800	10M	2
3FBG10M	2400	800	800	10M	3
4FBG10M	2400	800	800	10M	4
2FBG14M	2400	800	800	14M	2
3FBG14M	2400	800	800	14M	3
4FBG14M	2400	800	800	14M	4

Where 2, 3, 4 number is Si/Al ratio, 6M, 10M and 14 M is molarity of NaOH solution

55.2.5 Preparation of Geopolymer Samples

GBFS blended with bottom ash and fly ash based geopolymer samples were prepared with various activator solutions 6M, 10M and 14M sodium hydroxide by maintain various Si/Al ratio 2,3 and 4 by mass. It is shown in Table 55.4. The size of cylindrical sample is as per standard (diameter is 3.48 cm and height is 4.30 cm).

55.2.6 Compressive Strength Test

After curing at 7-, 28- and 60-days triplicate samples were used for determination of C.S of Samples. The loading rate was 2 MPa/min was used in testing machine. The unit of compressive strength measured in MPa.

55.2.7 Durability Test

The durability test of sample was conducted in various concentration of H_2SO_4, CH_3COOH, Na_2SO_4, $MgSO_4$ and NaCl solutions for exposure duration 7, 28 and 60 days. The C.S of various sample was determined after test and find out the extent of reduction in compressive strength which is caused by exposure of various chemical environment.

55.3 Results

55.3.1 Result of Mineralogical Composition of Resource Material

The mineralogical composition of fly ash, bottom ash and blast furnace slag were determined by using XRD. XRD shows that mullite and quartz phase (Fig. 55.1a, b) were present in fly ash and bottom ash which is crystalline in nature. However, gehlenite phase (Fig. 55.1c) was present in granulated blast furnace slag (Singh et al. 2021).

55.3.2 Results of Compressive Strength

After curing for 28 days the compressive strength of FBG sample was the function of Si/Al ratio and concentration of activator solution (NaOH). The minimum strength was 15.71MPa for 6M NaOH solution with Silica/Alumina ratio 2 and the

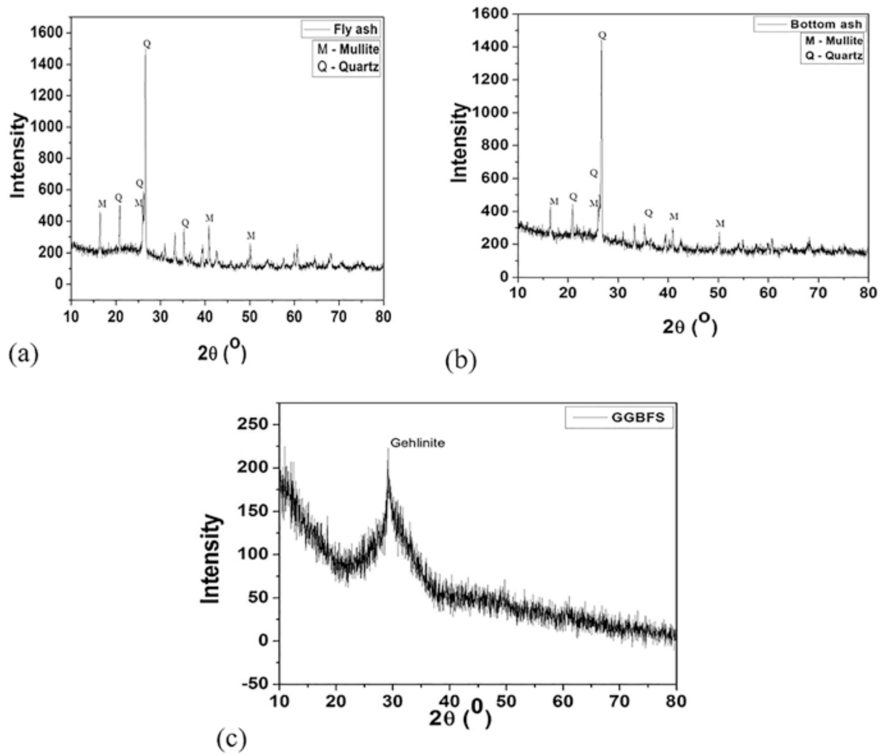
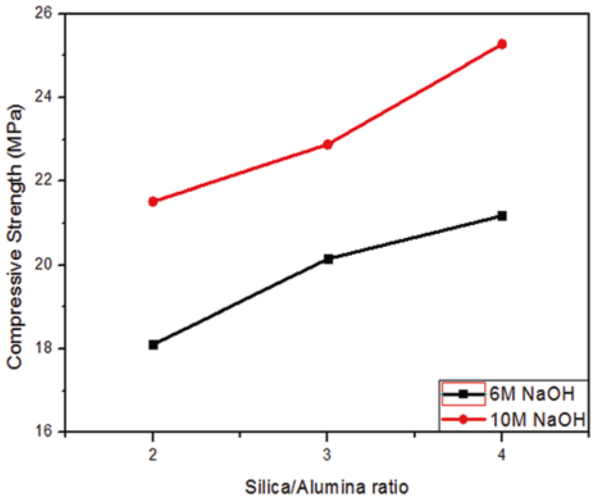


Fig. 55.1 (**a**) for Fly ash (**b**) for Bottom ash (**c**) for GBFS

Fig. 55.2 Variation in Compressive strength of Geopolymer samples (FBG)



maximum strength was 25.26 MPa for 10M NaOH solution with Silica/Alumina ratio 4 in FBG samples as shown in Fig. 55.2.

The strengths of the geopolymers depend on the concentration of the activator used in specimen preparation and Si/Al ratio. The specimens that were prepared with high concentration sodium hydroxide and high Si/Al ratio gained more compressive strength than specimens prepared with low concentration sodium hydroxide activator and low Si/Al ratio.

55.3.3 Result of Durability Test

According to IS456:2000, durability test was conducted in various chemical environment [1% and 3% H_2SO_4, CH3COOH, Na_2SO_4, $MgSO_4$ and NaCl solutions] for exposure duration of 7, 28 and 60 days. After 7, 28 and 60 days the compressive tests were done for find to how much reduced in compressive strength (C.S) in acid and salt solution to comparison to air exposed sample. The change in compressive strength for 7 days is shown in the Fig. 55.3, 55.4, 55.5, 55.6, 55.7, and 55.8. The results showed that the compressive strength of the specimens which were immersed in sulphuric acid decreased more in comparison to the specimens that were immersed in acetic acid. It depends on the concentration of the acid. Concrete requires different degrees of durability depending upon its use (Rodríguez et al. 2008). The C.S of samples immersed in acid was decreased to compare of bare samples (air). The graphs also showed that the C.S depends on concentration of activator solution in each case. Geopolymer FBG 14M specimens with Si/Al ratio 4 were the most resistant in acid as well as salt solution in all aged 7, 28 and 60 days. Mostly FBG samples are acidic resistant (Figs. 55.3, 55.4, 55.5, 55.6, 55.7, and 55.8). In sodium chloride solution, the compressive strength of the FBG samples was decreased in

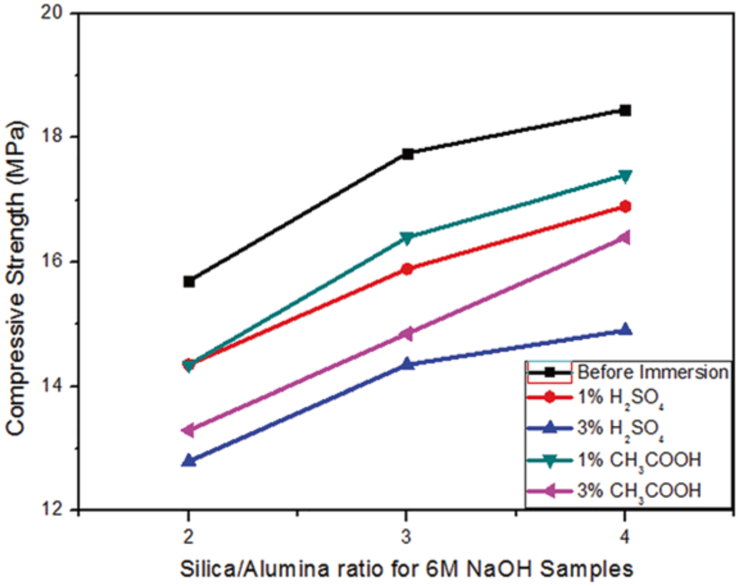


Fig. 55.3 C. S for FBG6M samples after 7 days exposure

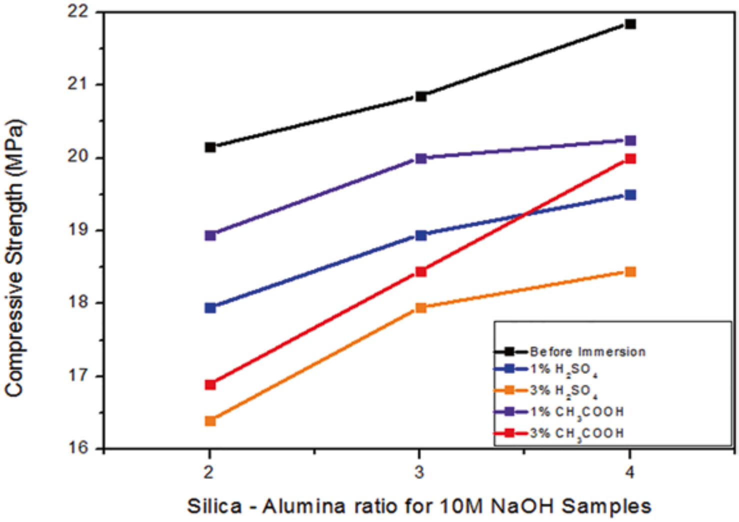


Fig. 55.4 C. S for FBG10M samples after 7 days exposure

comparison to the specimens that were immersed in other salt. FBG14 M sample (Si/Al ratio 4) was produced 30 MPa compressive strength (maximum) and more resistant in salt and acid solutions as shown in Figs. 55.5, 55.8, 55.11, 55.14, 55.17 and 55.20. The compressive strength of the samples decreased with increase of

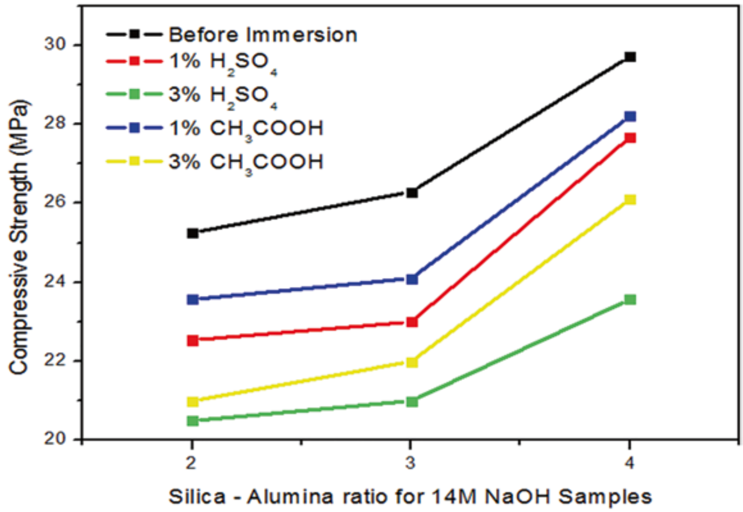


Fig. 55.5 C. S for FBG14M samples after 7 days exposure in acid solutions

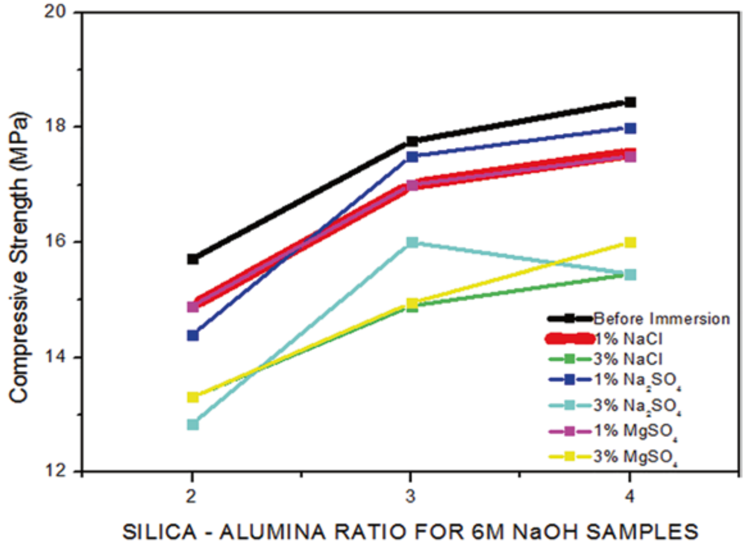


Fig. 55.6 C. S for FBG6M samples after 7 days exposure in salt solutions

sulphate and chloride concentration. The compressive strength of FBG samples were change in acid and salt solutions for 28 days are shown in Figs. 55.9, 55.10, 55.11, 55.12, 55.13, and 55.14. The compressive strength of samples decreased with increase of immersion time. The change in compressive strength of FBG geopolymer samples after immersion in acid and salt solutions for 60 days are shown in Figs. 55.15, 55.16, 55.17, 55.18, 55.19, and 55.20. Mostly similar trends were

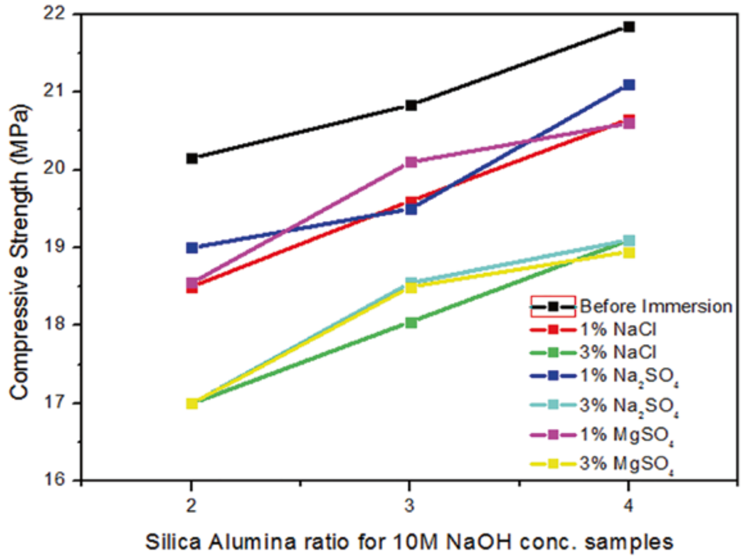


Fig. 55.7 C. S for FBG10M samples after 7 days exposure in salt solutions

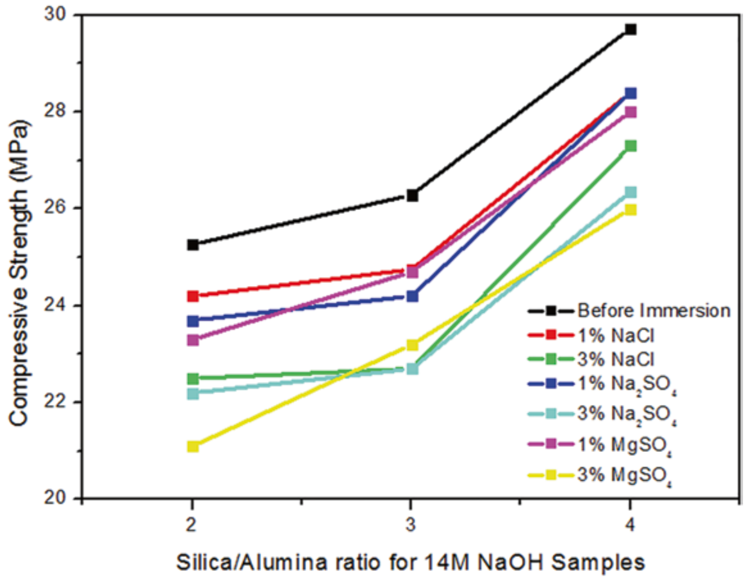


Fig. 55.8 C. S for FBG14M samples after 7 days exposure in salt solutions

observed. In acidic medium, the texture of the sample surface was changed due to deposition of acid ions. It also reacted with Si-O-Al skeleton bonds. Formation of Si-OH and Al-OH groups in geopolymers are responsible for the breakage of

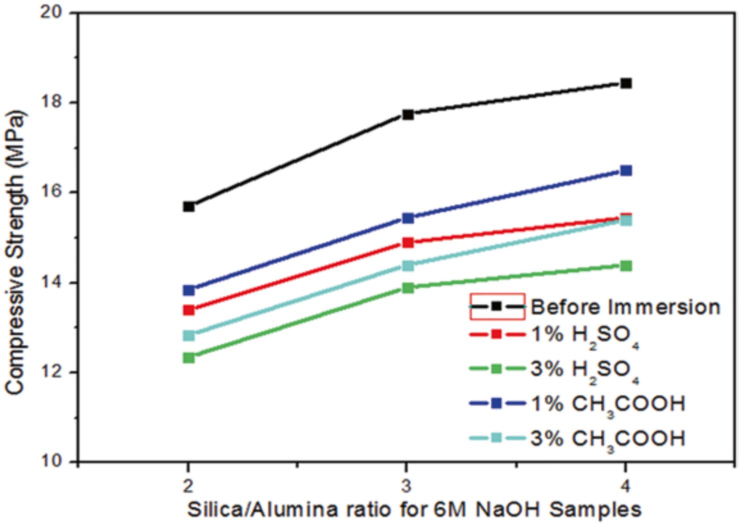


Fig. 55.9 C. S for FBG6M samples after 28 days exposure in acid solutions

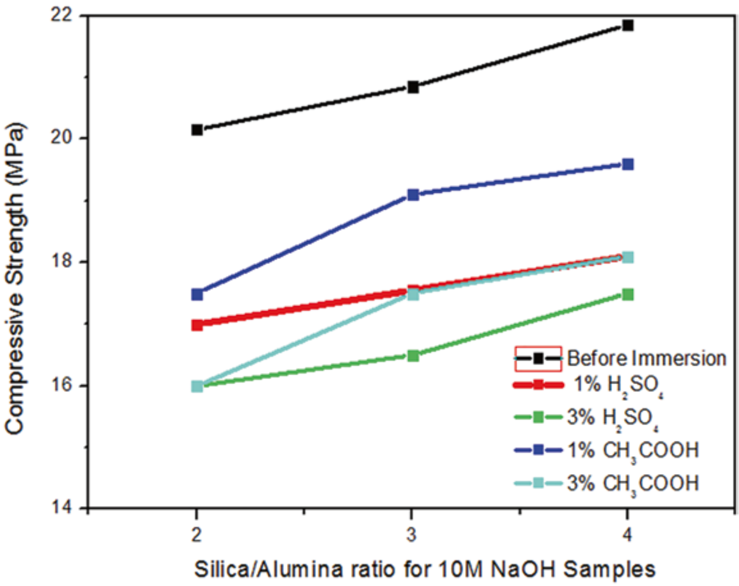


Fig. 55.10 C. S for FBG10M samples after 28 days exposure in acid solutions

geopolymer skeleton structure and increased amount of silicic acid ions and dimers in solution and this process provide to the weight loss of the geopolymer materials. After immersion in the H_2SO_4 solution the surface texture of samples changed from smooth to rough. There is no much change in the surface texture of samples after

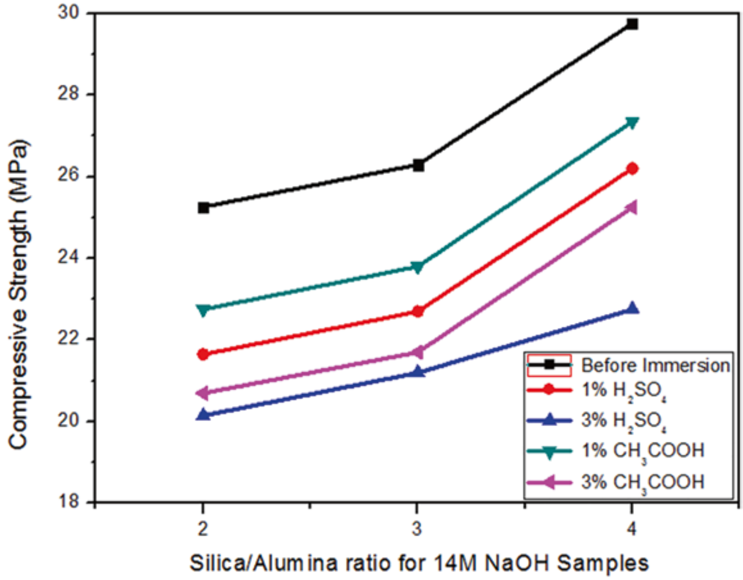


Fig. 55.11 C. S for FBG14M samples after 28 days exposure in acid solutions

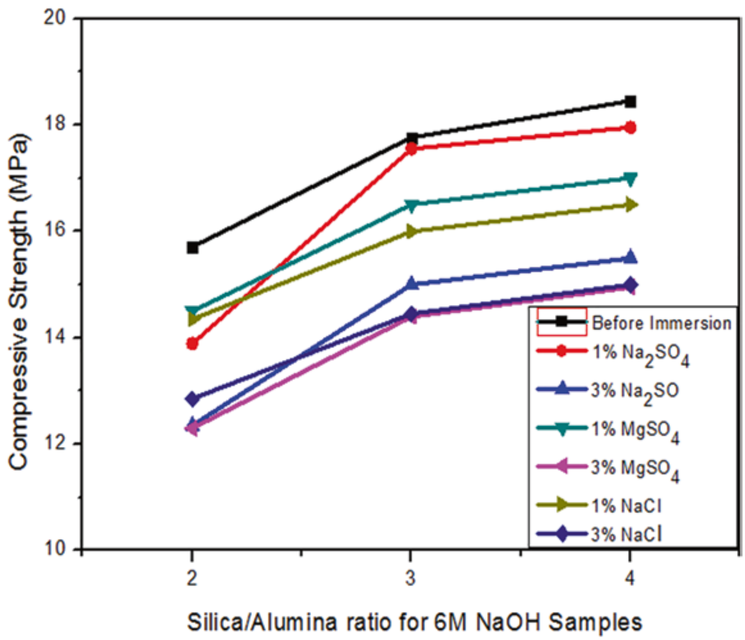


Fig. 55.12 C. S for FBG6M samples after 28 days exposure in salt solutions

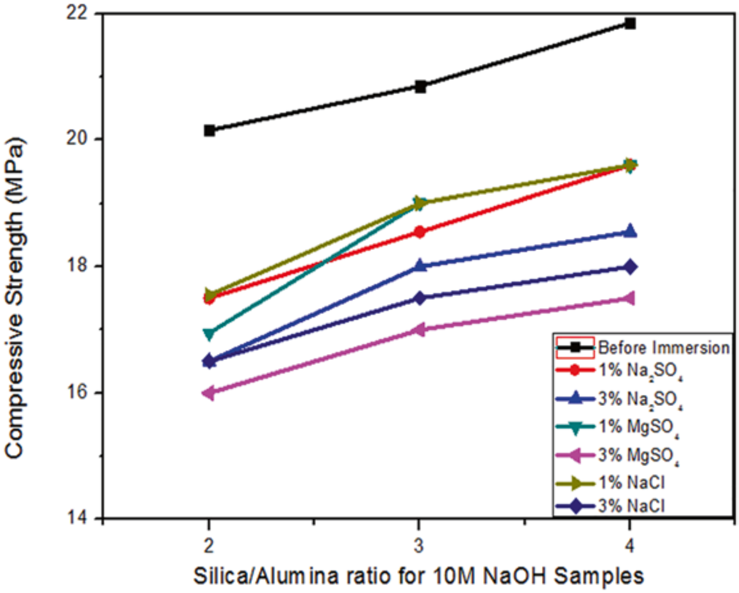


Fig. 55.13 C. S for FBG10M samples after 28 days exposure in salt solutions

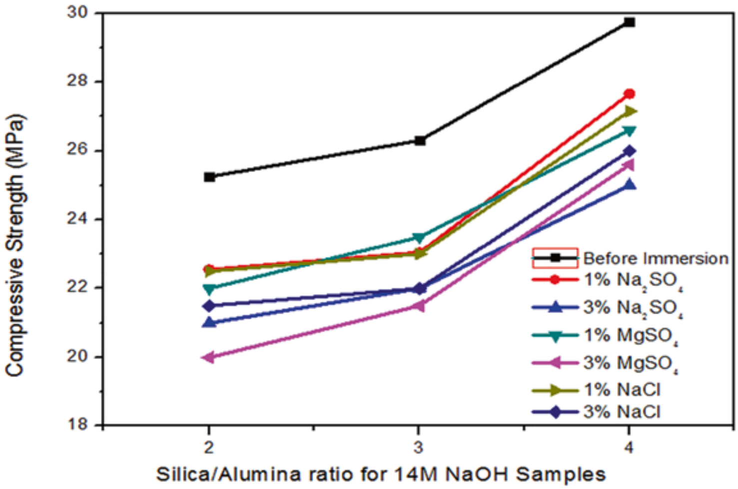


Fig. 55.14 C. S for FBG14M samples after 28 days exposure in salt solutions

immersion in acetic acid. In the salt solution; there was no change in surface. It was as smooth as before the test. Depositions of salt layers were observed on the samples after immersion in salt solutions.

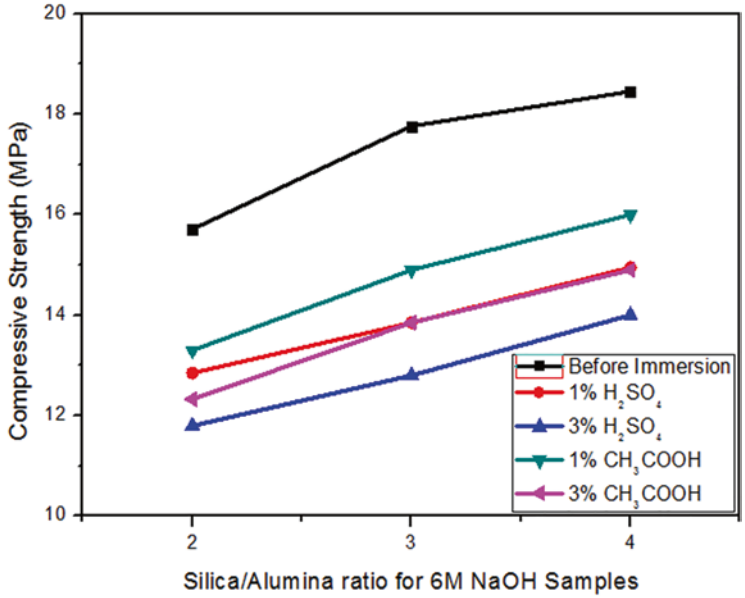


Fig. 55.15 C. S for FBG6M samples after 60 days exposure in acid solutions

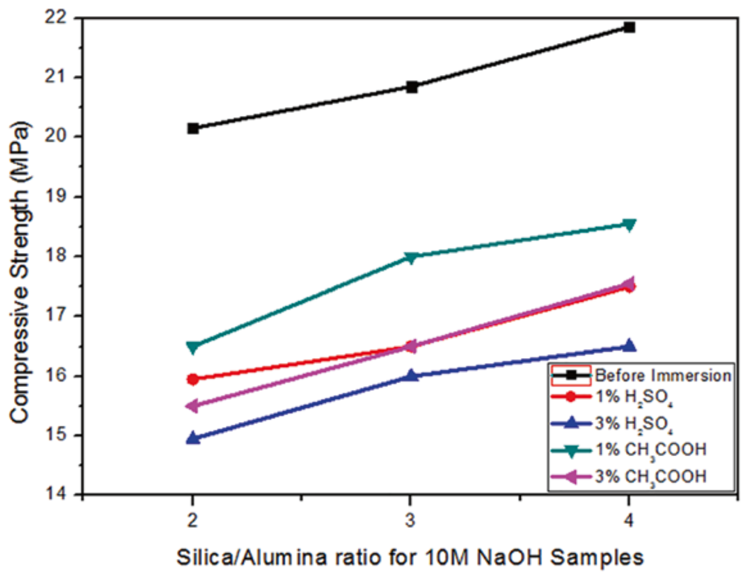


Fig. 55.16 C. S for FBG10M samples after 60 days exposure in acid solutions

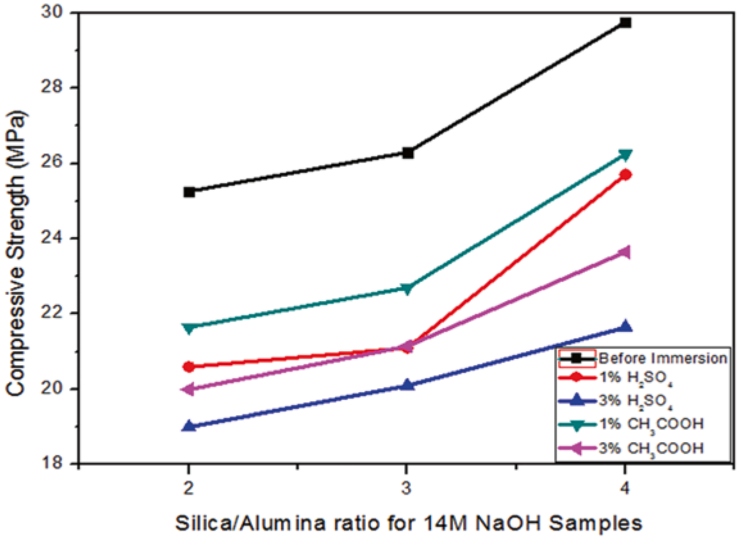


Fig. 55.17 C. S for FBG14M samples after 60 days exposure in acid solutions

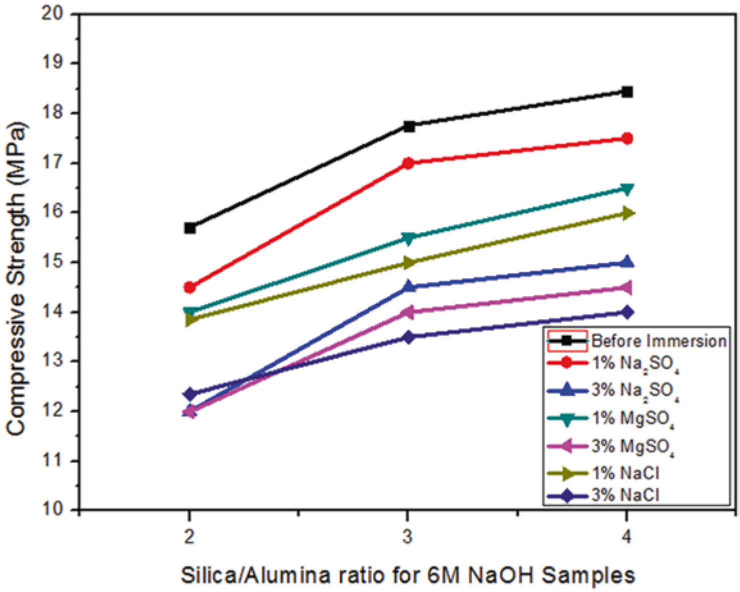


Fig. 55.18 C. S for FBG6M samples after 60 days exposure in salt solutions

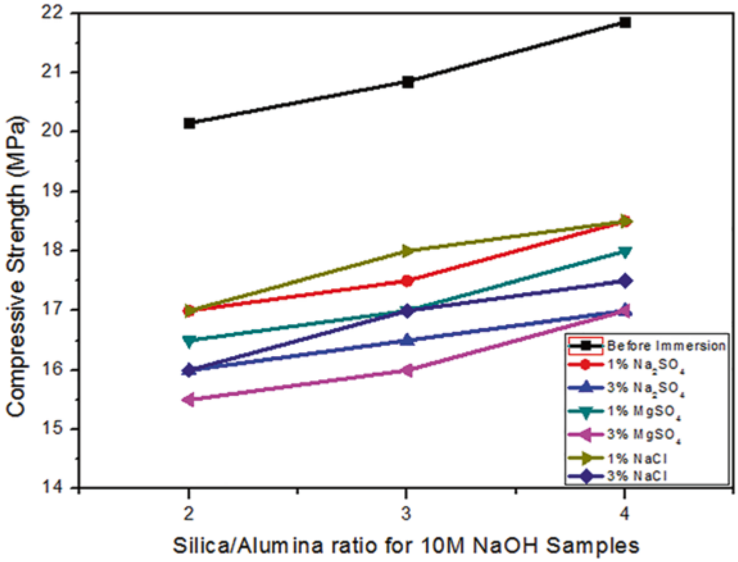


Fig. 55.19 C. S for FBG10M samples exposure of 60 days in salt solutions

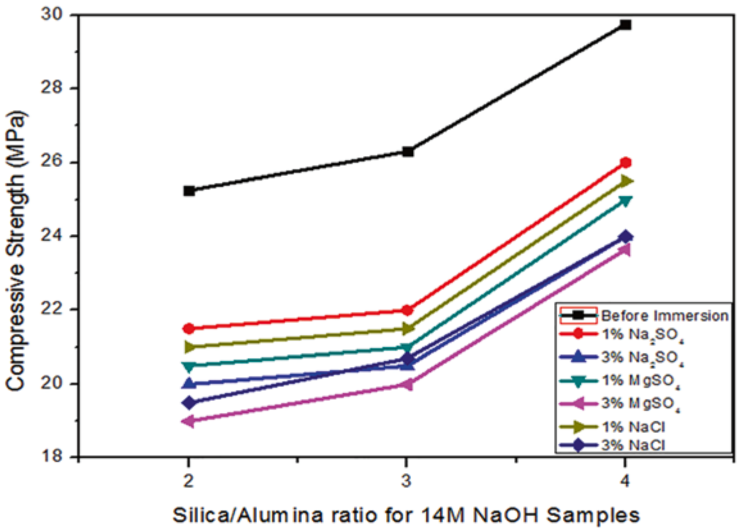


Fig. 55.20 C. S for FBG14M samples exposure of 60 days in salt solutions

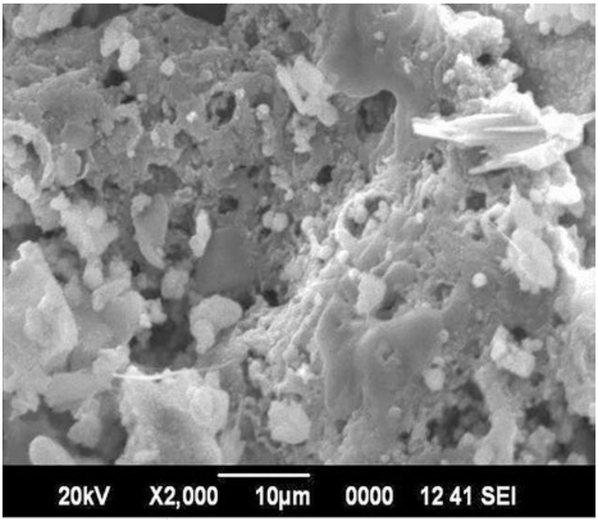
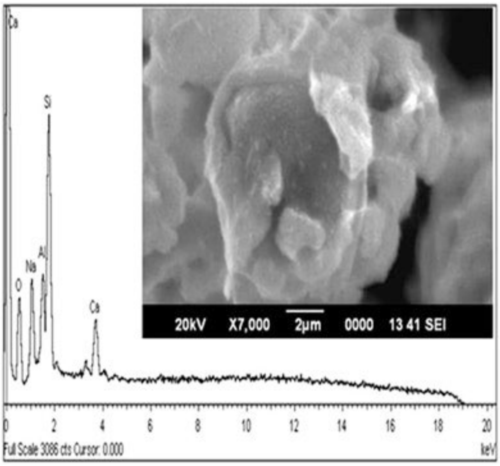


Fig. 55.21 Reactive geopolymeric phase of FBG6M Samples (Si/Al = 2)



Element	Weight%	Atomic%
O K	43.65	57.22
Na K	13.44	12.26
Al K	8.72	6.78
Si K	26.20	19.56
Ca K	7.99	4.18
Totals	100.00	

Fig. 55.22 Geopolymeric gel phase of FBG6M samples (Si/Al = 2) & their EDS

55.3.4 *Result of SEM and EDAX Analysis*

Morphological characterizations of the fractured samples were carried out by JEOL scanning electron microscope with an EDAX attachment. A 2 nm layer of carbon coated sample were used for imaging in the scanning electron microscope. Reactive geopolymeric phase of FBG6M Samples (Si/Al = 2) show highly heterogeneous material contain fly ash and slag grain shown in Fig. 55.21. Fly ash particle are

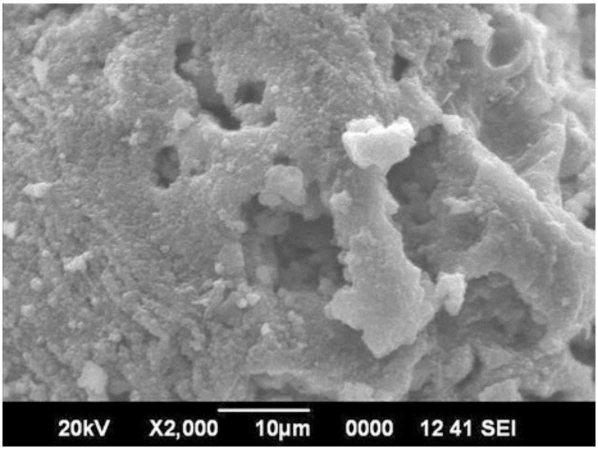
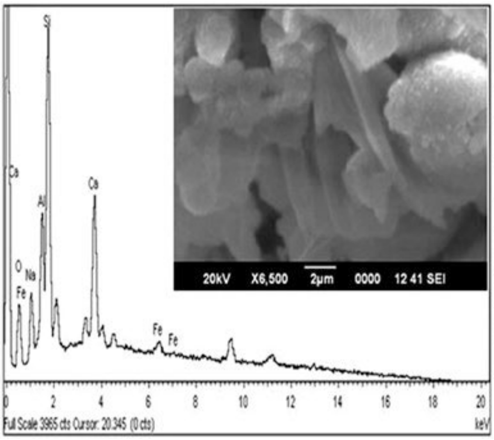


Fig. 55.23 Reactive geopolymeric phase of FBG6M Samples (Si/Al = 4)



Element	Weight%	Atomic%
O K	35.19	50.37
Na K	8.31	8.28
Al K	9.94	8.43
Si K	27.55	22.46
Ca K	16.48	9.42
Fe K	2.53	1.04
Totals	100.00	

Fig. 55.24 Geopolymeric gel phase of FBG6M samples (Si/Al ratio 4) & their EDS

spherical while slag (GBFS) is angular. Figure 55.22 show the microanalysis of geoplymeric gel phase of FBG6M samples, which contain 26% silica. The gel phase appears as a homogeneous phase and reaction also enhanced by increasing concentration of Si/Al ratio (Fig. 55.23) and their EDAX analysis (Fig. 55.24). It is clear that the reaction products consist of fly ash geopolymer phase and the remnant of a slag grain phase. The morphology and EDAX analysis of FBG10M samples are shown in Figs. 55.25 and 55.26. The thin-walled hollow sphere was clearly shown in Fig. 55.26. The SEM images and their EDAX analysis which clearly indicates that homogeneity and reactivity increase by increasing concentration of alkali and ratio of silica and alumina as shown in Figs. 55.27, 55.28, 55.29, and 55.30. According to EDAX analysis, the result was the atomic percentage of Si/Al ratio

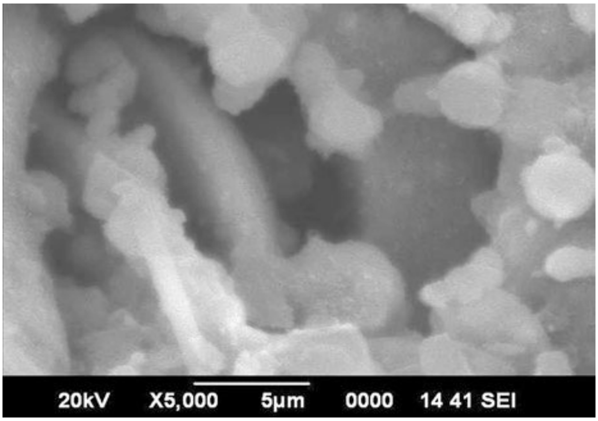
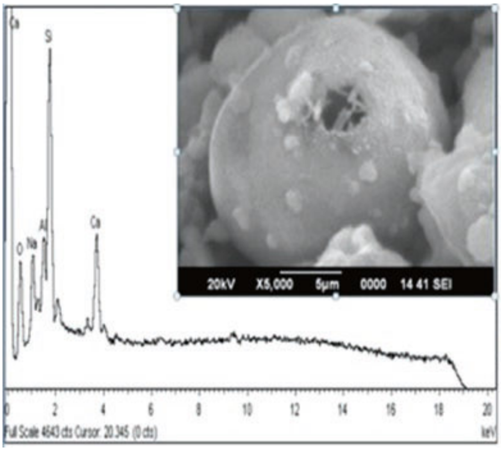


Fig. 55.25 Geopolymeric gel phase of FBG10M Samples (Si/Al = 4)



Element	Weight%	Atomic%
O K	45.61	60.07
Na K	9.95	9.12
Al K	6.88	5.37
Si K	25.40	19.05
Ca K	12.17	6.40
Totals	100.00	

Fig. 55.26 Reactive fly ash surface phase of FBG10M Samples (Si/Al = 4) & their EDS

2.88. The microstructure of the sample as shown in Fig. 55.29 was cenosphere (thin-walled hollow spheres) and texture of the surface is smooth and dense to highly porous. GBFS shape is edges and angles due to griding technique or inter-impacting and inter rubbing in ball mill with steel balls. Aluminosilicate gel was formed by the reaction between the fly ash and sodium silicate (alkaline activator) which covered the fly ash particles and produced a dense matrix (Fig. 55.29). The cementious phase of the geopolymers was observed in the Fig. 55.27. The improvement in micro structural homogeneity and reactivity is the main reason for the increase in mechanical properties at higher Si/Al ratios and higher concentration of alkali.

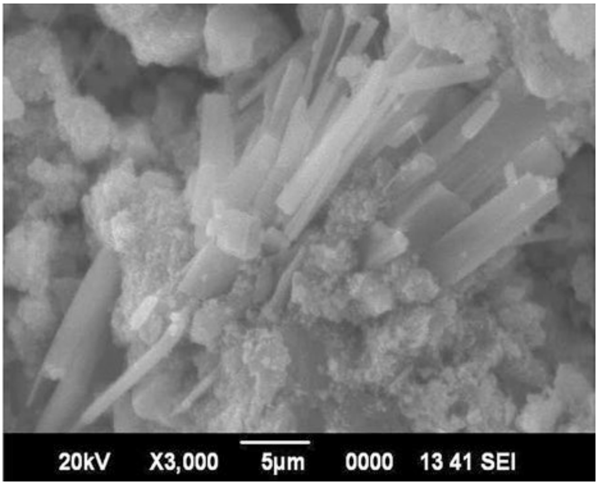
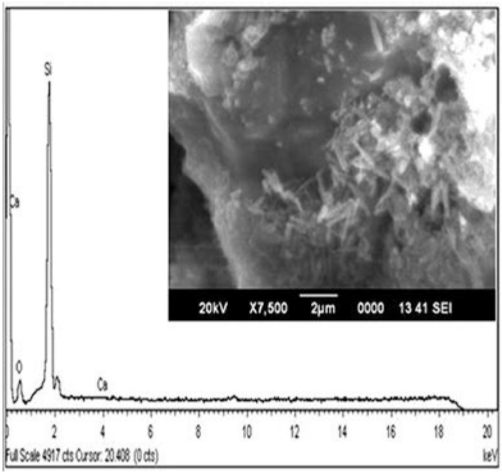


Fig. 55.27 Geopolymeric cementite phase of FBG14M Samples (Si/Al = 2)



Element	Weight%	Atomic%
O K	32.24	45.51
Si K	67.71	54.46
Ca K	0.05	0.03
Totals	100.00	

Fig. 55.28 Geopolymeric reactive phase of FBG14M Sample (Si/Al = 2) & their EDS

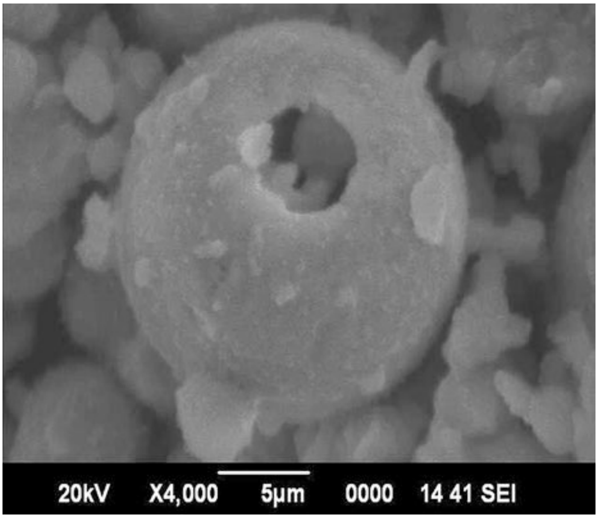
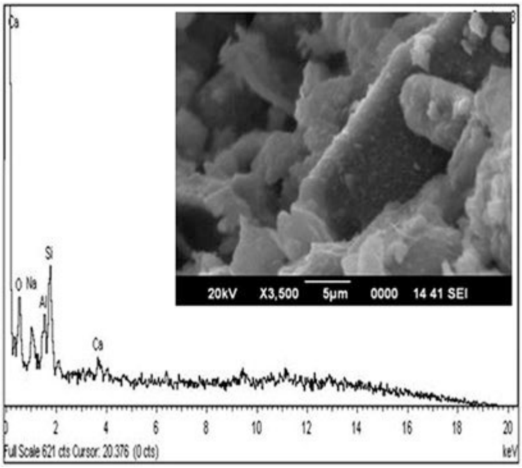


Fig. 55.29 Geopolymeric fly ash surface phase FBG14M Samples (Si/Al = 4)



Element	Weight%	Atomic%
O K	53.00	65.92
Na K	10.92	9.45
Al K	9.29	6.85
Si K	21.15	14.98
Ca K	5.65	2.80
Totals	100.00	

Fig. 55.30 Geopolymeric reactive phase of FBG14M sample (Si/Al = 4) & their EDS

55.4 Conclusions

The C. S of samples was depending on concentration of sodium hydroxide activator and Si/Al ratio. The maximum C. S was 30 MPa found in 4FBG14M samples. As per IS code SP 23- 1982. The samples is used as geopolymer concrete. The geopolymer samples were good resistance in acid and sulphate solution and their resistivity increased with increasing the concentration of alkali. The surface texture of the samples was changed from smooth to rough in exposure of H_2SO_4 solution and acetic acid solution. The reduction in compressive strength of the samples were more in sulfuric acid in comparison to acetic acid and also with increasing exposure duration (7, 28 and 60 days). After exposure of 1–3% in sulfuric acid, acetic acid, magnesium sulfate, sodium sulfate and sodium chloride solution reduction in compressive strength was in the range of 15–25%, 12–22%, 14–20%, 11–17% and 13–17% respectively. On the basis of results, it can be concluded that geopolymer samples were durable in 60 days exposure of various types of acids and salt solutions.

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Chapter 56
Comparative Studies of Compressive Strength on Different Brick Masonry Prisms

D. Jegatheeswaran and M. Soundar Rajan

Abstract This study explores the various brick categories and their masonry prisms in terms of their compressive loading. It aims to identify the similarities and differences in the strength of these various bricks. The horizontal impact resistance of a masonry infill wall prototype that is based on the strength of its masonry prism and the horizontal de-forming structure of its replica.

A masonry prism is a grouping of units that consists of mortar and grout. It is mainly used for construction of masonry buildings. Clay brick masonry prisms have the biggest cumulative energy dissipation and the greatest performance. However, their behavior is non-elastic.

Keywords Compressive forces · Consequence of brick samples · Masonry prototype · Stress-strain trajectory

56.1 Introduction

Masonry Structures is the primogenital construction ingredients familiar to gentleman supposed to use for over long ago. This type of building method remains moderately widespread in all over the world and is experienced widely at present (Crisafulli and Carr 2007; Foytong et al. 2013). It is comprised of couple of dissimilar ingredients specifically: the masonry assembly and the bonding segment. This assembly could be prepared of a mixture of ingredients. The dual stages in masonry were bonded with pathetic edge and this is commonly dull in lateral stress.

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This Structure is consequently expected to keep away on forces. Instead, masonry samples experienced to gain correct value of the strength in compression nature. The horizontal impact resistance capacity of the wall prototype depends on the compressive stress of the prism, and the horizontal deformations of the wall prototype relate the strain at the ultimate pressure of the prism. The compressive strength is a measure in relation to the compressive stress, which specifies the failure of the material un-der compressive loading (Mehrabi et al. 1996; FEMA 306 1998; Mostafaei and Kabeyasawa 2004).

56.2 Discussion on Materials

56.2.1 Bricks

This study examined the brick, masonry prisms and mortar bonding under compressive loading to find the similarity of compressive strength between various brick types. Four types of brick, which are generally used. They are Aerocon blocks, hollow brick, lightweight block and clay brick. Three samples of each brick type are tested. The average measurements of brick samples are shown in Table 56.1 and Fig. 56.1.

56.2.2 Masonry Prism

The masonry prism samples of each brick type are constructed and tested. A masonry prism sample has to be longer than 100 mm and is built of a minimum of two units. A ratio of height of specimen to thickness ratio of specimen is between 1.3 and 5.0. The dimension parameters of the brick masonry prism samples are expressed in Table 56.2. Two kinds of bricklaying mortar are used. Portland cement is used for the clay brick, Aerocon blocks and hollow brick samples with a compressive stress of 8.23 MPa, and light weight block bricklaying mortar is used for the lightweight block samples with a compressive stress of 17.78 MPa. After bricklaying, the samples were wrapped for 7 days. For the plastering mortar, Portland cement is used for the clay brick, Aerocon blocks and hollow brick samples, and light weight block plastering mortar is used for the lightweight block (Dayaratnam et al. 1981; Elangonmani 1983).

Table 56.1 Average dimensions and compressive stress of brick samples

Type	Length (cm)	Width (cm)	Height (cm)	Stress (MPa)
Aerocon Block (AB)	60.0	23.0	20.0	4.11
Hollow Block (HB)	38.9	6.5	19.0	4.76
Light Weight Blocks (LWB)	60.0	7.5	20.0	2.62
Clay Brick (CB)	13.9	6.0	5.5	14.65

Fig. 56.1 Type of brick samples

Table 56.2 Average dimensions masonry prism samples

Type	Length (cm)	Width (cm)	Height (cm)	h_p/t_p
Aerocon Block (AB)	49.4	37.7	8.93	4.23
Hollow Block (HB)	40.2	39.9	8.59	4.64
Light Weight Blocks (LWB)	40.7	40.4	9.37	4.31
Clay Brick (CB)	45.4	34.1	7.80	4.37

56.3 Experimental Program

Brick samples and masonry prism samples are tested under compressive loading by a universal testing machine with a capacity of 10,000 kN. All samples for both the brick and prisms are enclosed before testing. The compression load was transferred to the sample by inflexible beams. Two linear uneven differential transformers were placed to assess the deformation of the prism samples. During the investigation, the compression force and deformation were noted (Fig. 56.2).

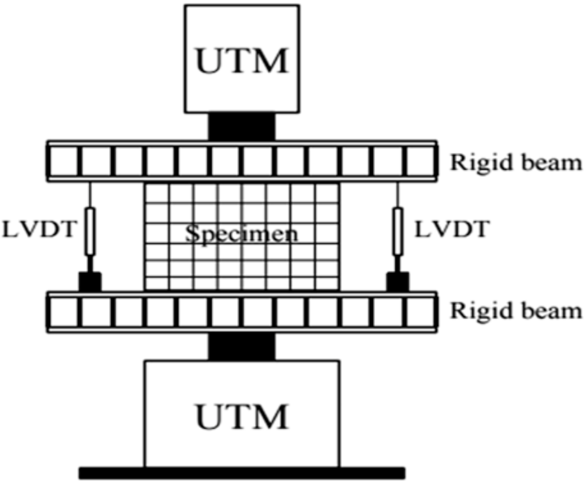

Fig. 56.2 Test setup for masonry prism samples

Table 56.3 Average compressive stress, strain and energy dissipation of masonry prism

Type	P_{max} (kN)	σ_{max} (MPa)	ε at σ_{max} (mm/mm)	Cum. energy dissipation at σ_{max} (N/mm)
AB	162.2	3.98	0.00588	153.7
HB	131.6	3.81	0.00490	115.2
LWB	135.3	3.55	0.00651	159.0
CB	146.1	4.12	0.00708	162.6

56.4 Experimental Results

56.4.1 Compressive Strength of Masonry Prisms

Aerocon Blocks shows largest compressive stress of 29.97 MPa. The compressive strength of LWB is the least with a value of 2.62 MPa. The clay brick strength is 14.6 MPa. The compressive strength of clay brick is superior to the strength of the hollow brick and light weight block, respectively (Gumaste et al. 2004; Raghunath and Jagadish 1998).

The correction factors for the masonry prism samples are included in testing. Three samples are investigated for each brick type. The stress-strain relationship is obtained for all masonry prisms under compressive loading. The ultimate compressive force, ultimate compressive stress and strain at the ultimate stress of the prism for each brick type specimen samples are listed in Table 56.3 and Figs. 56.3, 56.4, 56.5, 56.6 and 56.7.

The stress-strain relationships of the masonry prism for the similar brick type start with the parallel trend of initial slope. After cracking of the materials in the masonry prism, the material properties are dissimilar. The stress behavior of each masonry prism is yielding, after the peak stress of masonry prism feels more deformation (Sarangapani et al. 2005).

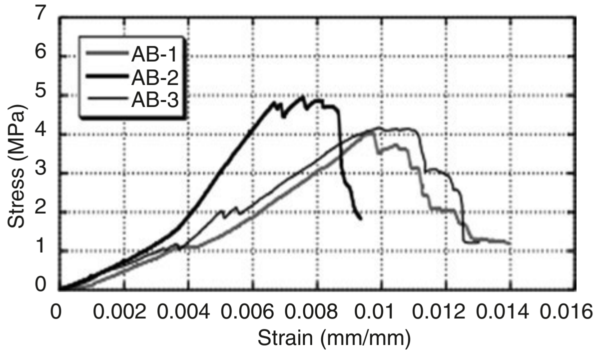

Fig. 56.3 Stress – Strain trajectory relationship for Aerocon block masonry prism

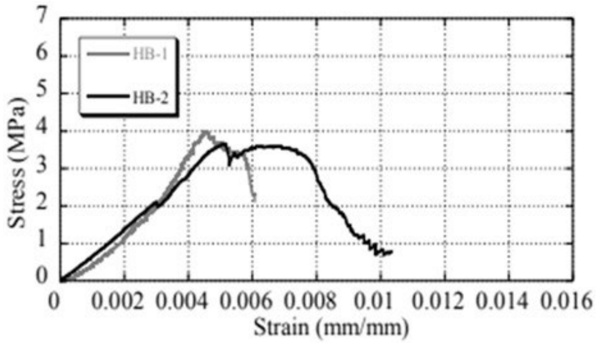

Fig. 56.4 Stress – Strain trajectory relationship for Hollow block masonry prism

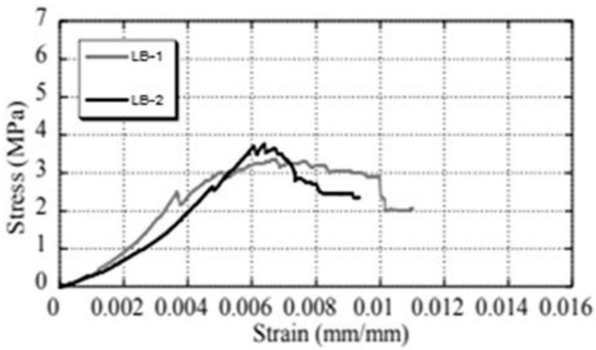

Fig. 56.5 Stress – Strain trajectory relationship for Light weight block masonry prism

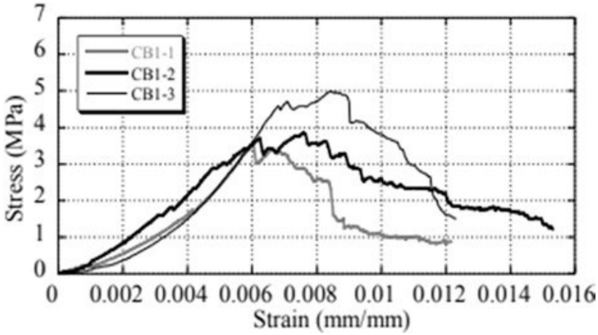

Fig. 56.6 Stress – Strain trajectory relationship for Clay brick masonry prism

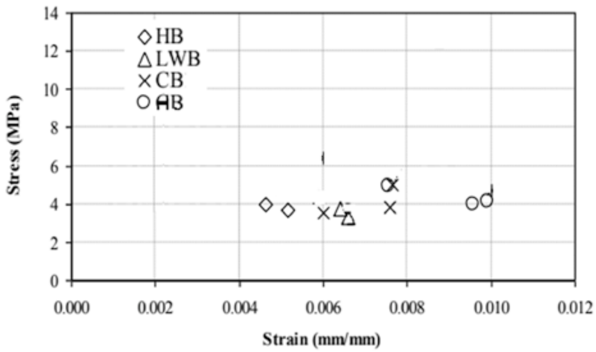

Fig. 56.7 Comparison of ultimate stress – Strain trajectory relationship of masonry prism

The development of ultimate compressive strength of masonry prism and brick is similar. The ultimate compressive stress is in the masonry prism made of CB with the compressive stress of 10.80 MPa.

The least compressive stress is the masonry prism made of LWB with the ultimate confining stress of 3.55 MPa. The strength of each prism was sorted from ultimate to minimum, based on masonry prisms made of CB, HB, AB and LWB with the compressive stresses of 10.80 MPa, 5.55 MPa, 4.37 and 3.55 MPa, respectively.

The compressive strengths of masonry prisms made of clay brick are still greater than the compressive strengths of prisms made of hollow brick and light weight block (Varghese and Ashok Kumar 1965). However, the different stresses of the masonry prisms are not big as those of the brick types, due to the properties of brick type and manufacturing practices.

Strains at the ultimate stress of the prisms made of the similar brick type are drawn-out. Strains of prisms made of typically clay brick are larger than the strain of prisms of hollow block, Aerocon block and light weight block. The collective energy dissipation at the ultimate stress for all brick masonry prism samples is also exposed. The ultimate collective energy indulgence of prisms made of CB is largest at 162.6 N/mm.

56.5 Conclusion

This paper investigates the compressive stress of brick masonry prisms according to ASTM standard as the fundamental limitations for appraising horizontal impact resistance of walls and to identify the similarity of compressive strength between various brick types.

- A solid clay brick gives the ultimate compressive stress of 29.37 MPa. The compressive stress of LWB is the minimum stress of 2.62 MPa.
- The compressive stresses of clay brick are superior than the compressive stresses of Aerocon block, hollow brick and lightweight block.
- The stress-strain curves of masonry prisms for the same brick type initiate with a like trend of an initial slope.
- Behind the peak stress, the behavior of the prism is yielding that undergoes additional deformation.
- The least compressive stress is prism made of lightweight block with the compressive stress of 3.55 MPa.
- The extreme stress-strain of brick masonry prisms made of clay brick are larger than those made of hollow brick and lightweight block.
- The masonry prisms made of clay brick display the most excellent performance with the major stress and largest cumulative energy dissipation, but their behavior is non-yielding.

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Chapter 57
Monitoring and Management of Construction Sites Using Drone

M. N. A. Gulshan Taj, R. Prema, S. Anand, A. Haneefi, R. P. Kanishka, and D. H. A. Mythra

Abstract Drone is an emerging technology, recently the application of drone has been increased for the purpose of surveying. Drone surveying is safer and fast, compared to conventional method of surveying. Its a cost-efficient way of surveying in case of inaccessible areas. Drones are affordable, faster and has very less health and safety risks compared to setting up scaffolding and access platform. The usage of drones is rapidly increasing in various fields, due to the rapid growth in technology. It acts as a tool to monitor their construction projects visually. The examination of structures using drone helps in development of efficiency and quality of the structure. The GPS point of the construction site to be monitored is marked manually with the help of GPS essential mobile application. They are exported as kml file to google earth software to make a boundary map of the site, the GPS points at the corners of the site are connected to make the boundary map and exported in the form of kml. This file is manually imported in Drone deploy application and the flight path is made according to the direction of the site, the basic settings such as altitude, overlap, flight speed, etc. are made and set to fly. The input data is collected in form of images are imported to context capture master software. The camera properties of the input data are checked and aero triangulation, reconstruction settings are made and final production is done to get 3Dmodel output of the images. The required data is processed from the 3D model. IOT has the ability to transfer data over a network, when linked with API, which is an intermediatory software that allows two applications to communicate each other, it transfers message between systems. A basic system application is developed with help of python, and linked with API to send the data obtained from the processed 3D model.

Keywords Drone · UAV · Construction site · Monitoring · IoT · Survey · API

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57.1 Introduction

Drone is an aircraft without human pilot on it, it has ability to capture high resolution images from air. Drones are also called as an unmanned aerial vehicle (UAV). A UAV is a type of unmanned aircraft that has six functional categories: target and decoy, combat, reconnaissance, logistics, and research and development (FajarRizki et al. 2017). Originally, drones were used for missions that were very dangerous or difficult to perform. As their popularity has grown, they are now being utilized in various other applications such as commercial, scientific, recreational, agricultural, policing and surveillance, product deliveries, aerial photography, infrastructure inspections, and drone racing.

In Civil engineering, surveying, monitoring and mapping plays a vital role (Fawad Ahmed Najam et al. 2018). To make a precise mapping drone are very effective. Drone surveying is safer, quicker and cost-effective way to perform survey at high altitude. It can be able to collect data of underground structures easily. The accuracy obtain from drone surveying is much greater than the conventional survey (Sarazzi et al. 2011). The accuracy and high resolution of images can be obtained by using good quality digital camera fixed on the drone. It can also be achieved by using modified lens attached to it.

Today, most drones are multirotor, fixed wing, and single rotor. These types of drones are commonly used for various applications. Some of them are photography, videography, and surveying. In fixed wing drones, the thrust produced by the wing's forward movement is used to generate vertical lift (Saadatseresht et al. 2015). These drones can also traverse long distances and stay within their target's proximity. A single rotor helicopter drone has the same thrust as a multi-rotor aircraft, and can be powered using a gasoline engine. Hybrid drones that can take off and fly vertically are also being developed. Some of the advantages of using drone survey include; reduced risk, better data quality, faster acquisition of data, and reduced cost of doing business (Ahmad 2011).

The usage of drone for monitoring of structures helps in development of efficiency and quality of the structure (Ham et al. 2016). The GPS points of the construction site to be monitored is marked manually with the help of GPS essential mobile application. They are exported as kml file to google earth software to make a boundary map of the site, the GPS points at the corners of the site are connected to make the boundary map and exported in the form of kml. This file is manually imported in Drone deploy application and the flight path is made according to the direction of the site, the basic settings such as altitude, overlap, flight speed, etc. are made and set to fly. The input data is collected in form of images are imported to context capture master software. The camera properties of the input data are checked and aero triangulation, reconstruction settings are made and final production is done to get 3D model output of the images. The required data is processed from the 3D model. IOT has the ability to transfer data over a network, when linked with API, which is an intermediatory software that allows two applications to communicate each other, it transfers message between systems. A basic system application is developed with help of python, and linked with API to send the data obtained from the processed 3D model.

57.2 Study Area and Feedback from Construction Site Labours on Drone

A general survey was conducted in the construction site in and around Salem for the project and received feedback. Totally around 107 has been visited. Feedback from various persons such as site engineer, site supervisor, executive engineer, architect, client, architect, senior planning engineer, etc. through both in offline mode and online mode. In online mode the feedback form was sent to many professionals in the and real feedback were received. The details of the survey are as follows (Figs. 57.1, 57.2, 57.3, 57.4, and 57.5):

57.2.1 *Study Area*

Our study area consisted of 3 sites located at in and around Salem, which have been monitored using DJI phantom 4 pro drone.

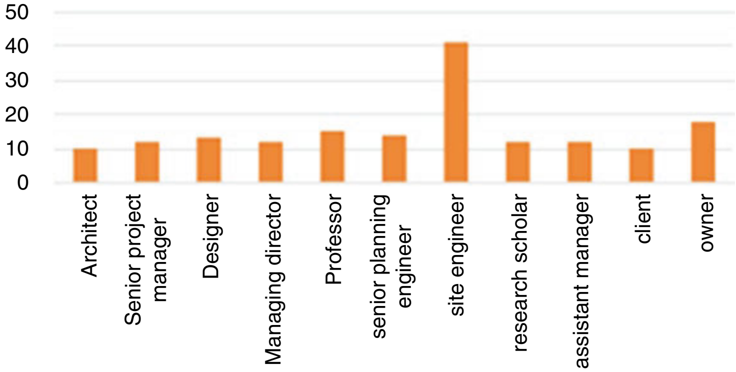

Fig. 57.1 Bar graph showing designation of the person filled the feedback

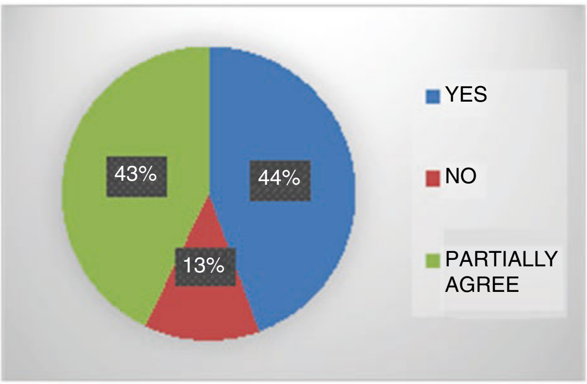

Fig. 57.2 Pie chart indicating the acceptance of gap between construction industry and modern technologies

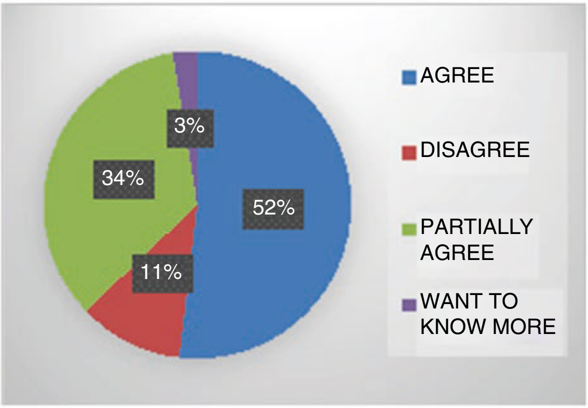

Fig. 57.3 Pie chart showing people's opinion on using drones in site for monitoring

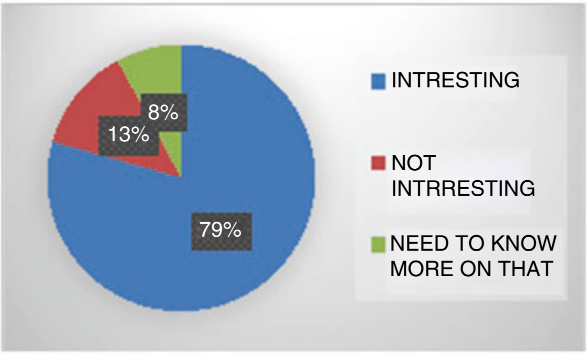

Fig. 57.4 Pie chart showing people's interest in opting drones for survey

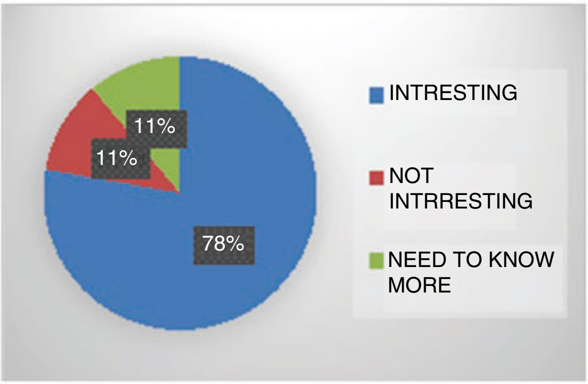

Fig. 57.5 Graph showing people's interest in opting IOT for easy access

The location details of the Site monitored are as follows:

- Sona arts college block at Salem (11°40′40.9″N, 78°07′36.3″E) – https://goo.gl/maps/Lb8A4SWVLL89rwt46
- Additional support building at Krishnagiri (12°33′02.7″N, 78°11′55.6″E) – https://goo.gl/maps/f79iv8SAnPuUZiek6
- Government Mohan kumaramangalam medical college boys' hostel, additional support building at Salem (11°40′13.8″N, 78°03′58.6″E) – https://goo.gl/maps/ksgEjEiC5Lyu17Bk6

57.3 Methodology and Various Stages of Monitoring Using Drones

This is to show the methodology of this work in the form of flow chart to make the understanding of the work in the effortless manner.

The following explains clearly the various stepwise procedures that has to be undergone during the execution of this monitoring using drones and this will help us to learn the importance of each step effectively (Fig. 57.6).

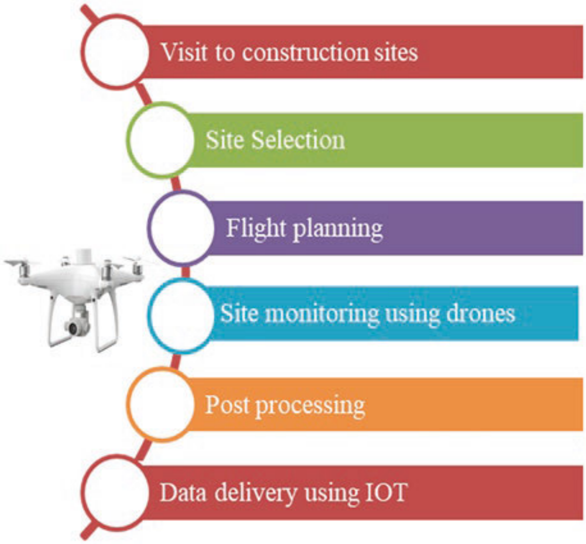

Fig. 57.6 Methodology of the work

57.3.1 Stepwise Procedure

The various stages of monitoring a site are

- Selection of Site for monitoring.
- Selection of drone as per the requirement.
- Choosing the software for the post processing.
- Site investigation and flight planning.
- Check camera settings.
- Fly and review.
- Post processing.

57.3.1.1 Selection of Site for Monitoring

Selection of site is the most primarily step used in the monitoring process. By selecting the site and to understand the difficulties that are faced in the site by the site engineer, senior architect, site supervisor and also resolving those will help us to get the precise results. The site with large area for monitoring, Sona Arts block, Government Mohan kumaramangalam medical college boys' hostel, additional support building (Figs. 57.7, 57.8, and 57.9).

Fig. 57.7 Sona arts college block at Salem

Fig. 57.8 Additional supports building at Krishnagiri

Fig. 57.9 Boys hostel at Mohan kumaramangalam medical college at Salem

Table 57.1 Configuration of the DJI phantom 4 pro drone

Specifications	DJI Mavic mini
Resolution	20 MP
Sensor	1” CMOS
Lens	FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 – f/11 auto focus at 1 m – ∞
Obstacle sensory range	0.6–23 feet (0.2–7 m)

57.3.1.2 DJI Phantom 4 Pro – Configuration

The drone used for monitoring is DJI Phantom 4 pro drone by DJI Technology Co., Ltd., (Table 57.1).

57.3.1.3 Fly and Review – Data Acquisition

This explains the detail process of image acquisition by using a mobile application which is connected to the drone. The main part of the drone monitoring is data collection. The data is collected in the form of images. The image is captured by drone and is stored in memory card and then later transferred to system for post processing. Basically, flight planning is the first step of data capturing. GPS essential is useful for flight planning by marking the GPS coordinates of the boundary of the site to be monitored. Drone deploy is used to aerial map and 3D model and can be installed in both IOS and Android mobile. The accuracy of the map varies from 1 to 5 cm. the device containing drone deploy is connected to the drone and the kml file is opened and the flight path is set as per the site location. Later the basic parameters like altitude, front overlap, side overlap and directions are set. Once all the settings are made the drone is set to fly over the site to be monitored for collecting images (Fig. 57.10).

57.3.1.4 Context Capture – Post Processing

Post processing can be done using software called context capture software. In this paper the detailed process and outcomes of context capture software are listed. The captured images are converted to 3D map post processing is the basic. Post processing using context capture has five major steps. They are,

(a) Photos/point cloud.
(b) Camera properties.
(c) Aero triangulation.
(d) Reconstruction settings.
(e) Production (Fig. 57.11).

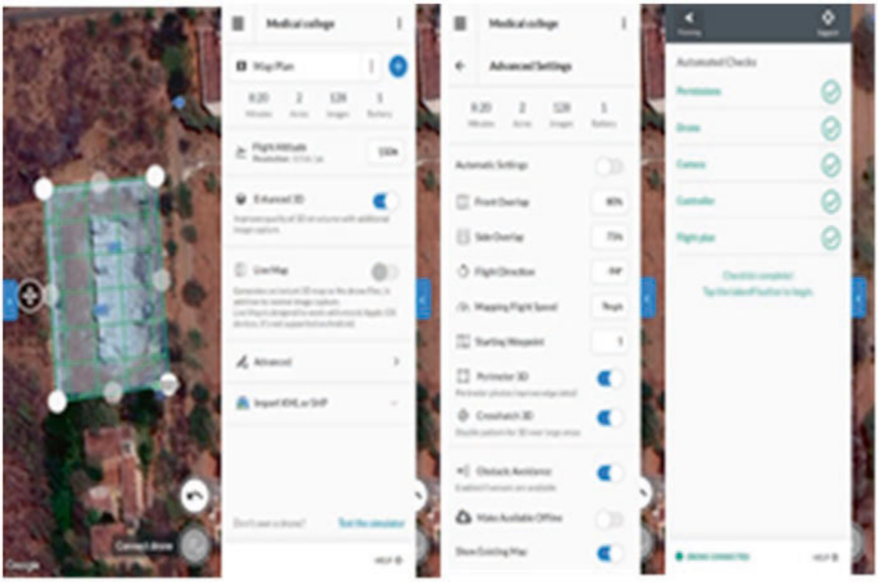

Fig. 57.10 Snap of basic settings to be done and automated check done in drone deploy

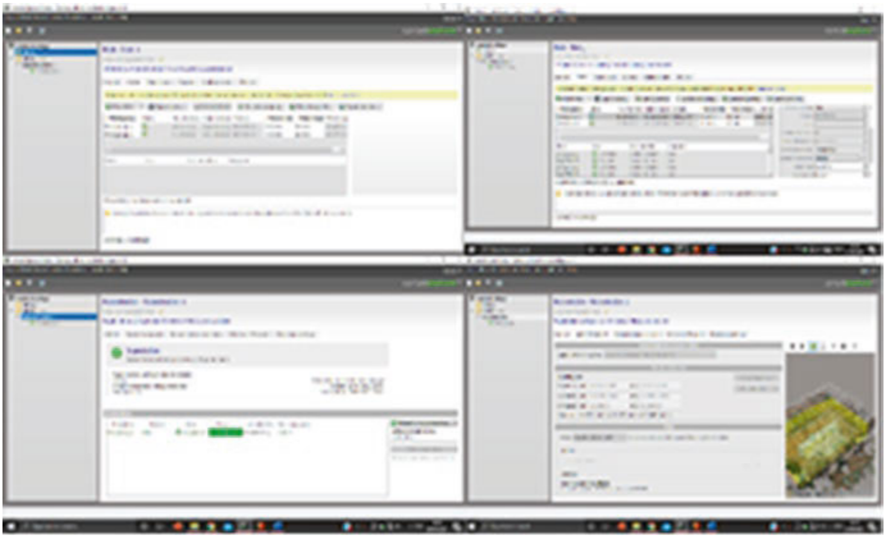

Fig. 57.11 Snap of major steps of post processing in context capture software

57.4 Construction Monitoring Using Drone

57.4.1 Site1: Sona Arts Building, Salem (Phase I)

The site is located in Sona college campus at Salem near Suramangalam. This is a new building constructed for arts and science college with a budget of 3cr.This building consists of 3 floors with parking provision at the basement. The entire building is constructed as 3 phases (Figs. 57.12 and 57.13)

Fig. 57.12 3DImage of Arts block Processed in Context capture

Fig. 57.13 Volume of M Sand Calculated from the3D model from context capture

57.4.2 Site1: Sona Arts Building, Salem (Phase II)

The site is located in Sona college campus at Salem near Suramangalam. This is a new building constructed for arts and science college with a budget of 3cr.This building consists of 3 floors with parking provision at the basement. The entire building is constructed as 3 phases (Figs. 57.14, 57.15 and 57.16).

Fig. 57.14 3D Image of Arts block Processed in Context capture (Phase II)

Fig. 57.15 **volume** of concrete for a column calculated from the 3D model from context capture (Phase II)

Fig. 57.16 **Area** of wall to be plastered Calculated from the 3D model from context capture (Phase II)

57.4.3 Site2: Government Mohan Kumaramangalam Boys Hostel Additional Wing

The site is located at Government Mohan kumaramangalam medical college at Pallapatty in Salem. This is an additional block constructed for an existing boy’s hostel. This building has 2 floors with total of 50 rooms (Figs. 57.17 and 57.18).

57.4.4 Site3: Additional Support Building, Krishnagiri

The site located at Krishnagiri, this an additional support building for collectorate building of Krishnagiri district. This is a G + 1 building with a budget of 7 cr (Figs. 57.19 and 57.20).

57.5 Internet of Things and Application Programming Interface

57.5.1 Internet of Things (IOT)

Internet of things is a complete system of computing devices that are interrelated with unique identifiers. IOT helps in data transaction without human and computer interactions.

Fig. 57.17 3D Image of Medical College boy's hostel processed in context capture

Fig. 57.18 Area of the building measured from the 3D model from context capture

57.5.2 Application Programming Interface (API)

API full form stands for Application Programming Interface. This intermediatory software helps in communication between two applications. For example: WhatsApp, Instagram and other social media that are used to send instant quick replies and messages comes under API usage.

Fig. 57.19 3D Image of Additional building site processed in context capture

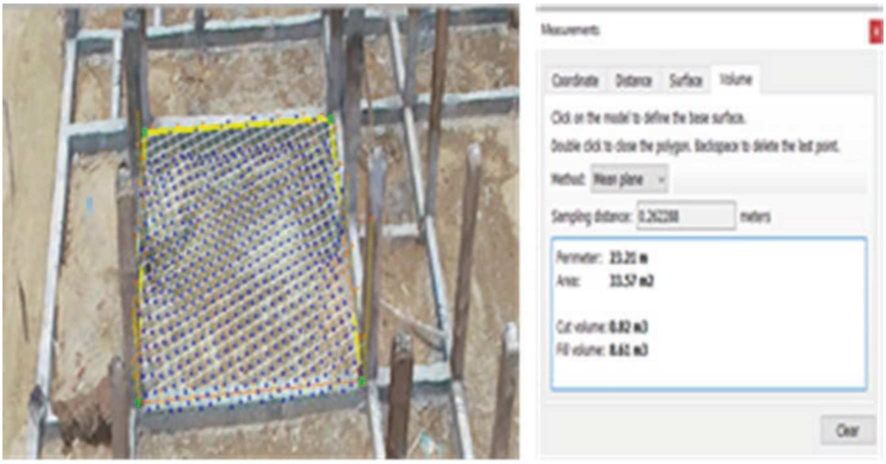

Fig. 57.20 Volume of sand filling to be done is measured from the 3D model from context capture

57.5.3 IOT and API

These IoT, APIs are the spot of interaction between an IoT device with the internet and other elements within the network limit (Figs. 57.21 and 57.22).

57.6 Summary

Surveying and monitoring of building construction which is located in three different locations has been done using DJI phantom 4 Pro multirotor drone and the help of drone deploy, context capture software. The results like total surface area of the

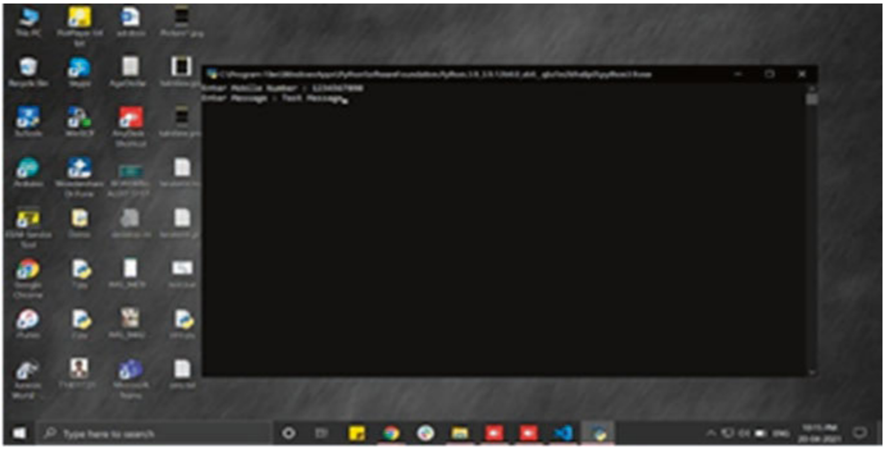

Fig. 57.21 Application that runs to send message by collecting mobile number and Data to be sent

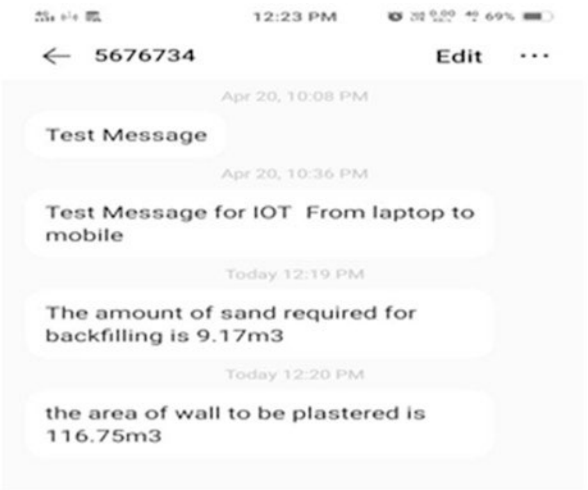

Fig. 57.22 Message received in mobile that has been sent from laptop

site, total volume of the site, difference of level at various points of the site, ortho-mosaic image, 3D image, DSM, DEM and contour are obtained. And also, the data processed is conveyed through message with the help of IOT. This also helps us to know that surveying using drone is the simple set and easiest way to get accurate values in short time.

This is also a cost effective and high-quality imaging can be obtained. The spatial resolution of the aerial photogrammetric depends on the flying height of the drone during the capturing of the image. With good quality images accuracy will be high and very useful for future development. Comparative study of the same place in future can also be possible.

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Chapter 58
Experimental Investigation on Buckling Behaviour of Transmission Tower Using Cold Formed and Hot Rolled Steel

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Abstract Transmission towers are essential component and needs to assess the reliability and safety of these towers to decrease the risk of disruption to power supply which may result from in-service tower failure. Latticed transmission towers are constructed using angle section members which might be capable to hold either tension or compression. Towers are widely appeared to analyze as one of the toughest forms of lattice structure. Factors including errors in fabrication, insufficient joint details variation of material properties and slenderness ratio are affecting the function of towers. Because of high slenderness, the design layout of tower is often governed with the buckling behaviour. In this paper, the buckling behaviour of electrical transmission tower is studied by using finite element analysis (FEA) software tool ANSYS. Initially, the tower is modelled and analyzed by means of STADD.pro software to find the failure members in the 220 kV self-persistent tower structure. The failure members were replaced by cold formed steel built up members. Finally, the axial capacities of hot-rolled and cold formed members are compared by carrying out various tests and numerical study.

Keywords Cold formed steel angle · Transmission tower · Finite element method · Stability · Buckling

58.1 Introduction

A steel lattice transmission tower is a freely standing tall skeleton structure. It is self-supporting structure firm to the footing or base (Al-Bermani and Kitipornchai 1992). Structural design tower is 3D space truss modelled as pin connection.

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Structural steel angle member is used in a variety of structures from which it can be fabricated and erected into structural component element. Legs, primary bracings, secondary bracings, and cross arm components make up a lattice structure known as a tower (Feng et al. 2012; Bhardwaj and Kaushik 2015; Vidya et al. 2019; Rao et al. 2012; Sai Avinash et al. 2016). Bolted butt joints link the two leg members. Self-supporting tower structures are generally composed of axial members (steel angle sections, single and double. All members are connected and axially loaded with minor deformations. Because tower structures are often tall and flexible, deflection must be considered, and it cannot be overlooked because it will result in secondary stresses (Zeng et al. 2019; Xie and Zhang 2014) The common advances in steel structure, it is subjected to axial loads may be concentric or eccentric. Structural steel angle may fail in local buckling, flexural buckling, torsional-flexural buckling (Xie and Zhang 2014; Shi et al. 2014). This failure may be either elastic or elastic-plastic. Linear elastic analysis method is generally analyzed for transmission tower. In this analysis method, leg member forces and deformations are determined.

Single angle compression members are a facile structural element used to analyze and design. These towers are capable to carry either tension/compression. Due to the presence of both tension and compression members, there is a great possibility for failure member in several conditions. Element members are usually connected to another element member by one leg. The major axes of the angle, on the other hand, do not coincide with the axes of the frame or truss. As a result, end circumstances have an impact on the member's ultimate load carrying capacity (Robert and Lemelin 2012).

Traditional transmission towers, which are typically built of hot rolled (HR) steel angle members, are less prone to local buckling and flexural-torsional buckling for all lengths due to their compact legs. For the replacement of hot rolled steel angles, cold formed steel (CFS) angles are becoming most prominent. Although cold form steel angle members frequently have thin walls, they are exposed to two buckling modes: the global flexural mode is superior for long members, while the local/global flexural-torsional mode is superior for shorter members. Because the warping constant of a simple angle member is nearly negligible, flexural-torsional buckling does not depend on the length of the member.

58.2 Objectives

The main objectives of this project are

- To investigate the buckling behavior of the steel angle member.
- To identify the failure member and for that failure member built up section is created to rectify the failed member in STAAD.Pro.
- Numerical analysis and experimental studies are carried out for the failure member and built-up member in ANSYS.
- Comparing numerical values and experimental values for both the member.

58.3 Failure Member Analyzed By STAAD.Pro

The high-power electrical transmission tower line is an indeterminate tower structure and a space truss. A 220 kV self-persistent tower structure is analyzed and designed by using STAAD.Pro software tools. The primary goal of this study is to provide a structural steel lattice tower system that can withstand a variety of loads while designing and checking the failure parts. While designing, the member must be cautious and cost-conscious. Total cost of the transmission tower line structure is about 35–45%. Transmission tower has almost small cross sections and the ratio between the height to maximum width is vast.

When comparing the aspect ratio of bracing, the inclined model is less efficient than the tapered model; as a result, the action of lateral loads and diagonal wind loads is particularly important for tall structures. Up to 50 m height, the secondary members exhibit budget friendly and diaphragm bracings takes up the higher bearing member.

While designing 220 kV capacity power for transmission tower, the bottom base widths (b) limits from 1/4th to 1/6th in some case it may differ from 1/8th to 1/12th of the total height (H) by considering seismic zone regions. The top width of the structure may vary between 1.5 and 3 m or more. Perth Metropolitan Model says wind loads are the significant factors in that the first and foremost failure factor is displacement. The design forces are reduced if the seismic load affects the structure in terms of displacement. Tower design is governed by self-weight, tower body, wind load, seismic load and other loads etc. The inputs have given to the tower structure while designing is height, length of the structure, ground clearance and conductor type.

58.4 Dimensions & Parameters of the Tower

As per, Electrical Rule 77(4) 1956, Fig. 58.1 shows the dimension and parameters of tower.

- Total height of the tower (H) is 48 m as per IS 5613 (part 2/sec 1) 1995
- Ground clearance (h1) is 7.01 m
- Maximum sag of the lower most conductor wire (h2) is 25.202 m
- Vertical distance between conductor wires (h3) is 7.5 m
- Vertical distance between conductor and ground wire (h4) is 7.798 m
- The base width of the tower is 6 m (square base)
- The top width of the tower is 3.2 m

In STAAD.Pro, By assigning the member property, support, loading conditions due to wind and steel design. Check code, member take off, and steel take off are assumed from the allowed stress design technique as per IS 802 (part 1/sec 1) when designing the steel (IS: 5613 1985). Figure 58.2 shows that they are the failure

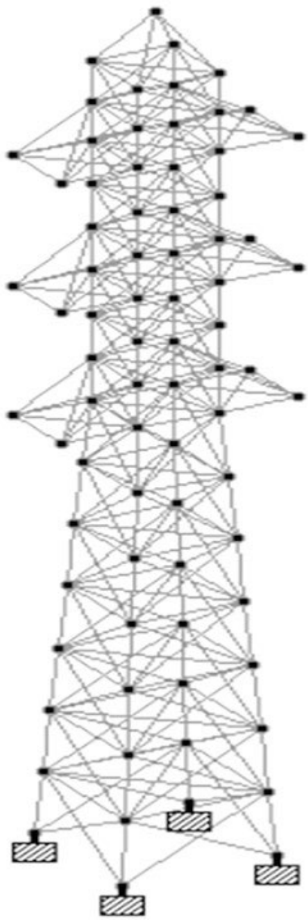


Fig. 58.1 Dimension and parameters of tower

member found as per the code IS: 802 (part 1/sec 1) (IS: 802 1995). In this failure member, hot rolled steels are used.

58.4.1 Built Up Section Created in STAAD.Pro

Cold formed back to back angle is used as built up section instead of hot rolled steel angle. This cold formed back to back steel angle is subsituted in failure member to avoid it from deformation. ISA 200 × 100 × 10 angle is replaced with the angle 80 × 50 × 5 (cold formed angle).

The code used for hot rolled steel is IS 802 (part 1/ sec 1) (IS: 802 1995) and for cold formed steel is IS 811 (IS: 811 1997). Both hot rolled and cold formed built up section is used in the transmission tower though both sections are used it is safe

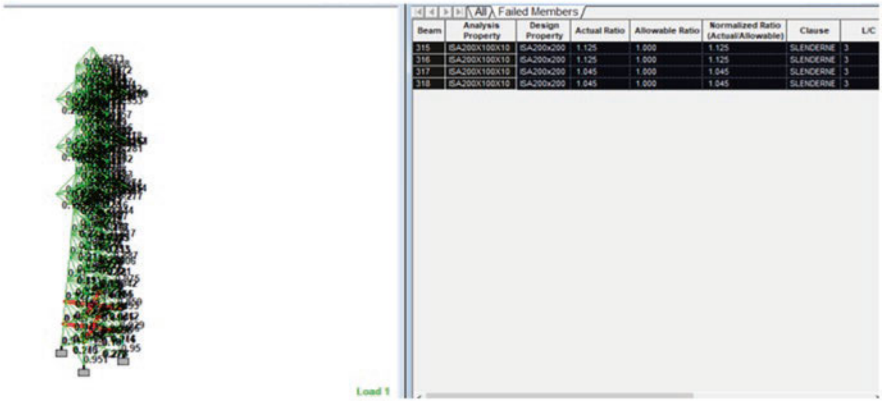


Fig. 58.2 Identification of failure member

from deformation. Figure 58.3 shows the modelled back to back channel in software. Figure 58.4 shows the deformed shape of the cold formed steel back to back angle member.

Figure 58.4 shows that the built-up members are safe from deflection/deformation and also it is economical.

58.5 Experimental Arrangements

The experimental investigation was carried out for the failure member occurred in the existing transmission tower. For doing experimental arrangements, the basic criteria are material testing, alignment of test specimen, fabrication of test specimens, test set-up and testing procedure to find out the buckling behavior of the member. Based on Indian standards [IS: 802 (part 1/Sec 1) 1995; IS: 811 1997; IS: 802 (Part 1/Sec 2) 1992; IS: 802 (Part 2) 1978a, b; IS: 808 1989) the basic criteria have been fulfilled.

58.5.1 Material Properties Test

Two different angle sizes, ISA 200 × 100 × 10 mm and ISA 80 × 50 × 2 mm of hot rolled steel and cold formed back-to-back section of same length were used to carry out experimental test. An effective length of 1 factor is considered to estimate the compression strength and cold formed back-to-back member is designed as screwing method in which the angles were concentrically loaded, and hinged. To calculate the ultimate load carrying capacity of the compression member, it is a common design to assume an effective length factor.

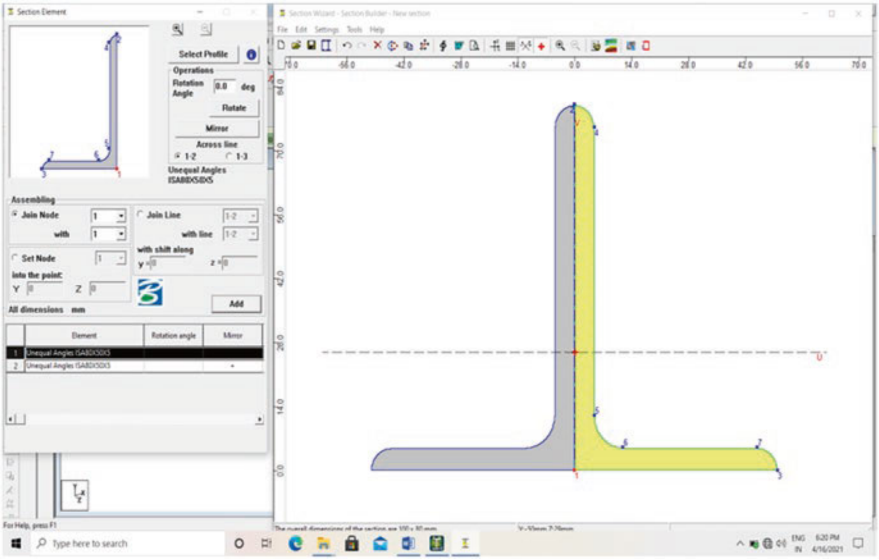


Fig. 58.3 Creation of CF B-B steel member

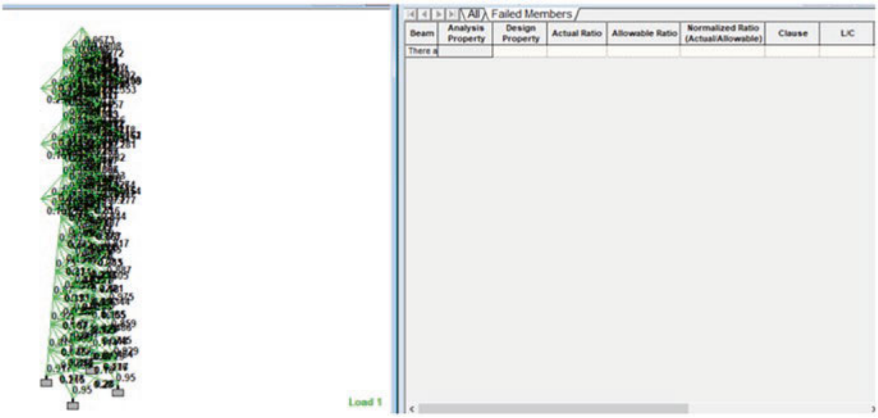


Fig. 58.4 Built up members are safe from failure

58.5.2 Fabrication of Test Specimens

Hot rolled angle member and cold formed member have been cut to required lengths. Both ends of these specimens have been milled which is perpendicular to the longitudinal axis of the member and parallel to one another. The assembly of hinge is made with bearing against the ends of the member.

58.5.3 Alignment of Test Specimens

The end conditions of cold formed and hot rolled steel were designed as fixed. The most important aspect of testing the specimen under concentric loads is its alignment. The member should be located in the testing frame in such manner that the longitudinal axis must coincide in the line of action of load. It is tough to ensure that the centroid of the member and point load application coincide, because the assembly of hinge at the top and bottom of the test specimen have been made with various freely rotating parts.

58.6 Testing

The compression tests were carried out using 350 kN capacity of loading frame. It was connected to a pump, which gives adequate control to the loading process. At the top of the loading piston, a load cell was placed which is used to measure the loads. Base plate was provided at each end with the thickness of 20 mm and the loading plates are kept to simulate hinged-end conditions, at both supports. The load was applied in increments of about 1–2 kN at regular interval. Based on the approach of failure load, the load increment was often reduced. Figure 58.5 shows the load cell, loading jack, top and bottom end plate assemblies, and buckled shapes of two test specimens. The dial gauges were used to measure the deformations of the specimens during testing. Two dial gauges were placed, one at middle span of the specimen to measure the lateral deformations and another at end plate of the specimen to measure the axial shortening of the specimen. Hydraulic jack was used to apply load at regular intervals and readings were measured. The load was applied until the specimens reach the ultimate load. The top and bottom end plate assemblies were checked for vertical alignment before each test. For concentric loading, the theory is validated and indicates the load displacement relationship, which in turn shows the member's axial stiffness in both pre and post buckling zones.

58.6.1 Testing Procedure for Buckling Analysis of Single Angle

In the loading frame by using hydraulic jack for loading and load cell is used to measure critical loads and dial gauge is used to measure the load deflection and that is how the compression test is carried out.

(i) The angle specimen is correctly assembled in the test setup.
(ii) The center of the hydraulic jack is coincided with the CG of the test specimen and the concentric loading line passes from these two. The effective length of

(a) (b)

Fig. 58.5 Test setup for (**a**) HR member, (**b**) CF B-B member

the angle specimen must be the intermediate distance between the roller end fixtures from this the definite location of the end support is identified.

(iii) After the angle specimen is correctly assembled, a minor load is implemented to position the angle specimen. It is the initial load on the angle specimen and all dial readings are measured at this stage.

(iv) By defining the proportional limit stress from the start of testing, the beginning of yielding of each angle specimen is initially determined. This is proportionate to the difference of yield stress to the maximum compressive residual stress measured.

(v) The angle specimen is tested in the loading frame with hydraulic jack; the load increment and the testing rate are calculated independently.

(vi) Depending on the sizes of each specimen, the load increment limits from 1 to 2 kN. Each and every load increment is balanced upto the readings were duplicated till the member reaches its maximum load.

(vii) The member must be noticed carefully prior to any form of local buckling.

(viii) Experimental study of angle section for both the steel is same and cold formed is screwed back-to-back and same procedure is repeated for calculating the ultimate load of the buckling behavior of the member.

The test setup is shown in Fig. 58.5. The strength and failure mode of the specimens are identified. Local and Torsional buckling mode of interaction was observed for both the specimens.

58.6.2 Experimental Readings

The interaction between local and torsional buckling mode was observed for both the specimens. The load carrying capacities of hot rolled steel is slightly high when compared with the cold formed back-to-back steel. The experimental results and the failure modes obtained from the experimental analysis.

From the below graphs, it is clear that the load carrying capacity of both forms of steel are same even though the thickness of hot rolled is higher than that of the cold form steel. The ultimate load carrying capacity of hot rolled is nearly 150 kN, on the other hand cold formed steel is 146 kN (Figs. 58.6 and 58.7).

58.6.3 Failure Mode Shape (Fig. 58.8)

58.7 Numerical Analysis in ANSYS

In this software, buckling behavior of steel members are identified for both the member. The numerical models were created using ANSYS 2003 software, which was also used to evaluate the ultimate capacity of hot rolled steel and cold formed back-to-back steel. This software has successfully been used in previous finite element studies by other researchers (Kasiviswanathan and Upadhyay 2017, 2019, 2021a, b) Many scientists have utilized this finite element programme. The Elastic Modulus and Poisson's Ratio were used to develop the model. Pre-processing, geometry, material properties, meshing, loading, and solving models are to identify the likely buckling behavior and also to investigate the ultimate load and failure of the member in non-linear analysis.

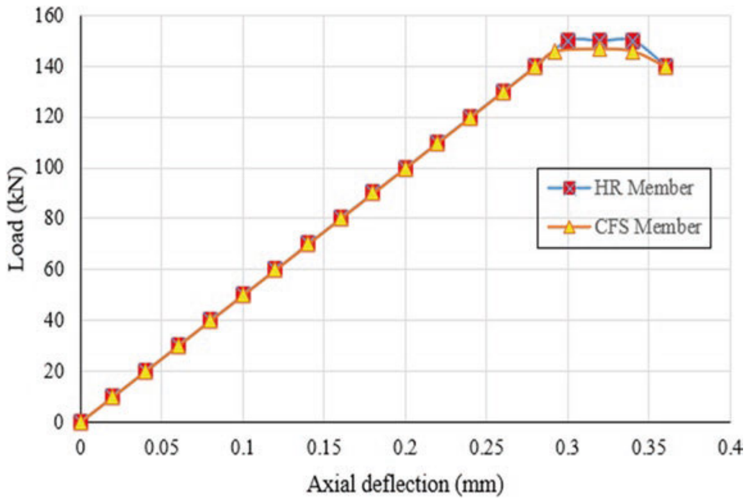


Fig. 58.6 Load vs axial defelcetion curve

58.7.1 Model Development

The model was created in ANSYS2003 software with standard model. It used 3D deformable shell elements. The model was created using co-ordinates or by sketch (Fig. 58.9).

58.7.2 Finite Element Mesh

To achieve an accurate and efficient FEM, the hot rolled member and cold formed back-to-back member were meshed for the whole section. The type of mesh used in this section is Tetrahedral. Meshing of the section is shown in Fig. 58.10.

58.8 Buckling Affected Area in Member

While analyzing in ANSYS2003, the member gets failed at the area where it cannot withstand the load and it buckles. Red colour in the below Fig. 58.11 shows the member is buckled at that area.

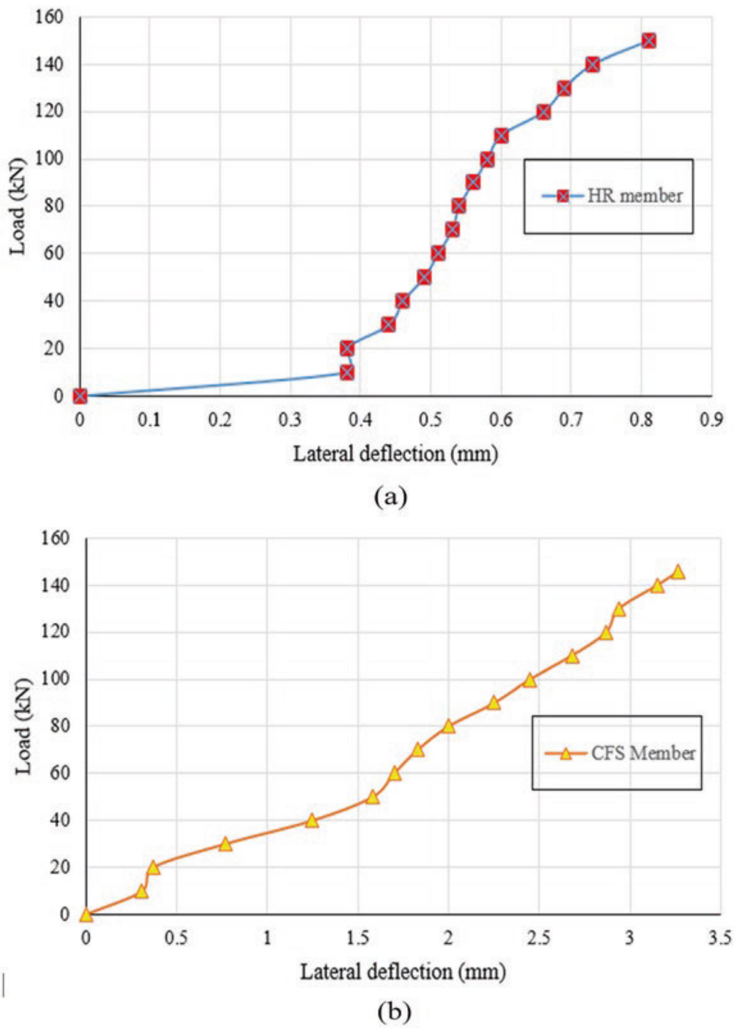


Fig. 58.7 Load vs lateral deflection curve (**a**) Hot rolled steel (**b**) Cold formed steel

58.8.1 Validation of ANSYS

The maximum load at which the buckling failure occurs is 149 kN for hot rolled member and for cold formed back-to-back member is 144 kN. The interaction of local, distortional buckling was observed during the analysis. The yield stress used for this member is 250 N/mm^2 and Poisson's ratio is 0.27 for hot rolled member; for cold formed back-to-back member is 0.3. Results show that, the developed finite element model, and procedure accurately predicts the ultimate load and failure modes of the tested specimen (Fig. 58.12).

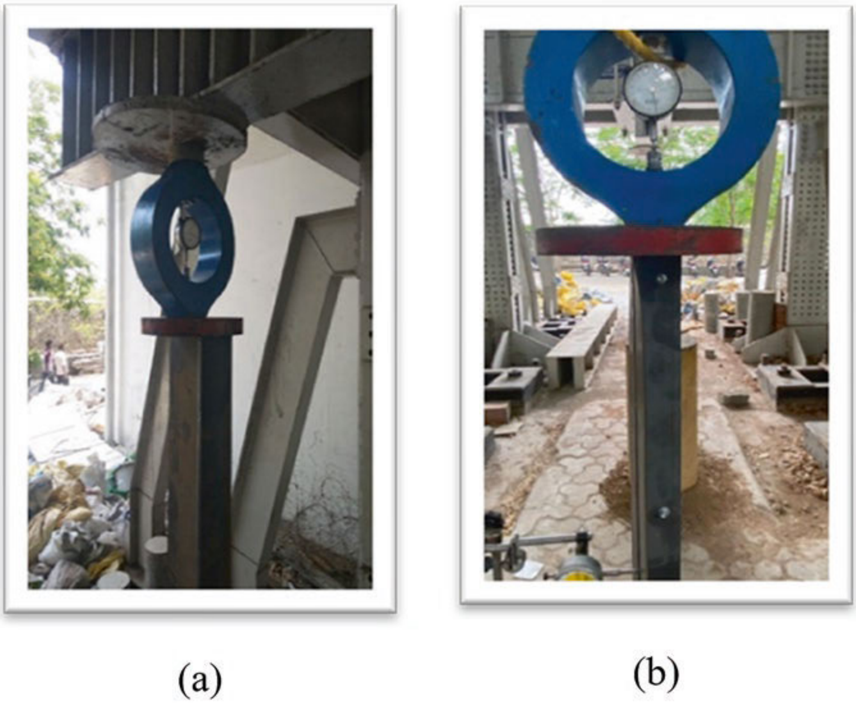
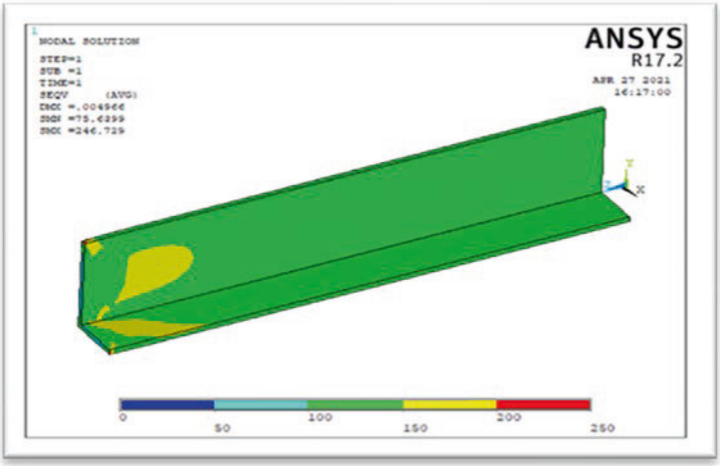


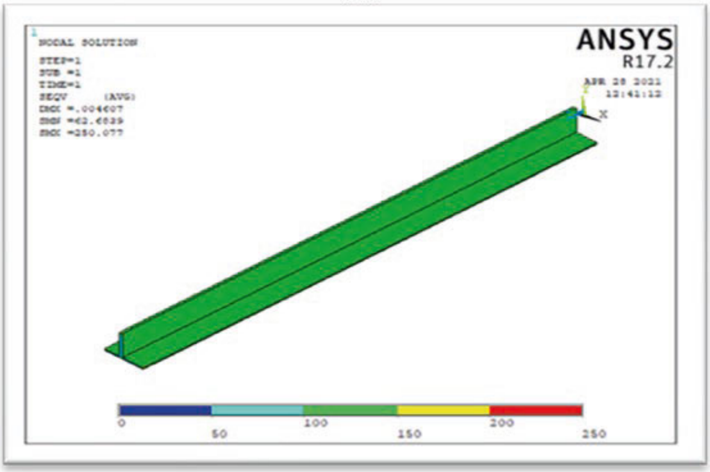
Fig. 58.8 Buckling mode shape. (**a**) HR member and (**b**) CF B-B member

58.8.2 Validation of Experimental Vs FEA Load

With the existing experimental loads, the proposed finite element model was validated. The interaction of local and torsional buckling was observed in all the specimens in the test as well as in FEA. Experimental ultimate loads were used to verify the generated finite element model. The experimental findings were compared to the ultimate loads, and failure modes were predicted using a finite element model. The mean values of P_{FEM}/P_{EXP} ratio were 0.99 for hot rolled member and P_{FEM}/P_{EXP} ratio was 0.98 for cold form steel member. The comparison of failure modes of the specimens obtained from Experimental and FEA are shown in Figs. 58.13 and 58.14 Comparisons of results are presented in Table 58.1.



(a)



(b)

Fig. 58.9 ANSYS model. (**a**) HR member and (**b**) CF B-B member

58.9 Conclusion

Although cold formed steel members have greater benefits than hot rolled steel, they are more susceptible to numerous buckling modes. Cold formed steel can undergo more deformations before failure, and they can resist almost same load as hot rolled section. While comparing the load carrying capacity, hot rolled steel members are failing in bending while cold formed steel members are failing due to distortion local buckling failure.

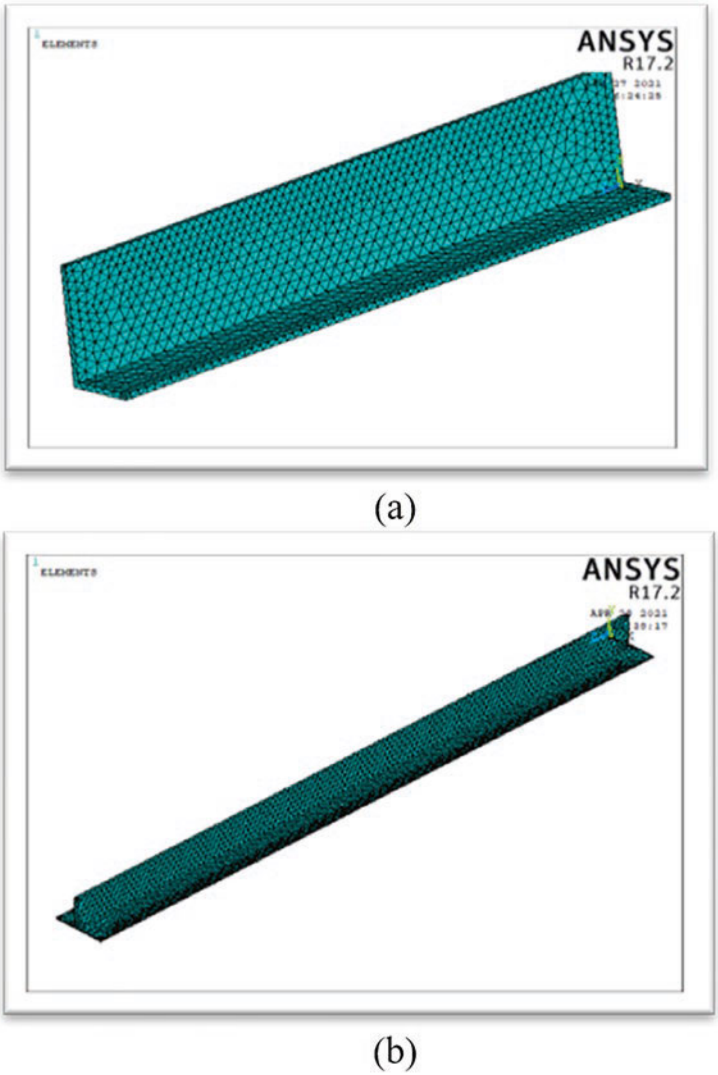
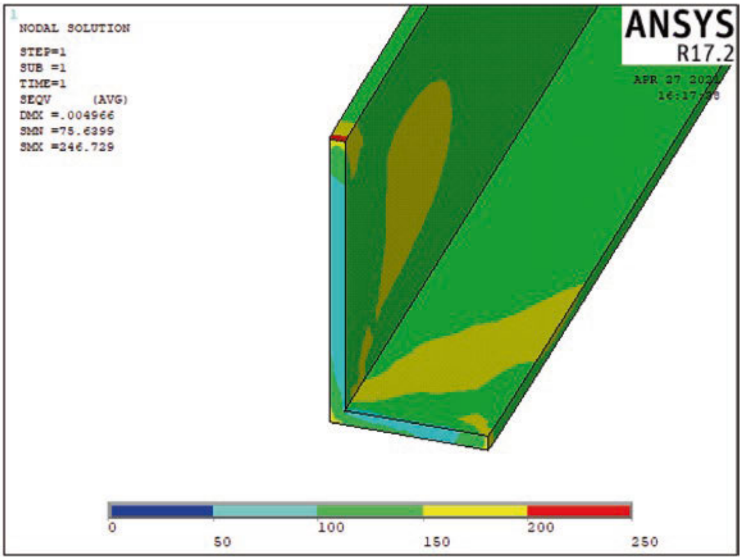
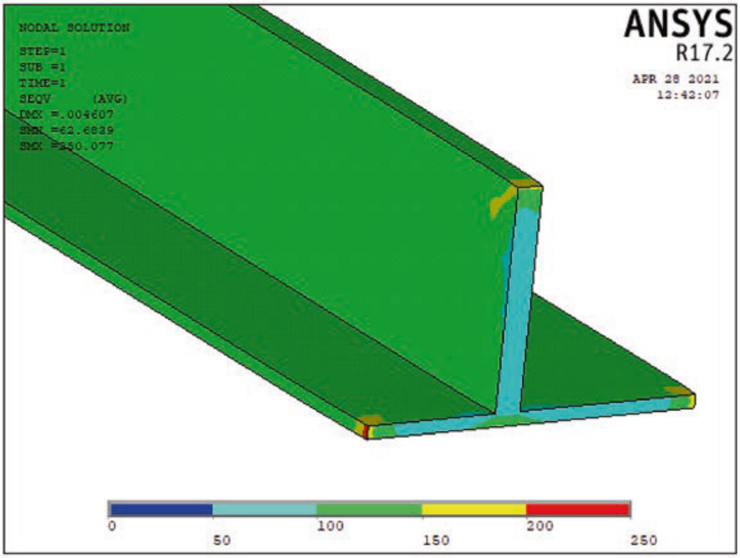


Fig. 58.10 Tetrahedral mesh. (**a**) HR member and (**b**) CF B-B member

- The failure member is analyzed in STAAD.Pro for an existing transmission tower. To rectify the failure member, built up section is created to avoid it from deflection/deformation. Cold formed back-to-back section is substituted in failure member and the member is safe.
- Developed finite element ANSYS model accurately predicts the strength and behavior of existing tested specimens.



(a)



(b)

Fig. 58.11 Buckled area for HR member and CF B-B member

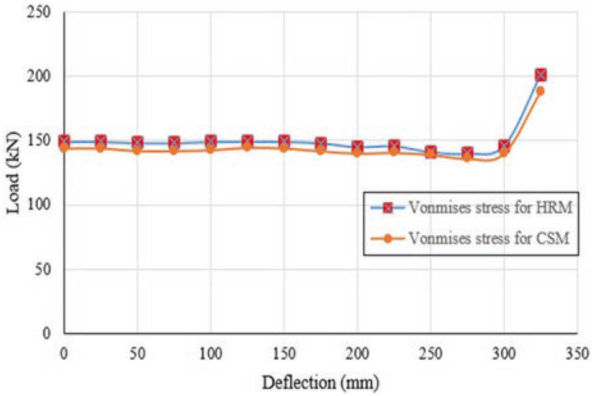


Fig. 58.12 Buckling analysis for HR member and CF B-B member

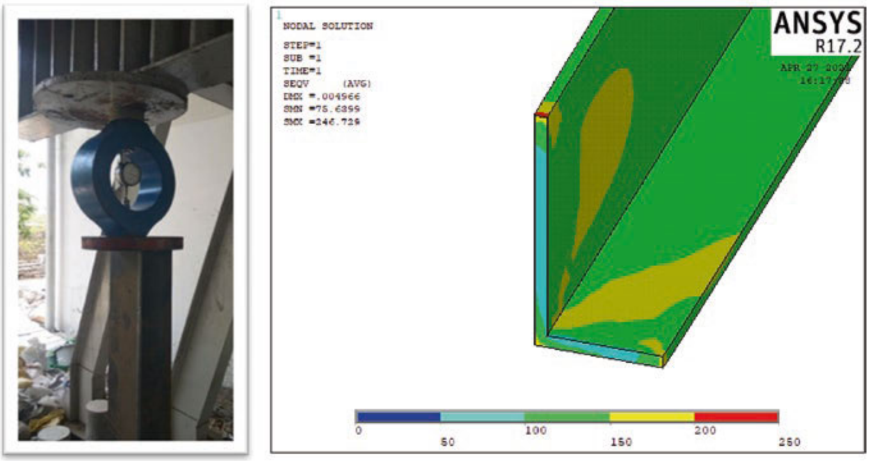


Fig. 58.13 Comparing the failure of experimental vs numerical for HR member

- In both the experimental and numerical analysis, the initial load applied to the member and the member gets failed beyond the limit load at top corner of both Hot rolled member and Cold formed back-to-back member.
- Almost the experimental results and numerical analysis are equivalent; the experimental results for HR member are 150 kN and for CF B-B member is 146 kN, while in numerical analysis for HR member is 149 kN and for CF B-B member is 144 kN.
- Though both the results are same, the interaction of local and torsional buckling was observed in both the specimens in the test as well as in FEA.

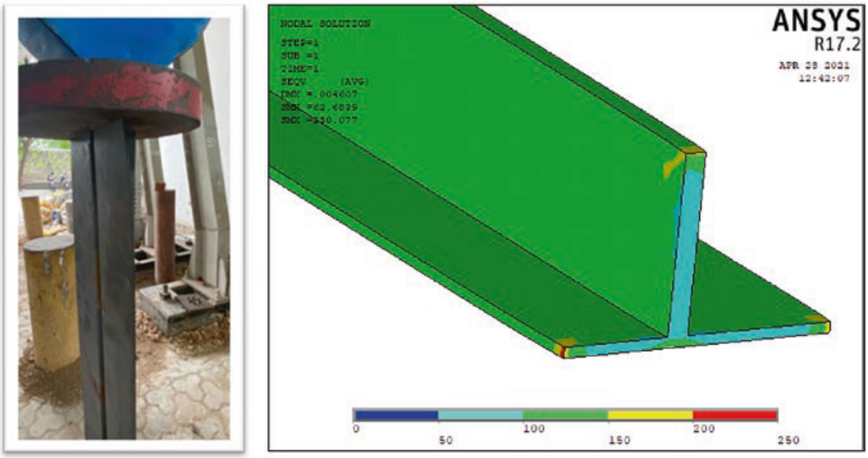


Fig. 58.14 Comparing the failure of experimental vs numerical for CF B-B member

Table. 58.1 Comparing experimental vs numerical results

Maximum load at which buckling occurs (kN)	Experimental results		Numerical analysis in ANSYS (Version R17)	
	For HR member	For CF B-B member	For HR member	For CF B-B member
	150	146	149	144

- Experimental ultimate loads were used to test the derived finite element model. The finite element analysis was used to anticipate failure modes and compare the experimental results with ultimate loads.

58.10 Future Scope

- Attempt can be made by designing a transmission tower with two different materials hot rolled steel angle and cold formed back-to-back steel angle in a structure which may lead to ideal results.
- Even if the cost of weathering for cold formed steel is roughly equal to that of hot rolled steel with hot galvanising, it is not uneconomic.
- This idea is used where the heavy wind occurred, which gives stability to the structure and resist the buckling strength of the transmission tower.
- Effective static loading on hybrid transmission tower can be supplanted with the actual conventional transmission tower and the results will be compared.

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Chapter 59
Assessment of Indoor Air Quality of Buildings Made of Bricks Developed from Paper Pulp Waste

Brij Bhushan, Varinder S. Kanwar, and Siby John

Abstract Urbanization, increase in population and change in lifestyle of human beings increased pressure on natural resources and accumulation of industrial waste in the environment. Dumping and landfilling of such industrial waste especially the solid waste is leading towards severe environmental degradation in the form of water pollution, air pollution and soil pollution etc. Due to increase in installation of more paper mills, there is rapid increase in generation of solid waste from these industries. Sludge having calcium carbonate (lime mud) generated from paper mill has been considered as a potential useable material. This reduces the quantity of waste and its disposal cost for landfilling/dumping. In this study, an attempt has been made to examine the behaviour of bricks developed using the waste sludge having calcium carbonate (lime mud) from paper industry by partial replacement of the clay varying from 10% to 50%. Results demonstrated that bricks made from partial replacement of clay with lime mud are light weight, having desirable compressive strength, corrosion resistant. Also, the indoor air quality assessment of buildings made of these bricks indicted little to no impact on ambient air quality.

Keywords Bricks · Clay · Lime mud · Light weight · Compressive strength · Ambient air quality

59.1 Introduction

Due to exponential increase in the population in recent years all over the world, there is exalted demand for construction material for housing and other infrastructure and thus increasing pressure on virgin instinctive resources causing shortage of

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these materials. Such activities are leading towards the generation of more waste materials and thus consequently generation of more environmental pollution. Bricks are of the major building materials in modern day is having a very high environmental cost due to its excessive use of topsoil and energy intensive manufacturing process. So, to achieve the sustainable development, the concept of circular economy wherein the waste generated from one industry(s) is used a raw material in another. It is also a defiance to the environmental and civil engineers to tap the supplementary waste cementitious materials produced at comparatively low cost with minimum environmental impact. Therefore, there cycle/reuse of such waste from industries beside minimizing the adverse impact on environment and ecology also help in conservation of natural resources. Pulp and Paper manufacturing industries are presently facing the problems regarding implementation of solid waste management plan for disposal of its industrial solid waste in economically and scientifically sustainable manner. Paper industries generate solid waste in the form of lime mud and sludge from treatment of waste water. Despite having 40–50% calcium carbonate in pulp and paper industry waste sludge (lime mud), as per prevailing practices, such sludge is disposed of on open land in a very unscientific method.

In some cases, these wastes are incinerated in cement kiln as per one of the approved methods for safe disposal of hazardous wastes approved by the Central Pollution Control Board. Un-scientific disposal of these solid waste on open land is not only an offence but also due to scarcity of land and its high cost and huge treatment cost charged by common Treatment Storage and Disposal Facilities (TSDF), these methods are not economically feasible. Disposal of sludge on land also leads to other pollution problems like ground water pollution, soil pollution. Due to having high concentration of calcium carbonate this paper industry waste can be utilized as an alternate construction material thus not only reducing pollution but also help to reduce the carbon footprints. Thus, the development of new methods are warranted for scientifically and economically use of such waste materials. The waste material generated from the pulp and paper mill mainly in the form of lime sludge contains a high concentration of calcium carbonate thus draws the attention of civil and environmental engineers to conduct studies for utilization of this waste as a replacement of construction material in the development of bricks and concrete. The use of this waste will thus help in the preservation of natural resources and reduction in energy consumption and volume of waste sent to landfills.

Bricks are widely used as alternate of stone for building construction everywhere in the world. One of the most common raw materials uses for development of bricks is clay. Clay bricks are manufactured by adding required percentage of sand and by shaping to rectangular units of standard sizes. Clay bricks are commonly used due to its low cost, significant compressive strength and durability. The silica, lime and other constituents of clay add these engineering properties to the brick. As clay is used as a main raw material for manufacturing of brick, an attempt has been made to utilize the paper industry waste mainly lime mud (precipitated $CaCO_3$ which is generated during recaustizing process of green liquor to white liquor is commonly known as lime sludge or lime mud) as partial replacement of clay. The present research also intends to study the environmental impacts while using these waste bricks.

59.2 Literature Review

Sarkar et al. (2017) conducted the study to utilize industrial waste calcium carbonate and fly ash for the manufacturing of bricks. Waste $CaCO_3$ (lime mud) from a paper industry was blended with fly ash to manufacture unburnt bricks. Experiments studies conducted revealed that unburnt bricks are not conforms to the international standards, whereas addition of upto 20% lime mud in soil is satisfying the criteria prescribed by the International Standard Codes for burnt bricks.

Faith and Umit (2001) conducted a study to reach the conclusion that quality of brick is not deteriorated at a firing temperature of 950 °C with the addition of $CaCO_3$ upto 60%.They concluded that the use of $CaCO_3$ as partial replacement of clay/sand for the manufacturing of burnt clay bricks is an economically viable substitute to clay in addition to overcoming the disposal problem of such waste. Mistry et al. (2011) conducted an experimental examination and concluded that the bricks developed using waste such as fly ash reduce cost of these bricks upto 28% in comparison to the conventional red burnt bricks and masonry work. As compared to common burnt clay bricks, 33% saving was observed in the masonry work with new technology Rat-Trap bond in $CaCO_3$ brick. Amaral et al. (2013) conducted a study using the eggshell waste for the development of soil-cement brick being eggshell having calcium carbonate ($CaCO_3$) in abundance. Eggshell waste is considered to be a complex solid waste material and difficult to dispose of scientifically. It was investigated in this work to utilize the eggshell waste into a soil–cement brick body, by partial replacement of cement up to 30% weight. After uniaxially pressing and curing for 28 days, apparent density, water absorption and compressive strength of these bricks were determined. The results revealed that eggshell waste can be successfully partially replaced up to 30% by weight with Portland cement in manufacturing of in soil–cement bricks. Hence, use of eggshell could be one of the best management practices for development of a low-cost, alternative raw material. Younoussa et al. (2008) studied X-ray diffraction, infrared spectrometry, differential thermal analyses, scanning electron microscopy and energy dispersive spectrometry tests on adobe bricks and blocks using lime and clay for micro structural changes. They furnished that addition of lime caused the development of calcite and poorly crystallized Calcium Silicate Hydrate (CSH) which is mainly formed from the reaction of lime and tiny silica. Mechanical resistance of the adobe bricks was adversely affected by the excessive formation of portlandite and calcite, and the minor development of CSH. They further observed that by reducing the grain size of quartz, enhancing the duration of hydration and utilizing pressure paste from air elaborate strong and compact lime-clay adobe bricks.

59.3 Materials and Methodology

59.3.1 Methodology

59.3.1.1 Bricks

Waste sludge (lime mud) from paper industry located in Kala Amb, District Sirmour (HP) was obtained in powdered form. The clay soil and other materials used for manufacturing of bricks were collected from a brick kiln located nearby. The chemical compositions of materials and paper industry waste sludge (lime sludge) used in the study were studied using X-Ray Florescence (XRF) and X-Ray Diffraction (XRD).

59.3.2 Characteristic of Materials

59.3.2.1 Clay

Materials used in the study were collected from nearby situated brick kiln. Table 59.1 below shows XRD analysis for compound study of clay used. Silica contents in the clay were found 67% present as a free form (SiO_2) and in the form of compounds when mixed with other elements such as aluminum oxide (Al_2O_3) to form kaolinite ($Al_2(Si2O_5)(OH)_4$) in the feldspar group.

59.3.2.2 Pulp and Paper Mill Sludge

Paper industry waste in the form of sludge having calcium carbonate (lime mud) were collected in powder form packed in bags from a pulp and paper mill situated in Himachal Pradesh. The sludge was kept in containers. Table 59.2 below present the physical properties of this waste.

The chemical composition of the waste (lime mud) was calculated by conducting XRF tests. The chemical composition of waste is depicted in Table 59.3 given below;

59.3.3 Mixing and Proportions

All the material used for manufacturing of brick i.e., clay, sand and lime mud were mixed in required proportions. Specimen of Bricks were prepared of IS standard size (180 bricks, 30 bricks for each mix). Samples of bricks prepared from all these mixes (each mix having varied quantity of lime mud replaced) were tested for different properties to determine the strength. Percentage of Paper Sludge (lime mud) replaced in different mixes are given in Table 59.4.

Table 59.1 XRD analysis for compound study of clay

Compounds of clay	Percentage
SiO_2	67
Al_2O_3	26
Fe_2O_3	3
Na_2O	1
MgO	1
P_2O_5	Trace
SO_3	0.5
K_2O	2
CaO	0.1
Cr_2O_3	Trace
MnO	Trace
NiO	Trace
CuO	Trace
ZnO	Trace
Cl	Trace

Table 59.2 Physical properties of paper industry sludge (lime mud)

Type of waste	Specific gravity	Fineness modulus
Pulp and paper mill lime mud	1.89	1.44

Table 59.3 Chemical composition of pulp & paper mill sludge

Element	Quantity
Oxygen	44.74%
Calcium	37.34%
Carbon	11.70%
Silicon	4.25%
Sodium	0.86%
Magnesium	0.50%
Potassium	0.21%
Phosphorus	0.10%
Sulfur	0.09%
Iron	0.06%
Chlorine	0.06%
Aluminum	0.05%
Strontium	0.01%
Manganese	38 ppm
Copper	30 ppm
Nickle	30 ppm
Zinc	27 ppm

Table 59.4 Different mix proportions using lime mud

Mark of brick	Clayey soil (kg)	Paper sludge (kg)	Percentage of sludge used
A1	80	0	0
A2	72	8	10
A3	64	16	20
A4	56	24	30
A5	48	32	40
A6	40	40	50

Table 59.5 Weight of bricks

Mark of brick	Average brick weight (kg)
A1	3.10
A2	2.56
A3	2.43
A4	2.23
A5	1.96
A6	1.77

59.3.4 Weight of Brick After Formation

Few samples of each type of brick were weighed and then average weight was calculated for each type of brick. The average weight of different types of bricks is shown in Table 59.5.

59.3.5 Monitoring of Ambient Air Quality

To examine the adverse impact of bricks developed using waste lime mud, two rooms were constructed using bricks developed with lime mud and standard burnt clay bricks. Quality of ambient air of both rooms and outside these rooms was monitored with the help of Respirable Dust Sampler (RDS). Monitoring was conducted for four parameters namely Sulphur Dioxide, Nitrogen Dioxide, Particulate Matters size less than 10 micron (PM_{10}), and Particulate Matters size less than 2.5 micron ($PM_{2.5}$). One RDS was placed on the top of the room built with ordinary bricks (away from high rise building for availability of free flow of air) to measure ambient air monitoring outside the rooms and other two RDS were placed, each inside both rooms. Glass Microfiber filter papers were used for this monitoring.

The health consequences of exposure to polluted air are considerable. Exposure to outdoor air pollution and indoor pollution is associated with a broad range of acute and chronic health effect. Source of outdoor pollution are industries, vehicles, road sweeping, pollens etc. and inhouse heating systems, paints and varnishes on walls, cleaning agents and construction materials etc. are the major source of indoor pollution. The vulnerable groups of indoor pollution include infants, the elderly, and housewives. SO_2 has the deteriorating impact many building materials, including limestone, marble, roofing slate, and mortar. Dust particles of size less than 10 micron adversely damage the lungs by accumulating deep into the lungs. Whereas dust particles larger than 10 micron tend to be trapped in the nose, mouth or throat. So, an attempt has been made to evaluate whether there is the generation of any toxic gases from the bricks manufactured using paper industry sludge having calcium carbonate (lime mud).

Monitoring was carried out from the month January 2021 to June 2021 in three shifts in a day, each shift of 8 h (Fig. 59.1).

Tables 59.6, 59.7, 59.8, 59.9, 59.10, 59.11, 59.12, 59.13, 59.14, 59.15, 59.16, 59.17, 59.18, 59.19, 59.20, 59.21, 59.22, and 59.23 below show the value for quality of ambient air monitored for different seasons.

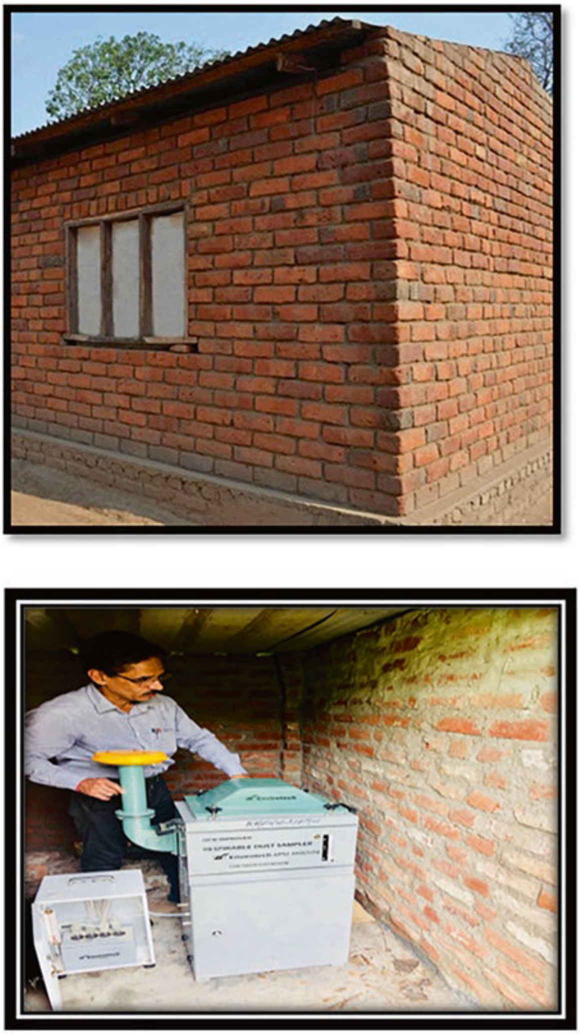

Fig. 59.1 Ambient air quality monitoring in the rooms constructed using sludge

Table 59.6 Ambient air quality monitoring (normal bricks inside room) January 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.01.2021	Not detected	4.6	47.8	15.00
04.01.2021	Not detected	7.2	48.5	13.54
06.01.2021	Not detected	4.6	42.8	12.52
08.01.2021	Not detected	4.6	53.2	11.93
11.01.2021	Not detected	4.6	52.1	11.59
13.01.2021	Not detected	4.6	52.2	12.57
15.01.2021	Not detected	4.6	55.0	14.37
18.01.2021	Not detected	4.6	56.6	16.04
20.01.2021	Not detected	4.6	52.0	13.94
22.01.2021	Not detected	4.6	52.2	15.80
27.01.2021	Not detected	4.6	53.6	14.41
29.01.2021	Not detected	4.6	51.9	11.39

All values are 24 h average in $\mu g/m^3$

Table 59.7 Ambient air quality monitoring (sludge bricks inside room) January 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.01.2021	Not detected	4.3	47.5	14.97
04.01.2021	Not detected	6.8	48.2	13.52
06.01.2021	Not detected	4.3	42.5	12.0
08.01.2021	Not detected	4.3	52.8	11.0
11.01.2021	Not detected	4.2	51.9	11.57
13.01.2021	Not detected	4.3	51.8	12.55
15.01.2021	Not detected	4.4	54.7	14.33
18.01.2021	Not detected	4.3	56.3	16.01
20.01.2021	Not detected	4.2	51.6	13.91
22.01.2021	Not detected	4.3	51.8	15.76
27.01.2021	Not detected	4.3	53.3	14.37
29.01.2021	Not detected	4.2	51.6	11.35

All values are 24 h average in $\mu g/m^3$

Table 59.8 Ambient air quality monitoring (normal bricks inside room) February 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.02.2021	Not detected	9.2	51.6	11.49
03.02.2021	Not detected	6.0	47.7	11.81
05.02.2021	Not detected	4.4	50.7	12.59
08.02.2021	Not detected	4.3	52.5	15.22
10.02.2021	Not detected	7.0	51.4	13.52
12.02.2021	Not detected	4.4	51.0	10.12
15.02.2021	Not detected	4.5	45.2	12.23
17.02.2021	Not detected	4.3	49.1	13.65
19.02.2021	Not detected	4.5	52.1	12.49
22.02.2021	Not detected	4.4	50.7	11.92
24.02.2021	Not detected	7.2	51.5	14.33
26.02.2021	Not detected	5.7	49.8	12.93

All values are 24 h average in $\mu g/m^3$

Table 59.9 Ambient air quality monitoring (sludge bricks Inside room) February 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.02.2021	Not detected	8.9	51.3	11.36
03.02.2021	Not detected	5.8	47.4	11.68
05.02.2021	Not detected	4.2	50.3	12.48
08.02.2021	Not detected	4.1	52.2	15.23
10.02.2021	Not detected	6.7	51.1	13.41
12.02.2021	Not detected	4.1	49.8	10.12
15.02.2021	Not detected	4.2	44.9	12.12
17.02.2021	Not detected	4.0	48.9	13.54
19.02.2021	Not detected	4.2	51.8	12.37
22.02.2021	Not detected	4.1	50.6	11.81
24.02.2021	Not detected	6.8	51.3	14.21
26.02.2021	Not detected	5.4	49.5	12.82

All values are 24 h average in μg/m^3

Table 59.10 Ambient air quality monitoring (normal bricks inside room) March 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.03.2021	Not detected	4.5	45.6	11.86
03.03.2021	Not detected	7.1	45.4	12.27
05.03.2021	Not detected	4.5	53.7	11.28
08.03.2021	Not detected	4.5	45.6	15.29
10.03.2021	Not detected	4.5	53.6	15.68
12.03.2021	Not detected	4.5	46.8	13.68
15.03.2021	Not detected	4.5	45.8	14.26
17.03.2021	Not detected	4.5	44.7	13.87
19.03.2021	Not detected	4.5	48.8	13.25
22.03.2021	Not detected	4.5	43.7	11.26
24.03.2021	Not detected	4.5	44.6	11.17
26.03.2021	Not detected	4.5	47.9	11.65
31.03.2021	Not detected	4.5	46.2	11.89

All values are 24 h average in μg/m^3

Table 59.11 Ambient air quality monitoring (Sludge bricks inside room) March 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.03.2021	Not detected	4.1	45.4	11.74
03.03.2021	Not detected	6.9	45.1	12.16
05.03.2021	Not detected	9.2	53.4	11.24
08.03.2021	Not detected	9.0	45.2	15.16
10.03.2021	Not detected	4.1	53.4	15.54
12.03.2021	Not detected	4.1	46.6	13.54
15.03.2021	Not detected	7.1	45.7	14.12
17.03.2021	Not detected	4.2	44.5	13.64
19.03.2021	Not detected	8.7	48.3	13.01
22.03.2021	Not detected	4.1	43.0	11.12
24.03.2021	Not detected	4.2	44.1	11.02
26.03.2021	Not detected	4.1	47.3	11.41
31.03.2021	Not detected	9.0	45.8	11.76

All values are 24 h average in μg/m^3

Table 59.12 Ambient air quality monitoring (normal bricks inside Room) April 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
05.04.2021	Not detected	10.4	48.7	11.82
07.04.2021	Not detected	7.0	45.2	11.26
09.04.2021	Not detected	6.0	46.1	11.33
12.04.2021	Not detected	10.1	43.3	10.56
17.04.2021	Not detected	9.3	47.4	14.09
19.04.2021	Not detected	5.9	50.2	11.13
23.04.2021	Not detected	5.5	37.0	10.24
26.04.2021	Not detected	4.3	48.2	11.38
28.04.2021	Not detected	7.2	49.9	11.52
30.04.2021	Not detected	4.3	47.5	10.78

All values are 24 h average in μg/m^3

Table 59.13 Ambient air quality monitoring (Sludge bricks inside room) April 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
05.04.2021	Not detected	10.1	48.4	11.81
07.04.2021	Not detected	6.8	44.9	11.23
09.04.2021	Not detected	5.8	45.7	11.32
12.04.2021	Not detected	9.8	43.1	10.56
17.04.2021	Not detected	9.1	47.1	14.06
19.04.2021	Not detected	5.6	49.8	11.12
23.04.2021	Not detected	5.2	36.6	10.21
26.04.2021	Not detected	4.1	47.8	11.34
28.04.2021	Not detected	6.5	49.5	11.50
30.04.2021	Not detected	4.1	47.2	10.75

All values are 24 h average in μg/m^3

Table 59.14 Ambient air quality monitoring (normal bricks inside room) May 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
03.05.2021	Not detected	4.1	48.0	14.89
05.05.2021	Not detected	4.2	44.6	13.43
10.05.2021	Not detected	4.1	43.7	12.41
12.05.2021	Not detected	4.3	43.1	11.82
17.05.2021	Not detected	4.5	42.0	11.49
19.05.2021	Not detected	4.4	34.6	12.46
21.05.2021	Not detected	4.2	27.7	14.26
24.05.2021	Not detected	4.3	26.8	15.17
28.05.2021	Not detected	4.5	41.2	13.71
31.05.2021	Not detected	4.3	48.7	14.86

All values are 24 h average in μg/m^3

Table 59.15 Ambient air quality monitoring (Sludge bricks inside room) May 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
03.05.2021	Not detected	4.2	47.6	14.76
05.05.2021	Not detected	4.2	44.4	13.39
10.05.2021	Not detected	4.1	43.5	12.38
12.05.2021	Not detected	4.2	42.9	11.76
17.05.2021	Not detected	4.4	41.8	11.43
19.05.2021	Not detected	4.3	34.2	12.42
21.05.2021	Not detected	4.3	27.5	14.21
24.05.2021	Not detected	4.2	26.4	15.18
28.05.2021	Not detected	4.4	41.3	13.73
31.05.2021	Not detected	4.3	48.4	14.78

All values are 24 h average in μg/m^3

Table 59.16 Ambient air quality monitoring (normal bricks inside room) June 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
04.06.2021	Not detected	4.3	42.1	9.13
07.06.2021	Not detected	4.2	43.8	9.17
09.06.2021	Not detected	4.4	44.7	9.43
11.06.2021	Not detected	4.3	43.1	8.78
14.06.2021	Not detected	4.4	41.2	10.69
16.06.2021	Not detected	4.5	36.2	6.48
18.06.2021	Not detected	4.3	31.4	7.65
21.06.2021	Not detected	4.2	30.1	7.36
23.06.2021	Not detected	4.4	31.5	6.85
25.06.2021	Not detected	4.5	40.6	10.26
30.06.2021	Not detected	4.3	41.1	9.57

All values are 24 h average in μg/m^3

Table 59.17 Ambient air quality monitoring (sludge bricks inside room) June 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
04.06.2021	Not detected	4.2	41.9	9.12
07.06.2021	Not detected	4.1	42.6	9.13
09.06.2021	Not detected	4.3	44.5	9.31
11.06.2021	Not detected	4.3	42.7	8.62
14.06.2021	Not detected	4.3	40.0	10.56
16.06.2021	Not detected	4.4	36.1	6.34
18.06.2021	Not detected	4.3	31.5	7.46
21.06.2021	Not detected	4.3	30.2	7.27
23.06.2021	Not detected	4.4	31.2	6.63
25.06.2021	Not detected	4.4	40.4	10.15
30.06.2021	Not detected	4.3	40.9	9.56

All values are 24 h average in μg/m^3

Table 59.18 Ambient air quality monitoring (outside rooms) January 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.01.2021	2.0	4.8	49.9	17.23
04.01.2021	2.0	7.4	50.4	15.44
06.01.2021	2.0	4.8	44.6	14.43
08.01.2021	2.0	4.8	55.0	13.85
11.01.2021	2.0	4.7	54.1	13.68
13.01.2021	2.0	4.7	54.0	14.65
15.01.2021	2.0	4.6	56.1	15.46
18.01.2021	2.0	4.8	567.5	18.13
20.01.2021	2.0	4.6	54.1	15.85
22.01.2021	2.0	4.7	54.0	17.72
27.01.2021	2.0	4.8	55.5	16.52
29.01.2021	2.0	4.6	53.7	13.47

All values are 24 h average in μg/m^3

Table 59.19 Ambient air quality monitoring (outside rooms) February 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.02.2021	2.0	9.4	53.5	11.58
03.02.2021	2.0	6.3	49.5	11.92
05.02.2021	2.0	4.7	52.4	12.62
08.02.2021	2.0	4.5	54.3	15.29
10.02.2021	2.0	7.4	53.2	13.61
12.02.2021	2.0	4.5	52.8	10.23
15.02.2021	2.0	4.5	47.1	12.53
17.02.2021	2.0	4.4	51.0	13.71
19.02.2021	2.0	4.5	53.9	12.52
22.02.2021	2.0	4.6	52.5	12.23
24.02.2021	2.0	7.4	53.2	15.21
26.02.2021	2.0	5.9	51.6	13.83

All values are 24 h average in μg/m^3

Table 59.20 Ambient air quality monitoring (outside rooms) March 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
01.03.2021	2.0	4.6	47.4	13.83
03.03.2021	2.0	7.2	47.2	12.35
05.03.2021	2.0	4.5	55.5	11.34
08.03.2021	2.0	4.6	47.4	15.36
11.03.2021	2.0	4.5	55.4	15.86
12.03.2021	2.0	4.6	48.5	13.86
15.03.2021	2.0	4.7	47.6	14.54
17.03.2021	2.0	4.5	46.4	13.95
19.03.2021	2.0	4.6	50.6	13.43
22.03.2021	2.0	4.7	45.4	11.44
24.03.2021	2.0	4.5	46.5	11.35
26.03.2021	2.0	4.7	49.6	11.84
31.03.2021	2.0	4.5	48.6	11.92

All values are 24 h average in μg/m^3

Table 59.21 Ambient air quality monitoring (outside rooms) April 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
05.04.2021	2.0	10.8	50.5	12.79
07.04.2021	2.0	7.8	47.0	12.34
09.04.2021	2.0	7.9	48.0	12.25
12.04.2021	2.0	10.7	45.1	11.64
17.04.2021	2.0	10.2	49.2	14.91
19.04.2021	2.0	7.2	51.1	13.72
23.04.2021	2.0	6.3	39.1	11.16
26.04.2021	2.0	5.5	49.1	12.23
28.04.2021	2.0	7.5	51.2	12.71
30.04.2021	2.0	5.4	49.3	11.86

All values are 24 h average in $\mu g/m^3$

Table 59.22 Ambient air quality monitoring (outside rooms) May 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
03.05.2021	2.0	4.6	50.2	14.97
05.05.2021	2.0	4.5	46.4	13.52
10.05.2021	2.0	4.4	45.5	12.50
12.05.2021	2.0	4.4	45.0	11.91
17.05.2021	2.0	4.5	43.7	11.58
19.05.2021	2.0	4.5	35.4	12.57
21.05.2021	2.0	4.6	29.6	14.34
24.05.2021	2.0	4.6	28.6	15.35
28.05.2021	2.0	4.5	43.1	13.50
31.05.2021	2.0	4.4	50.6	14.64

All values are 24 h average in $\mu g/m^3$

Table 59.23 Ambient air quality monitoring (outside rooms) June 2021

Sampling date	SO_2	NO_2	PM_{10}	$PM_{2.5}$
04.06.2021	2.0	4.5	44.2	9.21
07.06.2021	2.0	4.4	45.6	9.25
09.06.2021	2.0	4.5	43.5	9.52
11.06.2021	2.0	4.5	45.0	8.86
14.06.2021	2.0	4.5	43.1	10.78
16.06.2021	2.0	4.5	38.1	6.57
18.06.2021	2.0	4.4	33.2	7.84
21.06.2021	2.0	4.4	32.0	7.55
23.06.2021	2.0	4.5	33.4	6.93
25.06.2021	2.0	4.4	42.6	12.06
30.06.2021	2.0	4.5	43.1	11.43

All values are 24 h average in $\mu g/m^3$

59.4 Results and Discussion

59.4.1 Quality of Ambient Air

Air quality of both rooms was observed within prescribed standards notified by Central Pollution Control Board, Delhi. Difference in air quality of both rooms was found negligible in respect of Sulphur dioxide, Nitrogen Dioxide, PM_{10} (Particular matter of size less than 10 micron), and $PM_{2.5}$ (Particular matter of size less than 2.5 micron) in any season. Figures 59.2, 59.3, 59.4, 59.5, 59.6, 59.7, 59.8, 59.9, 59.10, 59.11, 59.12, 59.13, 59.14, 59.15, 59.16, 59.17, 59.18, and 59.19, presents the quality of ambient air in respect of Nitrogen Dioxide and Respirable Suspended Particulate Matters (PM_{10} and $PM_{2.5}$) for the month January 2021 to June 2021.

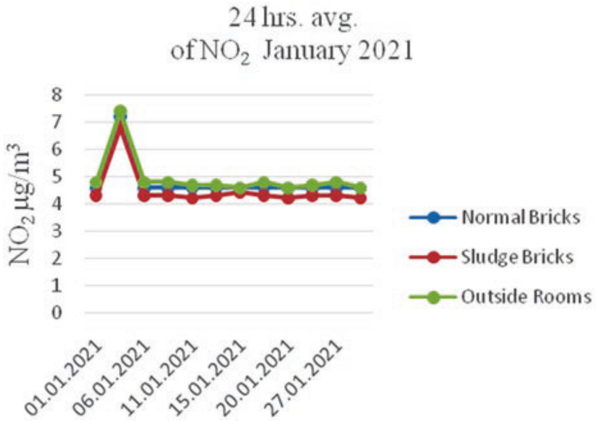

Fig. 59.2 Ambient air quality monitoring (Nitrogen Dioxide in January 2021)

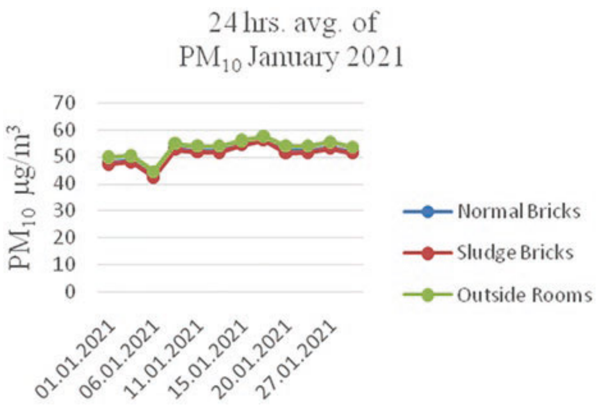

Fig. 59.3 Ambient air quality monitoring (PM_{10} in January 2021)

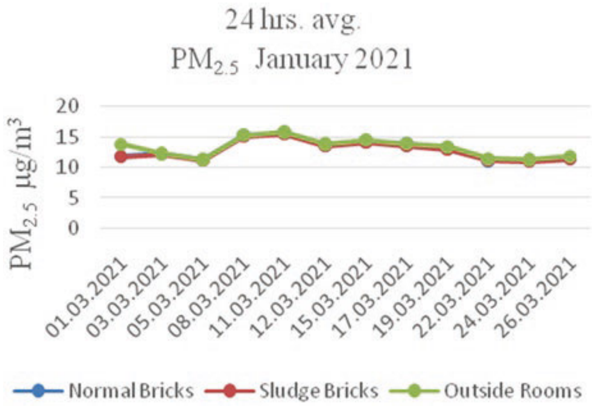

Fig. 59.4 Ambient air quality monitoring ($PM_{2.5}$ in January 2021)

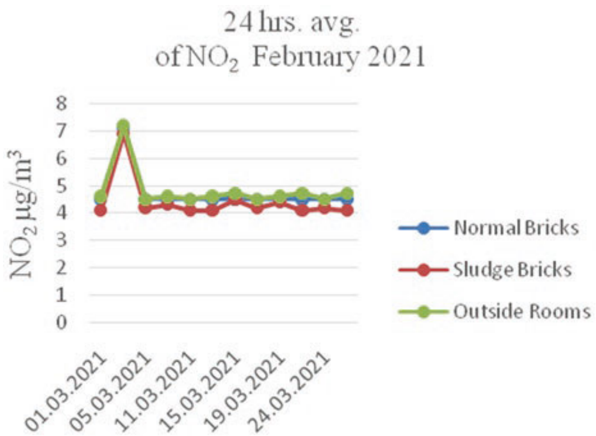

Fig. 59.5 Ambient air quality monitoring (Nitrogen Dioxide in February 2021)

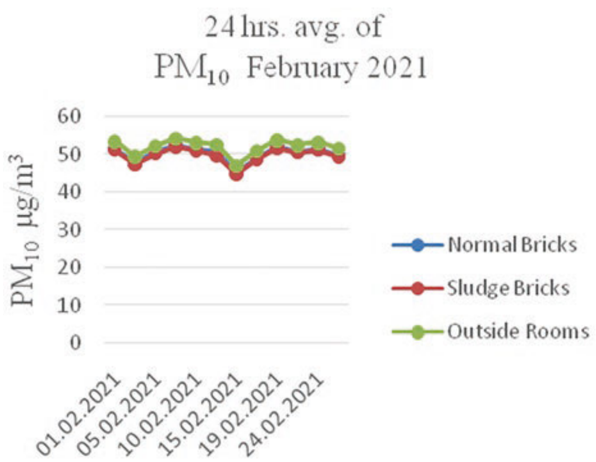

Fig. 59.6 Ambient air quality monitoring (PM_{10} in February 2021)

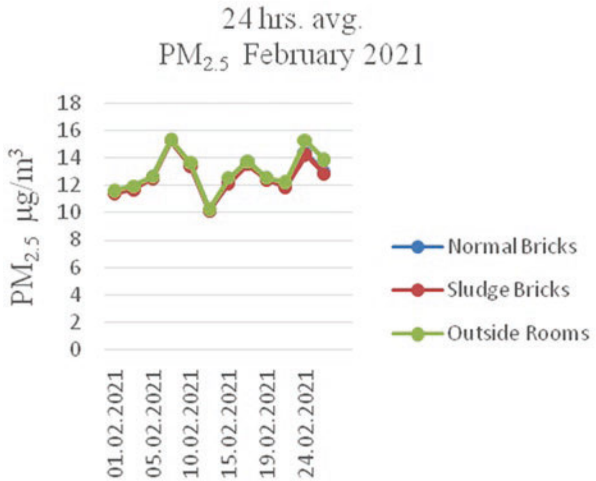

Fig. 59.7 Ambient air quality monitoring ($PM_{2.5}$ in February 2021)

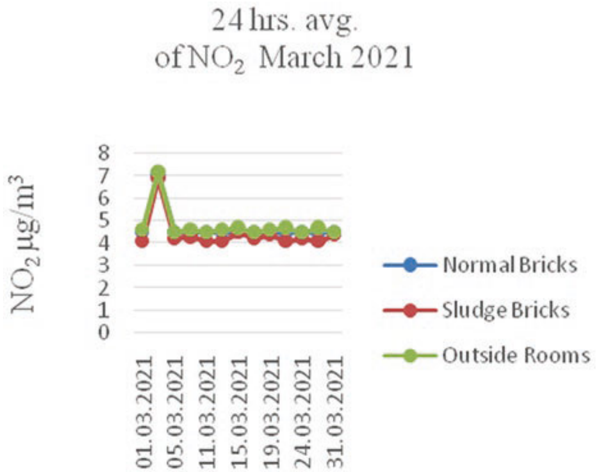

Fig. 59.8 Ambient air quality monitoring (Nitrogen Dioxide in March2021)

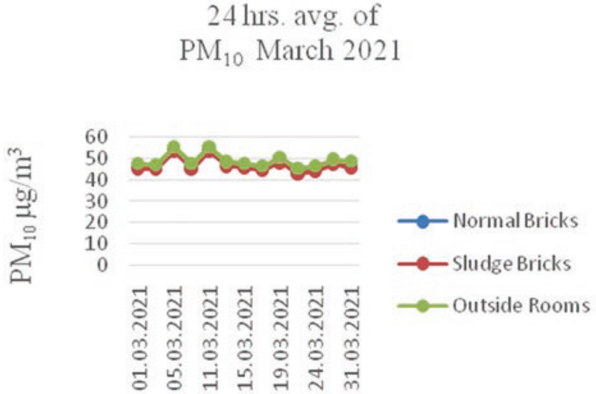

Fig. 59.9 Ambient air quality monitoring (PM_{10} in March 2021)

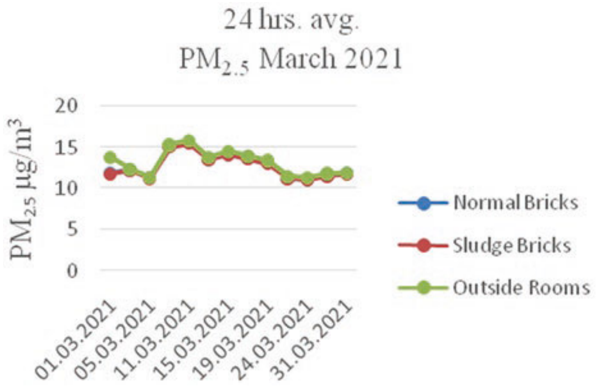

Fig. 59.10 Ambient air quality monitoring ($PM_{2.5}$ in March 2021)

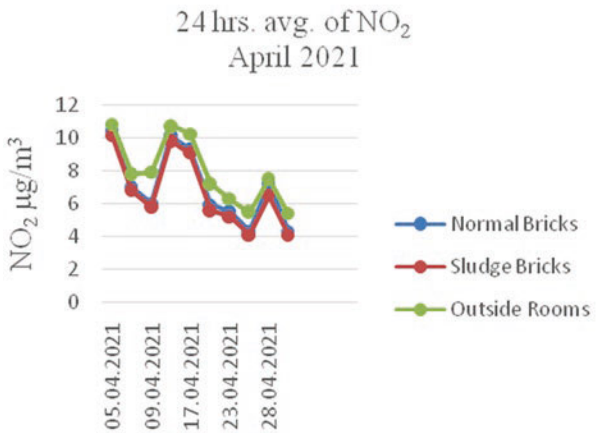

Fig. 59.11 Ambient air quality monitoring (Nitrogen Dioxide in April 2021)

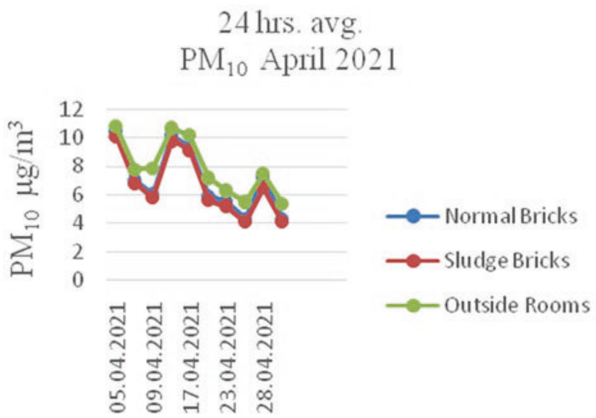

Fig. 59.12 Ambient air quality monitoring (PM_{10} in April 2021)

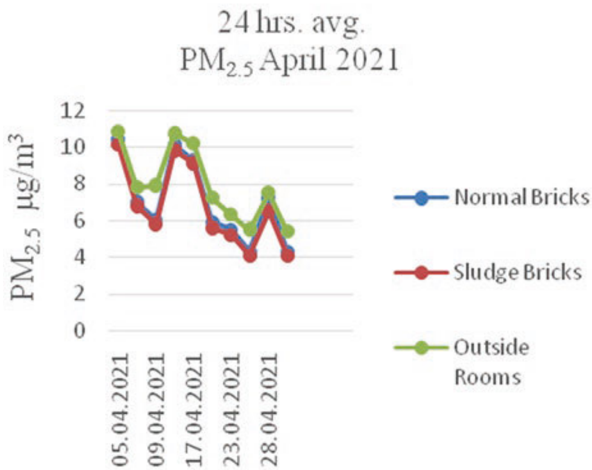

Fig. 59.13 Ambient air quality monitoring ($PM_{2.5}$ in April 2021)

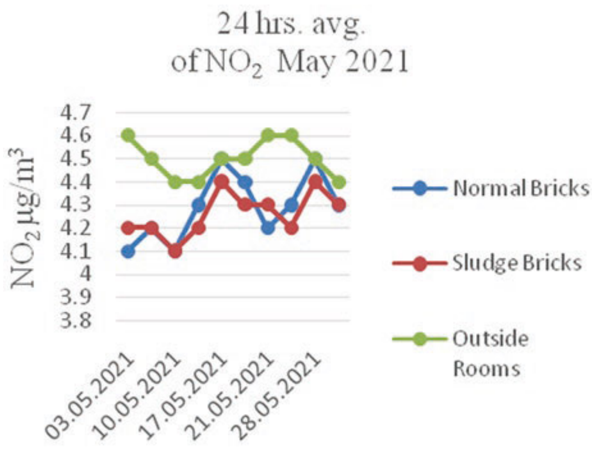

Fig. 59.14 Ambient air quality monitoring (Nitrogen Dioxide in May 2021)

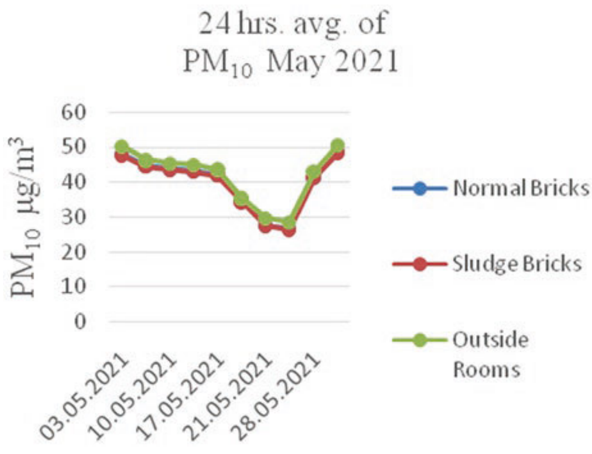

Fig. 59.15 Ambient air quality monitoring (PM_{10} in May 2021)

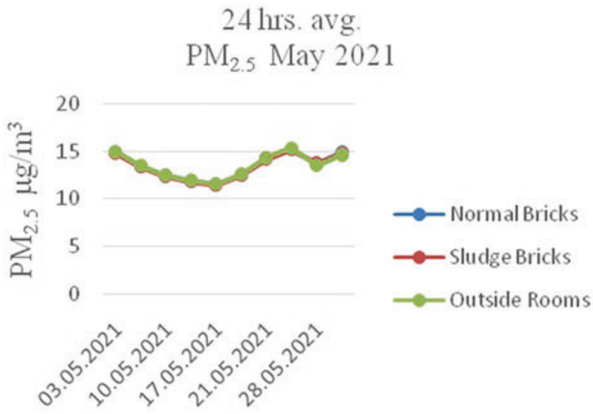

Fig. 59.16 Ambient air quality monitoring ($PM_{2.5}$ in May 2021)

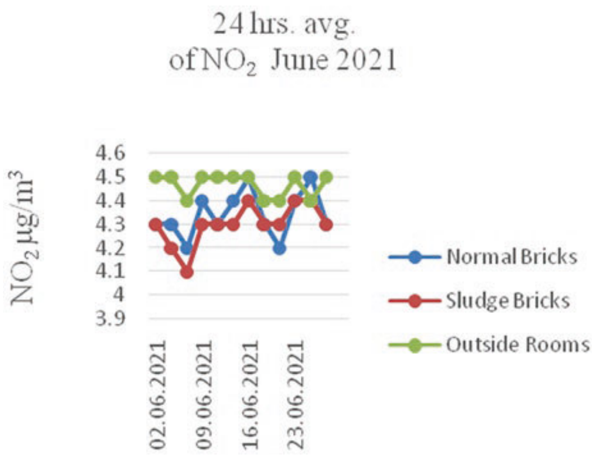

Fig. 59.17 Ambient air quality monitoring (Nitrogen Dioxide in June 2021)

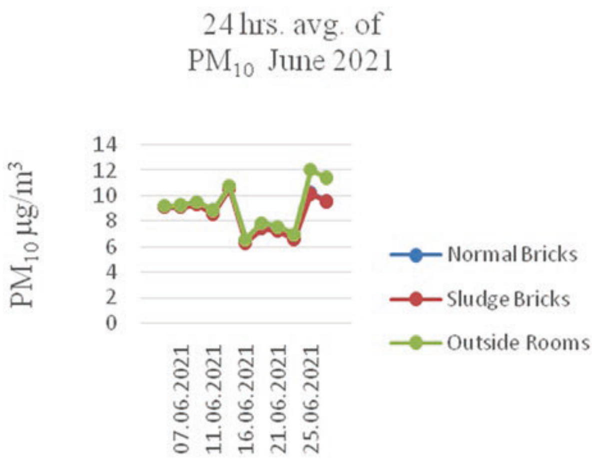

Fig. 59.18 Ambient air quality monitoring (PM_{10} in June 2021)

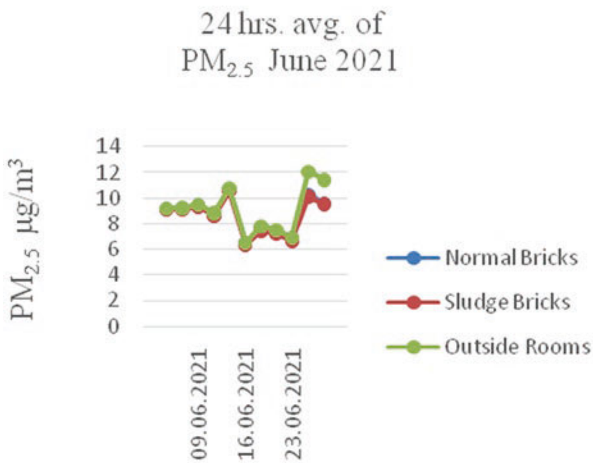

Fig. 59.19 Ambient air quality monitoring ($PM_{2.5}$ in June 2021)

59.5 Conclusion

In this study using paper industry waste (lime mud) in development of bricks and thereafter construction of room with these bricks, negligible difference between air quality of both rooms constructed using standard burnt clay bricks and bricks manufactured using lime mud was found in respect of Sulphur dioxide, Nitrogen Dioxide, $PM_{2.5}$ (Particular matter of size less than 10 micron) and $PM_{2.5}$ (Particular matter of size less than 2.5 micron) in any season. No adverse impact on indoor air quality of room constructed with paper industry waste (lime sludge) bricks was observed. Hence, the bricks developed using paper industry waste having calcium carbonate could be considered as environment-friendly.

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Chapter 60
Review on Shear Strengthened RC Rectangular Beams with FRP Composites

K. V. Satyanarayana and B. Ajitha

Abstract This paper presents an overview of various shear strengthening techniques used to enhance the shear capacity of RC beams. The conventional strengthening schemes increase the cross-sectional area and dead load. Whereas the use of FRP strengthening enhances the shear resistance capacity without increasing the dead load. There are various parameters such as type of FRP, wrapping methodology, polymer properties, orientation of fibres, thickness of FRP, inclination of FRP and anchorage has influence on the efficiency of FRP strengthening. The use of FRP strengthening increases the concrete shear capacity and stirrups shear capacity by acting as an external confinement. There are many empirical relations had been proposed to estimate the contribution of FRP in shear resistance. This article summarizes the various FRP shear strengthening schemes, influence of different parameters discussed above and also presents an overview of different models in estimating the shear capacity of FRP strengthened RC beams.

Keywords Shear strengthening · FRP · Shear span to depth ratio · RC beam · Brittle failure

60.1 Introduction

Brittle shear failure can be observed due to inadequate internal shear resistance of beams subjected to loading. To overcome this type of failure, Shear strengthening can be done with different techniques like RC-jacketing, Steel plate bonding and External wrapping of FRP composites. Implementation of External FRP wrapping (Fig. 60.1) in the form of Side wrapping, U-wrap and Full wraps with different fibre orientations can enhance the shear capacity of beam. Different types of FRP such as CFRP, BFRP, AFRP and GFRP are available with Uni-directional and Bi-directional fibre profiles.

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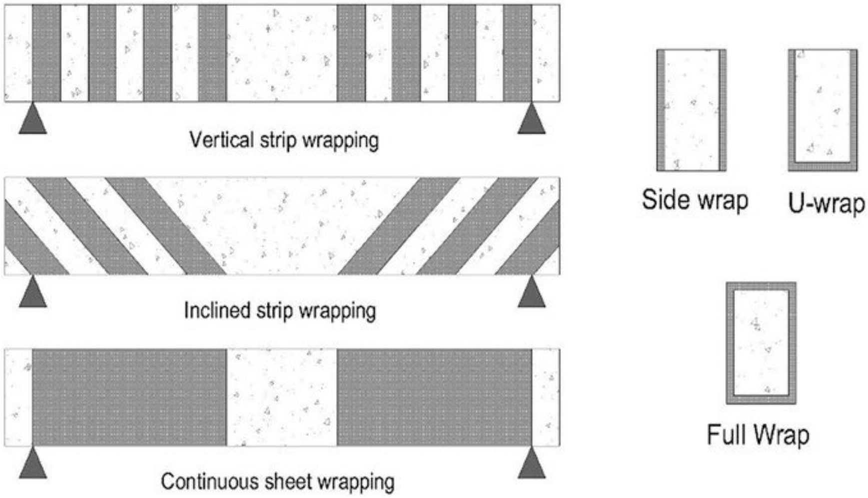

Fig. 60.1 Strengthening schemes

The behavior of FRP strengthened beams is generally controlled by two types of failure modes. One is Debonding failure and the other is Rupture failure. Debonding type of failure is most common and depends on the load transfer mechanism between externally bonded composites and concrete. Rupture failure can be seen in the FRP composites when the material experience tensile stress more than its designed stress which we can observe at higher failure loads compared to Debonding failure load. This can be achieved with the proper anchorage of composites. Anchorage can be done using different techniques represented in the Fig. 60.2 such as U-Anchorage, Plate anchorage, Sandwich plate anchorage, Hybrid-bonded anchorage and H-type anchorage (Hu et al. 2020) etc.

60.2 Analytical Study

60.2.1 As Per ACI Codal Provisions (ACI 440.2R. 2017)

Shear strength of FRP-strengthened RC members can be determined by Eq. 60.1

$$\varnothing V_n = \varnothing\left(V_c + V_s + \psi_f V_f\right) \tag{60.1}$$

Shear contribution of Externally bonded FRP composites can be calculated by Eq. 60.2

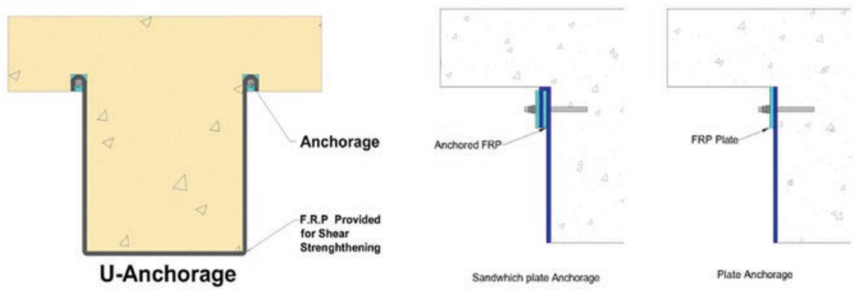

Fig. 60.2 (**a**) U-anchorage (**b**) Sandwich plate Anchorage (**c**) H-type end anchor (**d**) HB anchor

$$V_f = \frac{A_{fv} f_{fe} (\sin\alpha + \cos\alpha) d_{fv}}{S_f} \tag{60.2}$$

For Rectangular sections

$$A_{fv} = 2nt_f w_f \tag{60.3}$$

Tensile stress in the FRP shear reinforcement is given by the following Eq. 60.4

$$f_{fe} = E_f \varepsilon_{fe} \tag{60.4}$$

Effective FRP strain can be calculated as follows

For fully wrapped

$$\varepsilon_{fe} = 0.004 \leq 0.75\varepsilon_{fu} \tag{60.5}$$

For side bonding or U-wraps

$$\varepsilon_{fe} = K_v \varepsilon_{fu} \leq 0.04 \tag{60.6}$$

$$K_v = \frac{K_1 K_2 L_e}{11900\,\varepsilon_{fu}} \leq 0.75 \quad (SI) \tag{60.7}$$

$$L_e = \frac{23300}{(nt_f E_f)^{0.58}} (SI) \tag{60.8}$$

$$K_1 = \left(\frac{f_c'}{27}\right)^{2/3} (SI) \tag{60.9}$$

$$K_2 = \begin{cases} \dfrac{d_{fv} - 2L_e}{d_{fv}} & \text{for two sides bonded} \\ \dfrac{d_{fv} - L_e}{d_{fv}} & \text{for U-wraps} \end{cases} \tag{60.10}$$

60.2.2 Reinforcement Limits

As per ACI guidelines (ACI 318. 2019), the shear contributions of stirrups and FRP has to satisfy the following reinforcement limits

$$V_s + V_f \leq 0.66\sqrt{f_c'} b_w d \tag{60.11}$$

60.3 Literature

Khalifa and Nanni (2002) conducted an experimental investigation on shear deficient full-scale RC beams of rectangular cross-section to study the shear behavior and mode of failure. Two series of Beams, one is confined and the other is unconfined in the strengthening zone with different *a/d* ratios have been used in the study. Each series was designed to have different concrete compressive strength and fibre orientations. The strengthening process was done with CFRP strips and sheets of different widths and centre to centre spacing. Strips and sheets were wrapped to beams in two ways as side bonding and U-wraps.

Test results show that the shear strength of beams having internal shear reinforcement increases by 40–80% compared to control beams. Beams having no internal shear reinforcement shows an increment of 70–138%. This shows that the

CFRP contribution to shear capacity is more in case of unconfined beams than confined beams. Experimental results shows that the shear capacity of beam specimens depend on the *a/d* ratio of the beam.

Failure mode observed in the control beam is shear compression failure while Debonding of CFRP strips was observed in the unconfined beams with U-wraps. Splitting of concrete was also observed with debonding of CFRP in the confined beams (Khalifa and Nanni 2002).

Leung et al. (2007) investigated the shear capacity of beams with different spans and cross-section. CFRP strips were wrapped to beams in the form of U-wrap and Full wrap configurations with fibre orientation perpendicular to the longitudinal axis of the beam. Strip thickness, width and spacing between strips were taken as 0.44B/300, D/9 and D/3. Beams were heavily strengthened in Tension zone to prevent flexure failure so that the shear behaviour can be studied.

Test results show that the strengthening effectiveness of CFRP for U-wrap configuration is more for small cross-sections compared to large cross-sections whereas in full wrap configuration it is similar for all cross-sections. It is observed that the shear capacity of beams with larger cross-section has an improvement of 3.2–6.6% and an improvement of 59.5% for beams having smaller cross-sections. Validation of experimental results with different guidelines by ACI, FIB and JSCE resulted in conclusion that for Full wrap configurations ACI equation is overconservative, JSCE can be unconservative while FIB model can be employed for design calculations.

Failure mode observed in the experimentation is Debonding of FRP with a thin layer of concrete and Rupture failure for fully wrapped members.

Li and Leung (2017) An experimental program was conducted to study the effect of shear span to depth ratio on shear performance of rectangular beams. Beams specimens of different lengths and *a/d* ratio ranging from 1 to 3.5 were strengthened with CFRP strips in the form of U-wrap. Beam edges were rounded to prevent the premature debonding failure of FRP. Beams were designed to fail in shear though strengthened in shear span to observe the effect of *a/d* ratio.

It is observed that FRP wrapping led to the slow growth of diagonal cracks. Test results show that FRP contribution to shear capacity has increased by 2.5–31.8% for *a/d* ratio up to 2, beyond that the strengthening effectiveness is slightly decreased. Intermediate strips in the strengthening zone experienced more strain compared to strips near support and load point. Strain distribution follows parabolic path along the critical crack for beams with *a/d* ratio between 2 and 3.5. This suggests that CFRP strain distribution was significantly affected by shear span to depth ratio. Experimental shear strength had been validated with various guidelines (ACI 440.2R (2008), JSCE (2001), etc). All guidelines follow a similar pattern in estimating the FRP contribution and these overestimated the shear capacity for *a/d* ratio of 1.0.

Most of the strips failed by either Debonding or Rupture of FRP and strips near to support were not affected as they were not intercepted by crack. For beams of *a/d* ratio more than 3 the crack propagated rapidly after attaining the peak load which resulted in rupture of CFRP strips.

Beber and Campos Filho (2005) experimented on shear strengthened Rectangular RC beams with various FRP wrapping techniques such as Side bonding, U-wrap and Full wrap. The main aim is to study the effectiveness of various wrapping techniques with different fibre orientations in beams having no internal shear reinforcement. Prefabricated Laminates and InSite prepared sheets are used for strengthening, both having different mechanical properties. Strips and sheets of widths 50 mm and 655 mm with fibre orientations of 90° and 45° were wrapped to beams in shear span.

Experimental results show that there is an improvement of 64–151.1% for side wrapping, 63.3–143.1% for U-wrapping and 104.4–255.6% for Full wrapping. Based on experimental results it is observed that higher amount of externally bonded CFRP doesn't increase the load carrying capacity proportionally (Beber and Campos Filho 2005).

Tested beams show that failure mode is Debonding of CFRP strips for U-Shaped configuration and Rupture of CFRP for Full wrap. Continuous sheet strengthening with 90° fibre orientation in the form of Full wrap worked well in controlling the brittle shear failure which resulted in Flexural failure. Whereas the beams with side bonded inclined sheets failed by Debonding with a layer of cover concrete.

Triantafillou (1998) Experimental study was conducted on shear deficient Rectangular RC beams to observe the efficiency of shear strengthening. CFRP strips were wrapped to sides of the beam with different fibre orientations. Test results show that there is an improvement in shear strength of 141.93–203.87% and 162.58–205.16% for beams with 90° and 45° fibre orientations. Failure modes observed were FRP Rupture and Shear Debonding.

A model was proposed based on the assumption that effective strain is smaller than the ultimate tensile strain in FRP at the ultimate limit state (Triantafillou 1998). Development length depends on the axial rigidity of FRP, which can be estimated by area times the elastic modulus.

Karzad et al. (2019) An experimental investigation was performed to study the failure mode and shear behavior of shear strengthened Rectangular RC beams with different ratios of stirrups. All beams were strongly strengthened in flexure to make shear failure dominant. Shear strengthening was done to both pre-cracked and conventional beams. Some beams were preloaded to 70% of capacity and unloaded to 40% then strengthening was done with CFRP sheets in multiple layers.

Test results show that there is an improvement in the shear capacity of 60–104% for strengthened beams after repair and 24–99% for undamaged strengthened specimens. CFRP contribution to shear capacity is not significant with a higher ratio of stirrups.

It has been observed that the shear capacity of beams doubled by using two layers of CFRP with minimum stirrups ratio (Karzad et al. 2019). By experimental investigation, it is clear that the overall load carrying capacity of beams increased with CFRP strengthening. Repaired and strengthened beams attained similar strength to undamaged and strengthened beams.

Unstrengthened specimens without stirrups failed suddenly in shear with the propagation of diagonal shear crack and beams with stirrups developed one small flexural crack initially then failed in shear span with major diagonal cracks. Failure mode observed in the strengthened beams after repair was same as unstrengthened. Debonding failure of CFRP strips was observed in beams without internal shear reinforcement. Failure mode in the undamaged strengthened specimens was similar to pre-damaged and strengthened beams.

Diagana et al. (2003) An experimental study has been conducted on RC Rectangular beams to study the effectiveness of shear strengthening with different fibre orientations. The beams were categorized into two series, one series of beams were strengthened with externally bonded CFRP strips in the form of U-wraps and other series were strengthened in the form of Full wraps. Beams are tested as simply supported and subjected to three-point bending. To study the effect of FRP distribution on the shear behavior, different combinations of center to center spacing between CFF strips were considered, which ranges from 200 to 350 mm.

According to test results, significant improvement in the shear capacity of beams up to 61% has been observed. For U-wrap technique, beams with inclined fibres exhibited higher failure load compared to vertical strips. Whereas in Full wrap technique, beams with vertical strips exhibited higher failure loads. In both techniques, CFF strengthening worked well for beams which had less center to center spacing between strips. Shear contribution of carbon fabric observed is higher in case of beam having vertical strips in Full wrap technique with lesser center to center spacing between strips. Based on Strain data obtained from strain gauges, it is observed that externally bonded Carbon fabric strips experienced more strain than internal stirrups after the formation of diagonal crack. CFF strips near to support experienced lesser strain compared to other strips. All specimens failed in shear by developing the diagonal shear cracks, for strengthened specimens the initial and diagonal cracks formed at higher loads compared to control specimen. This shows that CFF strips delayed the propagation of cracks. Debonding of CFF strips with a thin layer of concrete has been observed in the beams with U-wrap technique whereas the beams strengthened with Full wrap technique failed by rupture of CFF strips in contact with main diagonal crack (Diagana et al. 2003).

Hu et al. (2020) conducted an experimental investigation to study the effect of proposed FRP anchorage system on shear behavior of Reinforced concrete beams. All beams were subjected to four point bending with a constant *a/d* ratio of 2.0. Strengthening was done on the right shear span of the beam. Stirrups are closely placed in the unstrengthened region compared to strengthened zone to observe the effectiveness of externally bonded CFRP strips. Hybrid-bonded (HB) and H-type end anchorage (EA) techniques are proposed with adjustable pressure application to fasten the CFRP strips represented in Fig. 60.3. The efficiency of proposed anchorage techniques is studied by varying parameters like number of plies, different

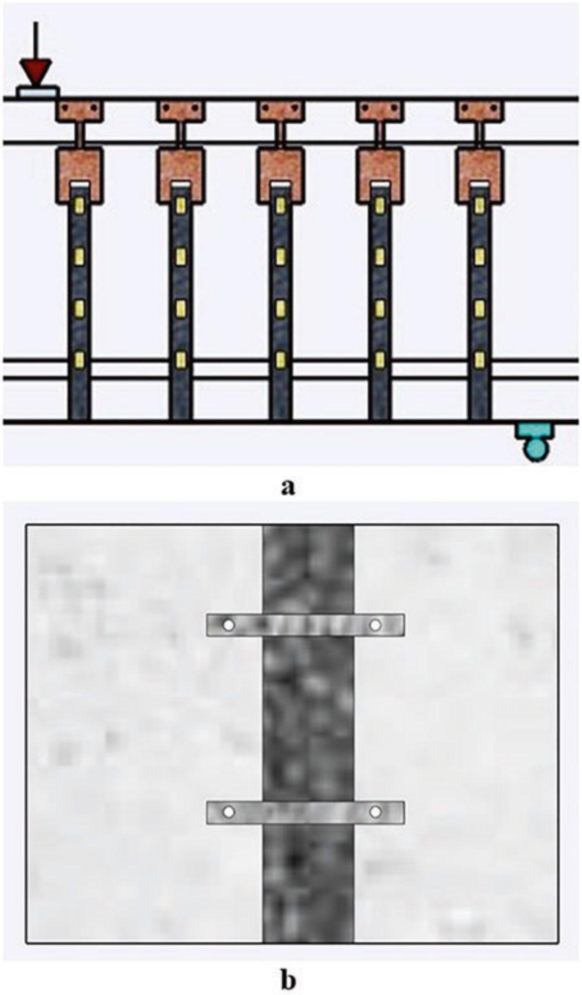

Fig. 60.3 Application of (**a**) H-type EA system and (**b**) HB anchor system

Torque moments applied on fasteners for HB anchor and different widths of deformation section for H-type system. Torque moments ranging from 3 to 12 N-m on mechanical fasteners were applied and deformation sections with width 5–15 mm for end anchorage system were used.

Ultimate load gradually increased up to 54% with increase in torque applied for HB anchored beams. Similar pattern has been observed in ultimate load increment by 48% up to deformation width of 12.5 mm in beams with EA system. Both anchorage systems were proved to be efficient by increasing the initial shear crack load.

Debonding of FRP strip observed in beam strengthened without anchorage system after attaining the peak load and in no time shear resistance dropped rapidly. Gradual Debonding of FRP strips at higher loads was observed in beams with toque up to 6 N-m whereas FRP ruptured with 12 N-m torque in HB anchorage system. Enhancement of shear capacity with EA system was achieved by ductile behavior of anchor.

Based on the failure pattern observed, parameters like applied torque and width of deformation section affects the inclination of crack. It is observed that H-type end anchor proved to be effective in enhancing the ductility (Hu et al. 2020).

Abdulqader et al. (2019) investigated the shear behavior of Self Compacting Concrete (SCC) beams strengthened with externally bonded CFRP composites. Beams were designed in a way that failure will be governed by shear. Comparison has been made among the beams strengthened with different FRP wrapping techniques such as side bonding and u-wraps. Horizontal strips were bonded along the shear spanas shown in Fig. 60.4. which act as an anchorage to CFRP strips.

Improvement in the initial cracking load was observed with the externally bonded CFRP strips. Ultimate load observed to be 54% more for side wrapping technique with two anchored strips. Similarly, an increment of 62.5% has observed for U-wrap technique with one anchored horizontal strip at the top. Full wrap technique was found to be more effective with an improvement of 74%.

Both strengthened and unstrengthened specimens exhibited similar cracking pattern except the beams strengthened with full wrap technique. Decrease in the crack width by 77–86% has been observed with the CFRP strengthening. Beams with full wrapping failed in flexure with enhanced Ductility compared to brittle shear failure of other beams (Abdulqader et al. 2019).

Baggio et al. (2014) investigated the behavior of shear deficient RC beams to evaluate the effectiveness of shear strengthening with FRP composites in the form of

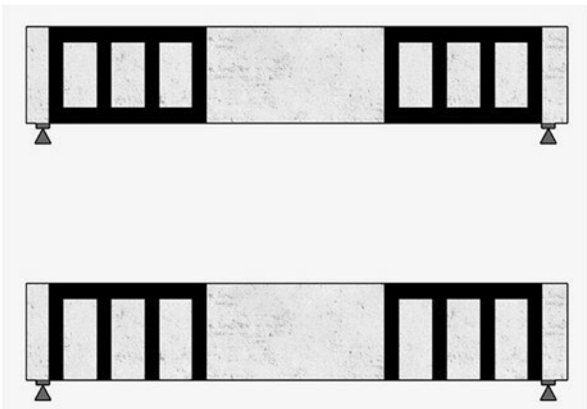

Fig. 60.4 Details of strengthening schemes

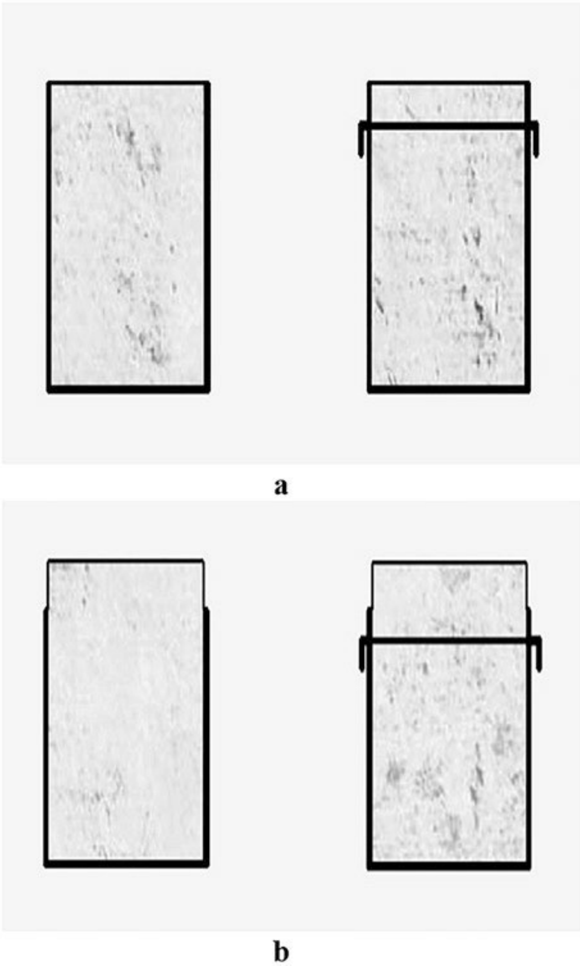

Fig. 60.5 Beams with anchors of (**a**) Full depth FRP U-wrap (**b**) Partial depth FRP U-wrap

U-wrap. CFRP and GFRP composites with and without anchorage were used for shear strengthening. CFRP and GFRP anchors were adopted and their application is as shown in the Fig. 60.5. GFRP strips with Partial depth and different type anchors were bonded to study the shear behavior of beam.

Test results show that beams strengthened with CFRP strips and anchors exhibited an increment in ultimate load of 67.5% and 75.1% over the control specimen. Partial depth GFRP strips without anchorage proved to be less effective compared to full depth strips. But the contribution of partial depth GFRP strips with anchorage was more over conventional GFRP strips (Baggio et al. 2014).

Control beam failed by the diagonal tension crack whereas the beams strengthened with GFRP strips failed by Debonding irrespective of depth. CFRP and GFRP anchors to GFRP strips effectively prevented the Debonding failure which resulted in shear compression failure.

Beams strengthened with CFRP strips started to develop flexural cracks with the increase in load along with the hairline shear cracks in between the strips which resulted in the Flexural failure of beams.

60.4 Conclusions

Based on the study, the following conclusions can be made:

- The use of U-wrapped FRP strengthening scheme enhances the shear carrying capacity of RC beams without increasing the cross-sectional area. But, the earlier delamination of FRP shows the reduction in efficacy of FRP strengthening scheme.
- Many shear strengthed beams exhibits higher shear strength but fails in brittle shear mode in the absence of end anchorage. This shows the importance of end anchorage in FRP strengthening technique. The use of end anchorage shows considerable amount of increase in the shear strength and offers better stress distribution than the beam without end anchorage.
- It is also understood that the internal confinement plays a crucial role in deciding the failure mode. The optimum amount of stirrups supports the FRP strengthening scheme in exhibiting better performance in terms of strength and ductility.
- The estimation of V_f alone is not a right way to estimate the contribution of FRP in shear resistance. Instead, the FRP strengthening scheme elevates the shear carrying capacity of concrete and stirrups. Thus, the shear carrying capacity of FRP strengthened beam should be the total shear carried by concrete, stirrups and FRP.

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Notations $\varnothing$ is strength reduction factor

V_c is nominal shear strength provided by concrete (kN/N)
V_s is nominal shear strength provided by steel stirrups (kN/N)
V_f is shear contribution of FRP (kN/N)
Ψ_f is FRP strength reduction factor
f_{fe} is effective stress in the FRP attained at section failure (MPa/GPa)
α is fibre orientation angle (deg)
ε_{fe} is effective strain in FRP reinforcement
ε_{fu} is design rupture strain of FRP reinforcement
k_1 and k_2 are the modification factors applied to k_v
L_e is the active bond length of FRP Laminate (mm/cm/m)

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Chapter 61
Machine Learning Based Quality Prediction of Reuse Water in Sewage Treatment Plant

Ankit and S. K. Singh

Abstract The proposed research is being conducted to determine the possibility of reusing water from a sewage treatment plants for use in certain domestic firm's different industrial applications. In this study, the water quality after the treatment of sewage in sewage treatment plants has been classify using different machines learning models like Support Vector Machine (SVM), Artificial Neural Network (ANN) and K-Nearest Neighbour (K-NN). Firstly, the data base of the sewage treatment plants at different stages have been collected at different stages. Secondly, a feature extraction and selection process has been implemented for the further process using Principal Component Analysis (PCA). Finally, different machine learning model are trained for the classification of the treated water. The proposed methodology is the perfect solution to make an automatic classification of treated water which can be further used for different industrial purpose.

Keywords Machine learning · Wastewater · Sewage treatment plant

61.1 Introduction

The increasing trend of using recovered municipal wastewater for landscaping, semi-industrial applications, agricultural products irrigation, groundwater levels recharging, and sporting impoundment frequently necessitates tertiary or advanced rainwater harvesting. Because this wastewater treatment application exposes recovered wastewater to the public, ensuring microbiological but, in particularly protection is critical (Mehta et al. 2015). Chemical coagulation, sedimentation, filtration, and disinfection are common treatment methods and activities for reuse in these scenarios, which are comparable to surface water treatment for potable water supply. A correctly functioning treatment system achieves a high level of pathogen

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elimination, ensuring the safety of the recovered wastewater. Two key operational requirements must be satisfied in tertiary wastewater treatment to enable effective virus elimination or inactivation. To decrease viral shielding, the effluent must be low in suspended solids and turbidity prior to disinfection, and adequate disinfection dosage and contact time must be supplied for wastewater. Buildings demolition components should be recycled because of rising trash generation and public awareness of environmental issues (Jha et al. 2011).

The fundamental purpose for waste water treatment and management is to ensure that the environment is protected and managed in such a manner that it is sustainable and suitable for human habitation, as well as to ensure that the public's health is not jeopardized by the threat represented by waste water (Gupta and Singh 2012). Treatment guarantees that the treated effluent may be discharged into water bodies without producing pollution, harming aquatic life, or harming the environment in general (Sharma et al. 2012). The treatment plant's purpose is to speed up the natural process of water purification. The utilization of a sewage system and water treatment facilities are the most frequent methods of water pollution management. Sewers collect municipal waste water from homes, businesses, and industries and transport it to a treatment facility with sophisticated machinery that treat the waste water stage by stage based on its composition (Jhamnani and Singh 2009).

Waste water may be characterized as drinkable water that has been polluted by natural or manufactured microbial chemicals as a result of human, commercial, or industrial activity, depending on the situation. The features of wastewater discharges would differ considerably depending on the populations of the municipality, the lot of industries present, the degree of segregation between rainfall and hygienic fluids, as well as the level of groundwater sources (Stamatis et al. 2010). Domestic waste water includes wastewater from the laundry, bathroom, and kitchen, as well as other waste water that individuals may pour down the drain accidently or purposefully. Domestic wastewater, as well as wastewater discharged from business institutions and other sources, are included in sanitary fluids or water. The schematic representation of the sewage treatment plant is shown in the image below (Gómez et al. 2007). Waste water is mostly derived from residential, commercial, and industrial water consumption, as well as ground water, surface water, and storm water. Residential sources and non-residential or industrial sources are the two primary categories of wastewater sources. The majority of it comes from our regular activities, such as doing laundry, flushing the toilet, dishwashing, watering our yard, and even taking a shower, for domestic sources. We have industrial customers, commercial or institutional customers, and a variety of additional liquid waste services, according to business sources. Waste water from industries, businesses, and institutions produces a one-of-a-kind need for treatment. Industrial, commercial, and institutional waste water has a considerably different need for treatment facilities than residential wastewater since it contains more complex pollutants. As a result, treatment costs are often greater. In comparison to ancient sewage systems, which collected sanitary and storm water in a single system, most current sewage systems are autonomous in nature.

In India, the practice of reusing treated sewage after sufficient treatment to suit industrial water needs has been in place for quite some time. For civic officials and planners, sewage disposal in India's fast developing cities has become a problem. Metropolitan sewage mismanagement, a lack of treatment facilities, a lack of proper data, inadequate and highly expensive treatment, inadequate cost recovery, and centralized functioning are all prevalent concerns in urban areas. Sewage is a steady and reliable supply of water that cannot be overlooked while meeting a region's water needs.

The method of water saving is reuse. The reuse of cleaned sewage is common in India because of two benefits:

(a) Pollution in receiving waters is being reduced.
(b) Reduction in the amount of fresh water required for various purposes

When wastewater enters a treatment plant, it initially goes through a process known as preliminary treatment. The goal of this step of therapy is to remove untreatable material that can be removed by physical means. Screens are used in the first step to remove bigger inorganic objects such as rags, wood, plastic, cans, paper, clogs, bottles and other physical debris that may be present. This operation is required because the influent sewage water must be processed for more treatment in the plant by totally removing or lowering undesirable influent features that might clog the operation process or lead to inflation of operation and processing costs unnecessarily. Typically, the shields are formed of identical steel and metal bars with holes. Physical unit operations are included in the preliminary therapy. Flow equalization and smell control are two further preliminary treatment activities. The material that has been removed is then collected and disposed of in landfills. Before the effluent is discharged to the main treatment segment, mechanically blended basins are engaged to remove any grit or sand-like material that may be present.

61.2 Related Work

Harmful compounds introduced into surface or ground water, whether directly or indirectly, are referred to as water pollution. Changes in surface (streams and rivers) and groundwater flows are known as hydrologic effects. Some of the early impetus for the environmental movement in the 1970s came from the sight and smell of severely polluted rivers (Bansal and Singh 2014). The risk of contaminated water to human health persuaded what became known as the "sanitary revolution" in the United States and Europe about a century before that, prioritizing sewer systems and clean water supplies in cities. Water pollution is still a severe global problem today, despite significant progress in cleaning up rivers. It has an impact on the health of freshwater ecosystem and the human communities who depends on them for water supply (Lu et al. 2015).

The volume and complexity of data have expanded dramatically over the previous decade as a result of improvements in data creation and storage, which are linked to lower costs and the availability of greater processing power. As a result, all of this data currently available can provide useful knowledge that can lead to a better understanding of phenomena, modelling, and reproduction, which can lead to some benefits and improvements in industrial operations (Pang et al. 2019). They incorporated microcontrollers, data collecting, and system maintenance technologies in treatment plants at the turn of the century. Sewage treatment plants can handle residential, commercial, and agricultural, each having its own set of features. To clean the wastewater, many technologies have been devised like reverse osmosis (Dai et al. 2018), adsorption, ion exchange (Tang et al. 2019), and precipitation (Cheng et al. 2019). Adsorption seems to be the most popular of these approaches due to its low cost, ease of use, and great efficiency. Adsorbents of many varieties have been created to combat water pollution like composite materials), organic polymers, carbon-based materials, biomasses, and inorganic minerals.

Sewage water treatment plants, inclusive of playing a good function in environmental preservation, represent a risk to employees and residents in the surrounding area (Nowojewski and Mniszek 2006). Bio-aerosol contains active microorganisms that can cause major inflammatory, infectious, and allergy disorders when released into the air. Employees at sewage treatment plants are often exposed to biological agents, which can cause illnesses such alveolitis, rhinitis, meningitis, conjunctiva, and intestinal parasites. Fungi in high quantities, in particular, can induce a wide range of disorders, from minor allergies to severe infections (Krajewski et al. 2004). Malaise, coughing, and breathing problems are among the most common problems reported by treatment plant personnel (Patil and Kamble 2017; Sánchez et al. 2008). Governing the disease transmission of air in the sewage water treatment plant and its surrounding area is vital due to health and environment risk induced by bio-aerosol emissions.

Many scholars concentrated on single-objective combinatorial optimization in which the objective function was resource, money, or carbon emissions. Some studies use more optimization problem to analyze the system's optimum position from several perspectives. A framework for modeling and optimizing a CHP segment that contains a diesel generator, fuel cell and organic Rankine cycle. They looked at the effects of important design and operational characteristics such fuel flow rate, fuel cell cooling capacity, static pressure, and flowing split proportion. The results depicted that now the CHP system's electricity and total efficiency w ere both 65.1% and 87.63%, respectively (Zhang et al. 2017). A thermodynamics model of a based scheme system that contains a gas turbine and a fuel cell that is intercooled and restored. Then they used entropy contraction to improve efficiency of the system. The results depicted that at a turbine intake temperature of 1800 K and an engine compression proportion of 20 (Choudhary 2017), optimum efficiency of 74.13% could be achieved. A biofuel partial combustion CHP segment with a geothermal heat pump (HP). They incorporated a Genetic Algorithm (GA) to enhance the system by utilising objective functions to assess constituent capacity and operational planning. A distributed power system's micro GA to attain optimal functioning in terms of energy effectiveness and convenience. A made by mixing nonlinear optimization approach is based on a Rankine's production cycle fed by biomass to boost power generation in small-scale CHP facilities. GA designed a CHP segment that is based on biogas production to lessen the yearly overall price. MILP was used to build and monitor a CHP facility in an industrial city, taking into account capital and operational expenses as well as CO2 emissions.

61.3 Data Collection and Methodology

The aim of this study is to determine the suitability of reusing treating wastewater from sewage treatment plants, as well as some waste water from factories situated down - stream of the residential sewage treatment plant's final disposal point. There are factories in the city that are experiencing water shortages. They acquire clean water for the industrial setting every day. Since the residential sewage treatment plant has enough water to provide for commercial purposes, treatability tests were conducted on the plant's processed wastewater, as well as the results were presented with techno-economic strategies.

61.3.1 Details of Sewage Treatment Plant

Systematic information collection aids in the successful completion of research projects. The data is recorded to aid in the identification of the plant's characteristics. Out of the total available domestic effluent plants in Chandigarh, the 3BRD Sewage Treatment Plant, which covers 48 acres in Punjab Territory, is situated in Sector 47, and selected looking at the availability of the data of last three years. The detail description about the sewage treatment plant is given in Table 61.1.

The Sewage Treatment Plant's current capacity is 30 MGD, despite the fact that it receives approximately 50 MLD of sewage. The water that arrives at S.T.P. is handled in three stages: primary, secondary, and tertiary. 35 mgd of the 48 mgd of water received at the Sewage Treatment Plant is treated to the secondary level, with the remaining 10 mgd being treated to the tertiary level. The tertiary treated sewage is returned to the city to be used to irrigate green fields and gardens. Increased waste flow has resulted from population growth and increased water consumption. The water treatment system had to be expanded as a result of this. The development of a 5 mgd wastewater treatment plant at Raipur Kalan has begun for the treatment of

Table 61.1 Detail description of the sewage treatment plants, Chandigarh

Capacity	50 MGD
Peak factor	2.25
Spread area	48 acres
Technical	Sewage flow 43000 cum/day

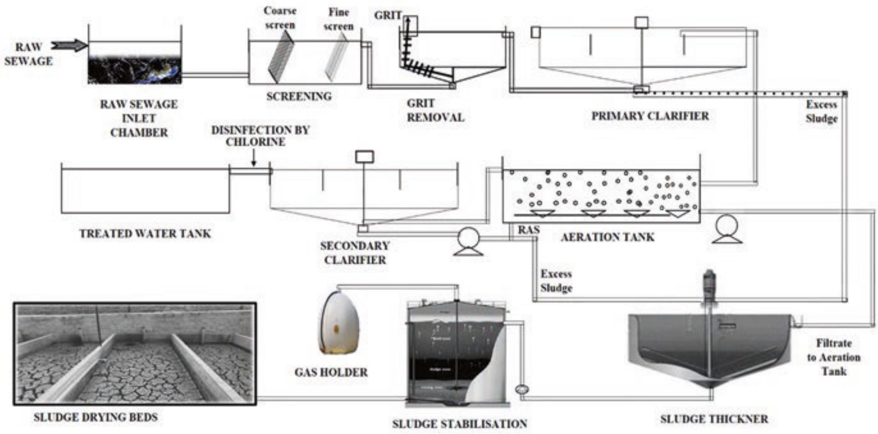

Fig. 61.1 Block Diagram of different process in sewage treatment plant

wastewater and the drainage of treated sewage into the free choe. Water treatment, subsidence, filtration, and decontamination are common management procedures and operations for reuse in these circumstances, as they are in surface water treatment for potable water source. A correctly managed treatment facility achieves a high level of pathogen clearance, ensuring the protection of the treated water. The block diagram of the mention sewage treatment plant is shown in Fig. 61.1.

61.3.2 Data Collection

Industrial wastewaters may have a wide range of characteristics, both inside and between industries. The effect of industrial discharges is determined not only by their overall characteristics, including such dissolved oxygen and particulate content, but also by the particular pollutants in the atmosphere present. In terms of handling industrial drainage, there are three choices. Control can occur at the plant's source of origin; wastewater can indeed be which was before for disposal to public treatment sources; or wastewater can be entirely treated just at plant and then reclaimed or dumped directly into wastewater effluents.

The used data of raw sewage and treated sewage water are more than of three years from sewage treatment plants, which is 1st of October, 2016 to 31st December, 2019 from sewage treatment plants Chandigarh. In this study, five important parameters are obtained to extract the relevant information from the raw sewage and treated sewage water from sewage treatment plants. The collected raw data sets of all the three conditions (S1-raw sewage water, S2-primary treated water, S3-outlet treated water) are used in implementation. The detailed summary of the collected data is discussed in Table 61.2.

Table 61.2 Details of the collected data from the sewage treatment plants

Duration of collected data	Oct, 2016 to 31st Dec., 2019
Parameters collected	instant do, pH value, TSS, COD, BOD
S1	Raw Sewage Water
S2	Primary Treated Water
S3	Outlet Treated Water

61.4 Characteristics of Sewage Treatment Plants

The water content of domestic sewage is approximately 99.9%. Natural and inorganic, suspended and dissolved solids, as well as microorganisms, make up the remainder. Water contamination occurs as a result of this 0.1%, and wastewater must be treated as a result.

The wastewater's composition is determined by the uses whereby the wastewater was put. Weather, social and economic conditions, and population preferences all influence these uses and how they were carried out. There is usually little concern in identifying the different substances that make up wastewater in the construction of a sewage treatment plants. This is due to the difficulties of performing the various experimental experiments, as well as the fact that the findings themselves cannot be used explicitly as design and process components. As a result, indirect criteria that reflect the character or polluting capacity of the wastewater in question are often preferred. These parameters define the quality of the sewage, some of parameters are described here,

61.4.1 Instant Dissolved Oxygen (DO)

The quantity of gaseous oxygen (O2) absorbed in waste water is introduced as dissolved oxygen. Direct penetration from the environment, accelerated change, or as a by result of plant photosynthesis are both ways oxygen reaches the water. It's usually measured in milligrams per litre (mg/L), which is the amount of oxygen absorbed divided by the concentration of the sample. Dissolved oxygen levels vary with water temperature and the amount of flowing water.

61.4.2 pH Value

The pH in water is an evaluation as to how acidic or basic it is. The spectrum is 0–14, with 7 denoting the neutral value. Acidity is denoted by a pH less than 7, even though a pH value more than 7 depicts a base. The pH in water is a vital indicator of the quality.

61.4.3 Total Suspended Solids (TSS)

Solids in sewage water that may be contained by a membrane are referred to as TSS. The sewage treatment sample is pumped into a pre-weighed filter to determine TSS. It's usually evaluated in milligrams per litre (mg/L), which is the quantity of oxygen absorbed divided by the concentration of the sample. The substance left on the filter is placed in the oven at 103–105 °C until it is no longer varies in weight.

61.4.4 Chemical Oxygen Demand (COD)

COD is a rough evaluation of the quantity of oxygen which can be absorbed by reactions in waste water. It's usually measured in milligrams per litre (mg/L), which is the quantity of oxygen absorbed divided by the concentration of the sample.

61.4.5 Biochemical Oxygen Demand (BOD)

The level of dissolved oxygen required (i.e., started demanding) by aerobic biological organisms to decompose the organic material contained in a wastewater sample at a specific temperature over a given time period is known as biochemical oxygen demand (BOD). It's usually measured in milligrams per litre (mg/L), which is the amount of oxygen absorbed divided by the concentration of the sample.

It is critical for those pursuing their FE credential to thoroughly comprehend how to control the biological characteristics of sewage using adequate methods of treatment. The different important threshold sewage characteristics in sewage treatment plants are discussed in Table 61.3.

In this segment, the procedure of the proposed work is interpreted based on the following inputs (i) Data collection (ii) Data handling (iii) Training of the machine learning models. The flow chart of the proposed methodology is shown in Fig. 61.2.

Table 61.3 Description of the threshold sewage characteristics in sewage treatment plants

Sr. No.	Parameters	Value of raw sewage	Value of treated sewage
1	pH value	6.5–8	6.5–8
2	TSS	Less than 330	Less than 10
3	BOD	Less than 350	Less than 20
4	COD	Less than 650	Less than 100

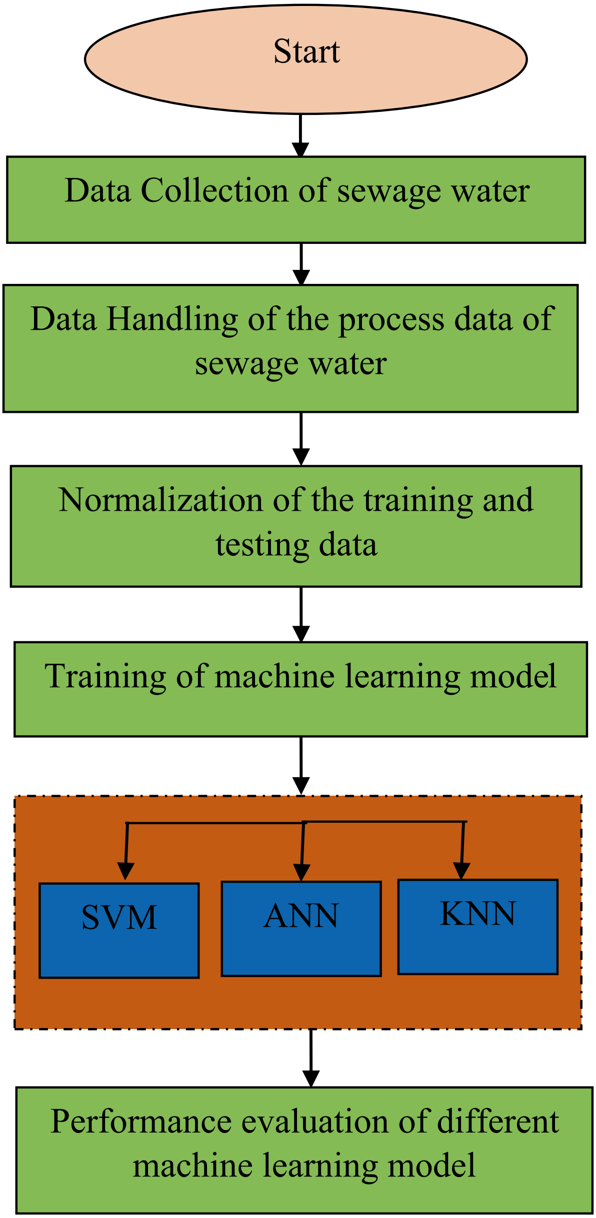

Fig. 61.2 Flowchart of the proposed methodology

61.5 Experimental Study

From the physical inspection of the sewage treatment plant, the industry's daily water use is estimated to be around 600 cu m. Storage tanks from the outside town bore wells are used to supply 90% of the available raw water consumption. The cost of purchasing water is Rs.150/- each tanker with a volume of 10 cu m. As a result, the corporation spends a lot of money on buying raw water from outside town bore wells. As an alternate source of water demand, the potential of utilizing treated sewage water from a neighbouring municipal facility was investigated. In the interests of the firm and the water conservation, a valuable natural resource, we attempted to discover a technically feasible and economically viable solution. The used data of raw sewage and treated sewage water are more than of three years from sewage treatment plants, which is 1st of October, 2016 to 31st December, 2019 from sewage treatment plants Chandigarh.

In this study, five primary features are used to obtain the relevant information from the raw sewage and treated sewage water from sewage treatment plants. The collected raw data sets of all the three conditions (S1-raw sewage water, S2-primary treated water, S3-outlet treated water) is proper normalized before used in implementation. The normalized values of the instant do and pH values are represented by Figs. 61.3, and 61.4. The normalized values of the TSS, COD and BOD are represented by the Figs. 61.5, 61.6, and 61.7 respectively. Each features values are plots with respects to the no of days of the collected data of raw sewage and treated sewage water from sewage treatment plants.

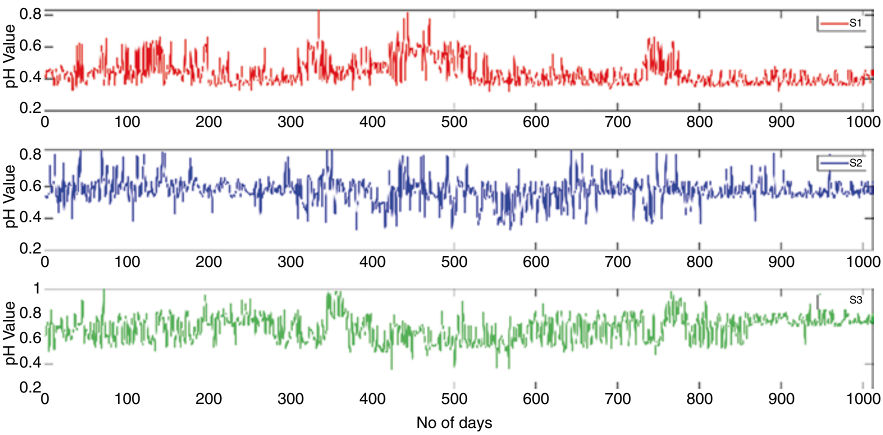

Fig. 61.3 Instant do values varies with the no of days

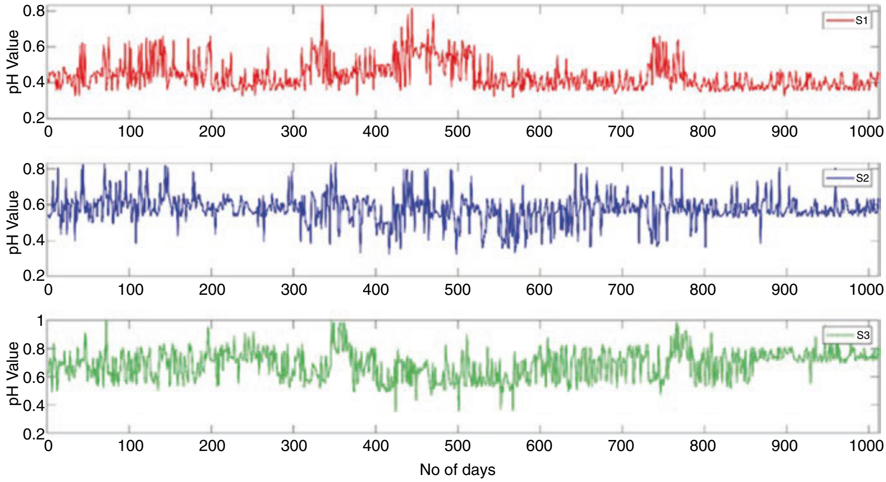

Fig. 61.4 pH values varies with the no of days

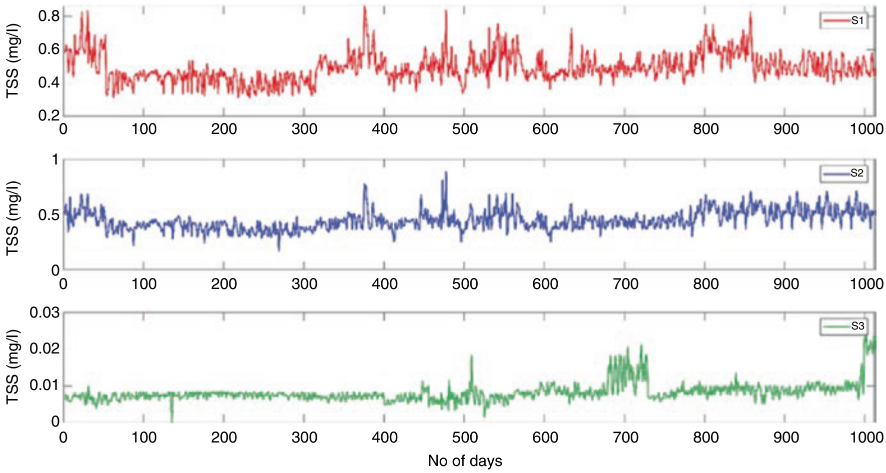

Fig. 61.5 TSS values varies with the no of days

61.5.1 Classification Using Machine Learning Model

The machine learning algorithms have couple of application in sewage treatment plants. The sewage treatment process has different steps in which different stages and their failures are occurring like failures due to leaking pipelines, flow rate, unanticipated variations of organic loadings etc. This thesis work is focus on the classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. Firstly, few standard features or parameters like instant do, pH value, TSS, COD, BOD have been used to as quality indicator of

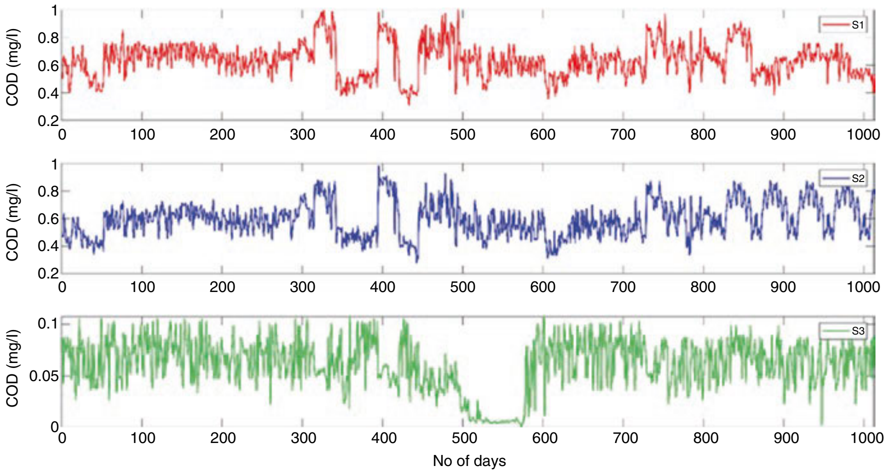

Fig. 61.6 COD values varies with the no of days

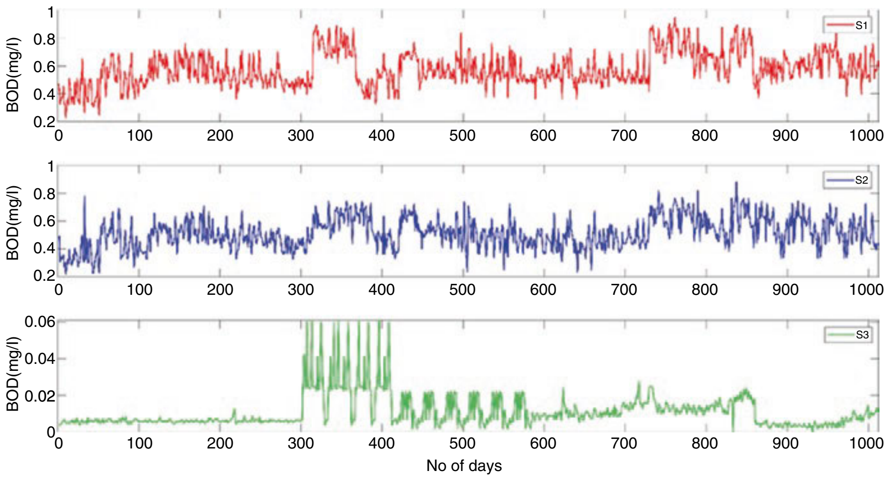

Fig. 61.7 BOD values varies with the no of days

treated and raw sewage water. Finally, this huge data is used to train the machine learning model such as K-NN, ANN, and SVM for father classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. Two different validation method are adopted namely cross fold validation and holdout validation to check the performance of the machine learning model. The proposed machine learning approach is an effective classification of treated water in complex environmental systems.

61.5.2 *Classification Using SVM*

SVM is a supervised classification technique that use categorization to solve problems with two or more classifications. Minor mistakes on restricted training datasets maintain the same small mistakes on independent test datasets, hence a large labelled training dataset is essential to train the SVM to increase the adaptive generation capacity of the learning machine as much as feasible. Through the complete implementation, five standard features or parameters like instant do, pH value, TSS, COD, BOD have been used to as quality indicator of treated and raw sewage water. Finally, this huge data is used to train the SVM model for father classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. The results of classification accuracy in the term of confusion matrix of the SVM classifier of is shown in Table 61.4. Also the true positive rate (TPR) and false negative rate (FNR) are discussed in term of accuracy as followed by (Choudhary et al. 2018). It can be seen that the developed method is able to classify into three mention conditions of treated water accurately. As shown in Table 61.4, the classification of the S3 (outlet treated water) is classify 100% but model has a little bit confused between S2 (raw sewage water) and S2 (primary treated sewage water), which 88.9% and 89.6% respectively. Therefore, it can be stated that the proposed intelligent system based on SVM model for treated water quality inspection has able to classify with good classification accuracy on the collected dataset.

61.5.3 *Classification Using ANN*

An ANN is made up of hundreds or thousands of artificial neurons called processing units that are connected via nodes. Input and output units make up these processing units. Based on an internal weighting mechanism, the input units receive diverse forms and structures of information, and the neural network strives to learn about the information supplied in order to create one output.

Table 61.4 Confusion matrix for three different treated water quality conditions using SVM

True Class \ Predicted Class	S1	S2	S3	TPR	FNR
S1	88.9%	11.1%	0%	88.9%	11.1%
S2	10.4%	89.6%	0%	89.6%	10.4%
S3	0%	0%	100%	100%	0%

Table 61.5 Confusion matrix for three different treated water quality conditions using ANN

True Class \ Predicted Class	S1	S2	S3	TPR	FNR
S1	91.4%	8.6%	0%	91.4%	8.6%
S2	9.9%	90.1%	0%	90.1%	9.9%
S3	0%	0%	100%	100%	0%

Through the complete implementation, five standard features or parameters like instant do, pH value, TSS, COD, BOD have been used to as quality indicator of treated and raw sewage water. Finally, this huge data is used to train the ANN model for father classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. The outcome of classification accuracy in the term of confusion matrix of the ANN classifier of is depicted in Table 61.5. Also the false negative rate (FNR) and true positive rate (TPR) are explained in term of accuracy as followed by (Choudhary et al. 2020). It can be seen that the developed method is able to classify into three mention conditions of treated water accurately. As shown in Table 61.5, the classification of the S3 (outlet treated water) is classify 100% but model has a little bit confused between S2 (raw sewage water) and S2 (primary treated sewage water), which 91.4% and 90.1% respectively. Therefore, it can be stated that the proposed intelligent system based on ANN model for treated water quality inspection has able to classify with good classification accuracy on the collected dataset.

61.5.4 Classification Using KNN

The KNN is a non-parametric classification which is engaged in the regression and categorization of data. The input in both conditions is the k closest training examples in the data set. Whether k-NN is utilized for classification or regression that evaluate the outcome. Through the complete implementation, five standard features or parameters like instant do, pH value, TSS, COD, BOD have been used to as quality indicator of treated and raw sewage water. Finally, this huge data is used to train the KNN model for father classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. The results of classification accuracy in the term of confusion matrix of the KNN classifier of is shown in Table 61.6. Also, the false negative rate (FNR) and true positive rate (TPR) are discussed in term of accuracy as followed by (Choudhary et al. 2021; Mehta et al. 2021). It can be seen that the developed method is able to classify into three mention

Table 61.6 Confusion matrix for three different treated water quality conditions using K-NN

True Class	Predicted Class S1	Predicted Class S2	Predicted Class S3	TPR	FNR
S1	90.8%	9.2%	0%	90.8%	9.2%
S2	9.2%	90.8%	0%	90.8%	9.2%
S3	0%	0%	100%	100%	0%

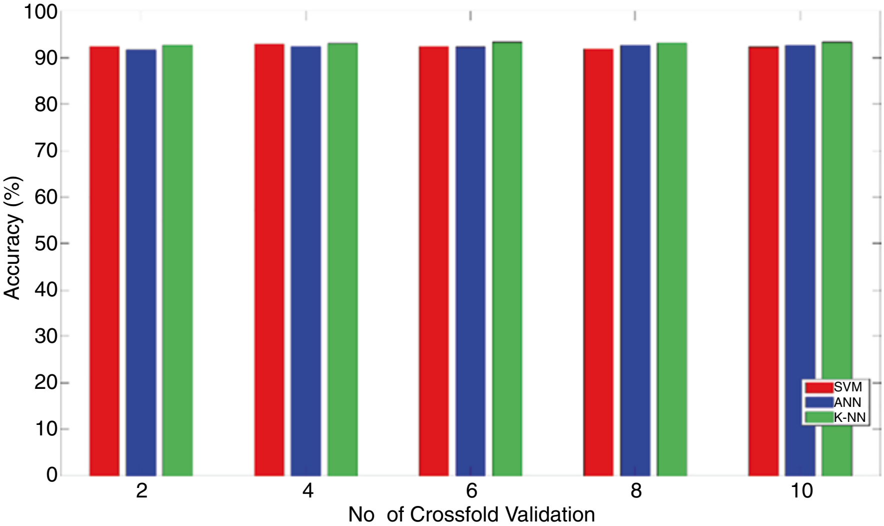

Fig. 61.8 Classification accuracy at different fold cross validation using SVM ANN and K-NN classifiers

conditions of treated water accurately. As shown in Table 61.6, the classification of the S3 (outlet treated water) is classify 100% but model has a little bit confused between S2 (raw sewage water) and S2 (primary treated sewage water), which given 90.8% accuracy in both the conditions. Therefore, it can be stated that the proposed intelligent system based on KNN model is outer perform the SVM and ANN in terms of overall classification accuracy for treated water quality inspection and has able to classify with good classification accuracy on the collected dataset.

The comparative study of the SVM, ANN and KNN classifiers based on classification accuracy of the treated and raw sewage water in sewage treatment plants. The result of the KNN is outer perform SVM and ANN for both cases at fold cross validation have been discussed in Table 61.4 and in therms of bar chats shown in Fig. 61.8. The result of the KNN and ANN are outer perform SVM with highest

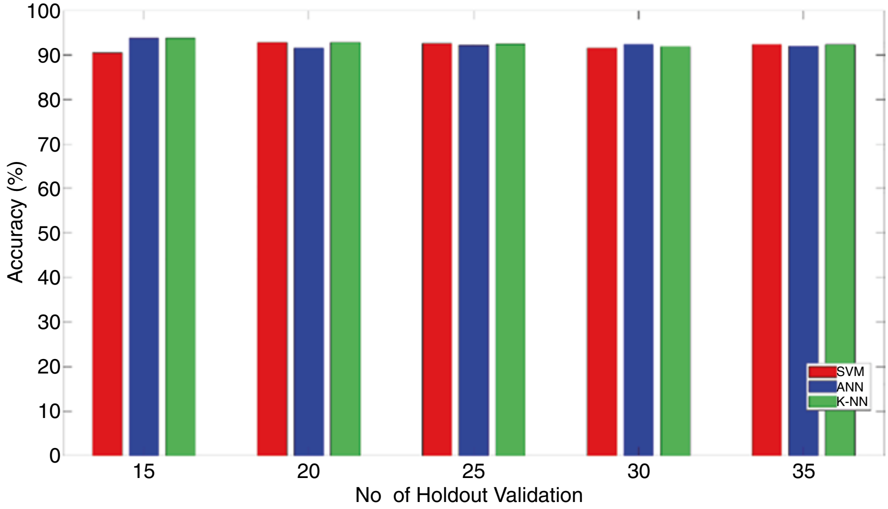

Fig. 61.9 Classification accuracy at different holdout validation using SVM, ANN, and K-NN classifiers

classification accuracy of 93.8% holdout validation as given in Table 61.5 and also with bar charts in Fig. 61.9, but in overall the KNN is outer perform ANN and SVM in at different cross fold and holdout validation. Promoting knowledge development and sharing decision-making experiences will help plant managers to maximize their system performance by using these sophisticated machine learning models for sewage treatment.

61.6 Result and Discussion

This section depicts the validation of the implemented work for the treated water quality classification in sewage treatment plants in which analyse the results of collated data from sewage treatment plants, Chandigarh, India, divide the treated water data into three different conditions (S1-raw sewage water, S2-primary treated water, S3-outlet treated water).The few standard features or parameters like instant do, pH value, TSS, COD, BOD have been used to as quality indicator of treated and raw sewage water. Finally, this huge data is used to train the machine learning model such as K-NN, ANN and SVM for father classification of the treated and raw sewage water in sewage treatment plants with higher classification accuracy. In this research work, a comparative study among three classifiers (ANN, SVM and k-NN) has been done and observed that KNN has the highest classification accuracy.

61.7 Conclusions

In this research work, author developed a useful machine learning model for the classification of the treated water quality from the sewage treatment plants. The proposed technique is based on the machine learning model, allowing to sharing automate decision-making syatem which will help enhance the overall performance of sewage treatment plant. The authors analyzed the three conditions (S1-raw sewage water, S2-primary treated water, S3-outlet treated water) treated water quality from the sewage treatment plants. In furthermore, all six features are provided to three distinct classifiers: ANN, SVM, and K-NN. It was observed that the KNN outperformed the SVM and ANN in terms of classification accuracy for treated water quality classification. All the claasifier are tested at different cross fold validation and holdout validation respectively. It is observed that, the KNN has highest classification accuracy and also compare with other classifiers namely SVM and k-NN in both cases at fold cross validation and holdout validation. The machine learning techniques are very useful for for the classification of the quality and also other harmful component present in the treated water from the sewage treatment plants.

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Chapter 62
"Prediction, Impact and Mitigation of Ambient Air Quality Pollutant Concentrations in Chandigarh" A Review

Debendra Dalai, Sanjay Sharma, Varinder Kanwar, and Jyotsna Kaushal

Abstract The air-quality forecasting is important tool for planning and decide on mitigation strategies. The predictive model will provide a effective warning system. There is a need to develop a city-scale goal for each air pollution source sector, which is currently missing from many of the urban areas. Each region and city has different characteristics in terms of air pollution sources, local administrative, social, and political conditions. Most of the studies conducted are based on identification of sources of air pollution; Specific research studies have not been conducted to work out long term & short-term mitigation strategy for control of air pollution by application of latest technological interventions. In view of limited research work/emissions inventory data available, there is a need to determine trends and status of ambient air quality and prediction through modeling, contribution of various emission sectors to pollutant concentrations in targeted locations, establish their correlation with meteorological parameters and accordingly formulate a long-term strategy for mitigation.

Keywords Air pollution · Mitigation strategy · Ambient air quality · Modeling · Parameters

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62.1 Introduction

To control air pollution, it is imperative to provide recommendations based on evidence. Air pollution has recently become environmental concern throughout the world. Emissions from industry and vehicles are major sources of poor air quality in urban areas. Increasing urbanisation, industrialisation, and other anthropogenic activities contribute to increasing air pollutant emissions and poor quality of air. By 2050, around 50% of the world population will be urban population (Gurjar et al. 2008). Air pollution is among the top risk factors causing mortality as per Health Equality Index (HEI 2019). CPCB is running a national mission of air monitoring. There are 804 monitoring stations covering about 350 cities/towns in all states and Union Territories. Pollutants such as SO_2, NO_2, PM_{10}, and $PM_{2.5}$ are being monitored regularly at all the locations. There are about 300 Continuous Air Quality Monitoring stations (CAAQMS) in various cities, to monitor PM_{10}, $PM_{2.5}$, NO_x, SO_2, NH_3, CO, O_3, and benzene. The purpose of NAMP is to assess the tends to air pollution and then find correlation with meteorological parameters. The monitoring is done for 24 h with 4 h for gaseous and 8 h for suspended matter, two times in a week.

Many researchers have studied for sources of emissions in India. There are some variations in procedure and time estimation, but there is general convergence of the results. As per TERI (Sharma et al. 2016), the $PM_{2.5}$ concentration are due to industrial (36%) and residential (39%) locations. Transport contributes 4% of $PM_{2.5}$ emissions at the country level. Burning agricultural residue in rural areas causes 7% of $PM_{2.5}$ concentration. Other sources contribute about 11% of air pollution. Thermal sector causes 4% of $PM_{2.5}$ concentration. “Air quality monitoring, emission inventory and source apportionment study for Indian cities” carried out during 2007–2010, in metro cities, show that dust from construction activities, and soil contributes most (6–58%) to PM_{10} concentrations. The contribution of the transport sector is small (PM_{10}) but increases in $PM_{2.5}$ (finer fractions) Sharma, S. Secondary particulates such as SO_2 and NO_x also contribute significantly to $PM_{2.5}$ concentrations. Government of India launched National Air Quality Index (AQI) in April, 2015 in 14 cities initially. It has been extended to 71 cities in 17 states (moef.gov.in/2019/05/NCAP report). The AQI is an effective tool to convey the status of air quality to people. It transforms the data of pollutants into a number i.e., index value. Six categories of AQI, which indicate, severe, very poor, poor, moderately polluted, satisfactory and good. These categories are based on health effects of these air pollutants. Lot of work has been carried out for air quality forecasting worldwide by application of various air quality prediction models. Artificial Neural Network has been used in many research studies to predict long term and short-term concentration levels for some of the key air pollutants. Comparison of regression analysis and Artificial Neural Network had been done taking the case study of Delhi. A multiple comparison strategy in constructing models to estimate future concentrations of CO, SPM and SO_2 have also been reported. The study proved that Neural Network outperformed over statistical technique (multiple linear regression). In one of the study, weather forecasting data was used to predict pollutant concentrations and to activate the alarming system. A special Multilayer Perception model for the forecasting of diurnal mean air quality index (AQI)was also reported using ANN as a forecasting method for higher levels of ambient CO. A novel hybrid ARIMA-ANN model was also suggested to get best forecasting results which proved that hybrid approaches are preferred for accurate results and for better ability to generalization. In one of the research studies, pollutant mass concentrations were converted into a single index number by a variety of methods worldwide. This single number is known as air quality index which is used to convey the air quality status to public of a particular region. Regression analysis to correlate concentration of air pollutants in ambient air with the meteorological parameters have also been reported and found significant results of the influence of temperature and relative humidity on the concentrations of Nitrogen Dioxide, Sulphur dioxide, and suspended particulate matter.

62.2 Review of Research Work

There is an urgent need to have comprehensive environment management plans in place for sustainable economic development of any urban area. The air-quality forecasting is an important tool for planning and decide on mitigation strategies. The modeling of an atmospheric pollutant for a specific site involves the development of functional relationships among input data and target data of prime pollutants that are needed to be modeled. As these parameters are site-dependent and vary from site to site, a site-specific model needs to be developed. Lot of work has been carried out for air quality forecasting worldwide by application of various air quality prediction models. The air-quality forecasting is an important tool for planning and decide on mitigation strategies. The modeling of an atmospheric pollutant for a specific site involves the development of functional relationships among input data and target data of prime pollutants that are needed to be modeled. As these parameters are site-dependent and vary from site to site, a site-specific model needs to be developed. Ansari TU, et al. proposed an online territorial science transportation model (WRF/Chem) to mimic the appropriation of gases in the Indian district. The spatial conveyance of these gases shows huge spatial decent variety in Indian district having expanded contamination level in thickly populated Gangetic Plains (IGP). The anthropogenic discharges and meteorology assume a critical job in choosing the follow as level and appropriation over the Indian district.

Amrita Thakur studied the Air quality trends and causes of trends for Bengaluru City of Karnataka. Data for analysis was collected from Karnataka State Pollution Control Board (KSPCB). Level of pollution was determined with the help of Exceedance factor developed by CPCB. Trends of parameters, SO_2, NO_2 and PM_{10} were analyzed by author. It was found that air quality of the city is within permissible limits as per CPCB standards. However, an increase in NO_2 and RSPM was observed. Transportation sector was the main cause for the increase in air pollution. As apart from PM_{10}, SO_2 and NO_2, vehicle also emit HC and CO which further increase level of pollution in air. Adoption of BS VI may help in decrease of air pollution due to vehicles. Brunelli et al. examined that counterfeit neural systems are useful elective procedures in displaying the many-sided vehicular fumes outflow scattering wonder. In this study, a repetitive neural system based on Elman model was used to forecast the expectation of every day most extreme convergences of air pollutants in the city of Palermo. Barman analyzed the air quality and category of Exceedance factor for different locations of the Assam. Total 5 places (These places were Golaghat, Tezpur Guwahati, Dibrugarh, and Bongaigaon) were selected for analysis in which instruments were set up at eight predefined locations. SPM, RSPM, NO_2 and SO_2 were selected for analysis of air quality. Data was selected from Assam Pollution Control Board for analysis for years 2007–2009. Exceedance factor is an important tool to categorise the air pollution of place in Critical, High Pollution, Moderate Pollution, and Low Pollution. The Exceedance factors show that NO_2 and SO_2 falls in category of low pollution. Author found that RSPM & SPM on all locations were in High or Critical category. Growing of Industries, increase traffic and dryness during winter were the major contributing factors of increase in particulate matter. Author also observed that in traffic, three wheels tempos were the major reason of air pollution. Chaudhary et al. carried out Ambient air quality assessment of Lucknow in North India using AQI. Measuring stations included Aliganj, Indira Nagar, IITR Campus and Aminabad. Out of the four stations first three stations were residential and remaining is Urban area. Four pollutants namely SPM, RSP, Oxides of nitrogen and Sulfur were analyzed for AQI along with concentration of metal in the air. Author found that major reason for higher level of the pollutant is vehicular emission. Total Four NAMP station was installed in the entire city for the measurement of the pollutants. RDS was used for monitoring of SPM and RSPM with gravity settling method for measurement of these pollutants. Similarly, the estimation of NOx and SOx was also carried out according to Jacob-Hochheiser method (1958) and West and Geake method (1956) respectively. Metals measured on filter paper were measured with the help of Atomic Absorption Spectrophotometer (AAS) (Model- GBC Avanta Sigma). Out of all residential area under consideration SPM was highest for Aligand which was due to high traffic, generators etc. While RSPM was maximum for Aminbad due to heavy traffic load and being commercial area. All values observed for the four locations exceeded the NAAQS permissible value which is 100 $\mu g/m^3$. Author concluded that high number of privately owned vehicles and obsolete two stroke engine vehicles are majorly responsible for air pollution in the urban cities of Lucknow. As they also result in increase of heavy and toxic metals in the atmosphere.

Cassano F et al. developed two recurrent neural network to forecast the level of pollutant in specific site by using the data received from the monitoring stations and conclude that prediction of data can be done for many days ahead. Population can be warned beforehand of air pollution level for the coming weeks. According to him only weather forecasting can be done in advance but alert for air pollution can also be done at early stage. Dayalet al. carried out survey of total 10 location in Bangalore city to study contribution of vehicular emission. Survey was carried out for 14 days by measuring pollutants namely SPM, NO_x & SO_2. It was found that out of 10 locations 6 locations were found to have SPM exceeding the standard limit while other pollutants were found close to standard limit. Overall, it was found that 1 place was clean, 4 lightly polluted and 5 were moderately polluted. Eotovos et al. analyzed the air pollutants considered in the determination of AQI. Air pollutants are classified as chemical and biological pollutants. Chemical pollutants included CO, O_3, SO_2, NO_x, dust (PM_{10}, soot, ash). Pollen is considered as biological pollutant. Author found that existing AQI only contain chemical pollutants, on the basis of these pollutants air quality is categorized as good, satisfactory, moderate, unhealthy and hazardous. Author suggested including biological pollutants in AQI. Goyal P. et al. monitored pollutant mass concentrations converted into a single index number by a variety of methods worldwide. This single number is known as air quality index which is used to convey air quality of a particular region to the public. Liu Y et al. Presented three efficient models for forecasting the concentration of air pollutants based on the related environmental factors. The models for forecasting are mainly based on two aspects. One is to predict air pollution emission; the other is to analyze the related environmental factors. In the BP model input where factors are coal consumption in industries, population density and traffic volume with the concentrations of SO_2 taken as output. The differences between the various models are also compared in this paper. BP model was easy to use with the development of computer technology. But the common problems of the models mentioned are that their late errors were not up to the mark. Nevertheless, urgent need to set up a continuous and long-term monitoring system required to predict the concentration of air pollutants in urban areas. Melas D, et al. attempted to model photochemical pollutant levels using a neural network. A model was developed that correlates maxima of pollutant concentrations to weather parameters, emission parameter sand indexes. The analysis is based on measurements of O_3 and NO_2 in Athens. Mittal N, et al. proposed a Layer recurrent neural network-based power system to forecasting load. The performance of various topologies is compared based on performance indices i.e., RMSE, MAPE and MAE and explored Layer recurrent neural network topology as the best topology for prediction. Ma J et al. explored the country wide selection of influential factors by using multivariate analysis. This fill the gap of studies in which the model was earlier site or state specific. In this, 171 influential factors are employed for the analysis. The machine learning algorithm called X-G-Boost was employed to filter the most significant influential factors. GIS was used to visualize the results. Tuning of parameters have been done by the Bayesian optimization. The most significant six parameters found helpful in solving practical solutions to reduce air pollution. Nigam et al. carried out comparative study of the six methods to analyze air quality. The AQI thus obtained is then compared with the standard scale to know the level of pollution. Second method is also similar except in this method geometric mean is taken. Third method known as Oak Ridge National Air Quality Index developed in USA. In another method, AQI is calculated by using dose response relationship of each pollutant to find break point concentration. Individual AQI is calculated by using linear segment principle. Author observed varying results for same location based on different methods. However overall AQI of the area was found to fall in satisfactory to moderate category of pollution level. PM_{10} which normally generated from thermal power plants and vehicles is major pollutant affecting air quality index.

Perez, P., et al. estimated NO and NO_2 values at noon on adjacent street with dense traffic scene in Santiago, Chile. The values were also found with linear regression and using multi and compared with approaches such as linear regression and neural network with multiple hidden layers and then finally prediction values were compared. Sarella et al. analyzed the ambient air quality by using AQI of Vapi city. AQI was measured at four locations in which two were industrial locations, one was commercial and one was residential location. Continuous 24 h sampling of 2 days in a week was done for four pollutants i.e RSPM, SPM, NOX and SOX. Particulate matters were collected on 8 hourly basis and gases were collected on 4 hourly bases by using gravimetric method and absorbing solution respectively. Author found that average overall values of AQI of the city fall under the category of moderate pollution i.e., 101–200. Saxena A, et al. proposed an algorithm-based classifier to classify air quality either good or harmful in which he used mathematical tools to formulate a cumulative index (CI) to evaluate the potential input based on the concentrations of individual pollutants. Slini T, et al. Proposed a factual examination strategy for the advancement of a natural determining device. An auto regressive coordinated moving normal (ARIMA) model is created foremost extreme ozone focus estimates in Athens, Greece. The model creates disapproved utilizing genuine information for 1 year. An assessment was done dependent on the list of understanding, it shows a decent file of an understanding yet powerless determining cautions joined by proposals made to improve the gauging execution. Spellman G. also employed an artificial neural network to determine correlation in complex datasets in the same way as conventional statistical methods and also used it in forecasting. The multi-layer perceptron neural network is proposed to estimate surface O_3 concentrations in summer using a surface meteorological parameter for five locations in the UK.

Sanderson HP et al. assorted the air pollution parameters that could be inculcated in the prediction of air quality parameter scenario. He introduced parameters which nullify the proposal of nationwide air quality index, according to which due to variation in geographical meteorological and topography played an important role in monitoring of pollutant level so nationwide air quality index is not valid. Song Z, et al. study was based on understanding the impact of steps taken in the direction of air quality improvement over the health of civilians and mortality rate. An industrial area of Pasir Gudang, Johor had been chosen to study the correlation of air quality parameter and influential factors 2 years data had been taken under consideration for the study artificial neural network found to be quite competitive for the prediction of pollutant concentrations and to study the complex relationship between the variables. PM_{10} concentrations was quite high and area came into non-attainment region in terms of PM_{10}. Tobias et al. studied the effect of lockdown on the quality of air in Barcelona (Spain). Study was carried out for the air quality of two station in which one station (TR- Traffic Station) was at the center of Urban area affected directly by the traffic emission and second station (UB-Urban Background) was away from the source of pollution represents contamination of the urban background. Author found significant decrease after two weeks of lockdown. A reduction of 28% and 31% was observed in PM_{10} for TR and UB stations respectively.

Similarly, reduction of 47% and 51% was observed for UB and TR station respectively. Author further found that during lockdown period there was slight reduction in SO_2 concentration for both stations while O_3 concentration increases. NO_2 in urban area which is generated from combustion especially from traffic using diesel to large extent, reduction in traffic resulted in the increase reduction of NO_2, this has also result in increase of ozone content in the atmosphere. Turias, I.J, et al. presented a multiple comparison strategy in constructing models to estimate pollutant concentrations in the industrial area of Campo de Gibraltar region, Spain. Two years data from 1999 to 2001 has been collected for this study. Very few studies have been done in this area. The study proved that neural network outperformed over statistical technique (multiple linear regression). Wu, H.M., et al. also discuss temporal and spatial distribution of air pollution and according to them, the turbulence strengthens in lower atmosphere which is beneficial for the pollutant's dispersion and diffusion. Hence possibility of accumulation of atmospheric pollutants decreased with the rise in air temperature during summer. On the contrary situation is different while the surface temperature is low.

62.3 Results & Discussion

It has been observed from literature review that sufficient work has been carried out to asses air quality of major urban cities all over the World by using different air quality forecasting models. The research related to air pollution in Chandigarh has also been reviewed and the same can briefly be discussed as below:

- **Evaluation of the sources of air pollution:** The research study is although a long-term study conducted during 1994–1996, It is limited to the quantification of elemental composition levels in ambient air and identification of sources of air pollution.
- **CO Pollution from traffic and occupational exposure:** It is a short-term study for the estimation of traffic related CO emissions in Chandigarh City.
- **Similar assessment has been made in respect of c**ontribution of 2 & 3- wheelers, cars, and commercial vehicles to pollutants. The research study is basically a survey report on transport sector in Chandigarh and limited to calculation of GHG emissions and mitigation using CDM.
- **Air quality assessment of Chandigarh City:** The research work is limited to compilation of grid-based emissions inventory for parameters $PM_{2.5,}$ PM_{10}, SO_2, NO_x, CO and VOCs on regional scale including area of 60 × 60 km. domain including Patiala and Ambala.
- COVID-19 pandemic: An outlook on its impact on air quality in major cities of Punjab and Chandigarh, India: This research was conducted to evaluate the impact of lockdown on air quality during the different phase of lockdown in the year 2020. The study is although a short-term study but provides an opportunity to identify air pollution sources and plan strategies to combat air pollution.

62.4 Conclusion

Most of the studies conducted are based on identification of sources of air pollution in the city; Trend Analysis of limited number of air pollutants; elemental analysis and some short-term research work conducted on impact of COVID-19 lock down in Chandigarh. Further research work needed on weather forecasting data used to predict pollutant concentrations and to activate the alarming system. There is no long-term study to evaluate air quality data of critically air pollutants covering all three seasons to correlate concentration of air pollutants in ambient air with the meteorological parameters and to assess the impact of influence of temperature and relative humidity on critical air pollutants. Specific research studies have not been conducted to work out long term &short-term mitigation strategy for control of air pollution in north region. It is concluded that in order to mitigate the impact of air pollution on health, there is a need to predict the trends of air pollution based on atmospheric factors such as humidity, wind speed, temperature etc. The development of prediction model for air quality trends based on atmospheric parameters will greatly help in formulating a policy to control air pollution and also plan recommended measures well in advance.

Hence, there is a need for a long-term study on the problem identification in terms of emission inventories, status, trends and impact of various atmospheric factors on air quality in Chandigarh; development of management tools like building statistical models for establishing correlation results among pollutants concentration and meteorological variables; technological interventions, identification & prioritization of control points. The combination of all these management tools will help in developing a control strategy on long term basis for mitigation of air pollution in Chandigarh

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Chapter 63
A Review of Environmental Flow Evaluation Methodologies – Limitations and Validations

Monika Sharma, C. Prakasam, R. Saravanan, Suresh C. Attri, Varinder S. Kanwar, and M. K. Sharma

Abstract The term "hydropower" clearly states that the main source for generating electricity would be "water" and this is done by tapping the flow of water from rivers and dams. The hydropower project in Himachal Pradesh are mostly run-of river projects. The conveyance process happens by channelizing a route passage in the underground for the generation of the Hydropower. Sources are generally considered to be very valuable in nature. Developments in the civilization have resulted in ecological changes which in turn has resulted in a situation wherein resources also have become an important criterion for the human survival and thus, we ought to use them cautiously and not generously. This applies to hydropower projects as well. So, a minimal flow of water is recommended to have a sustainable water management and ecosystem. To explain the term "Minimal flow", it is the minimal water present in the river after the exploitation for hydropower generation, to maintain the water subordinate condition or water dependent ecosystem. Minimal flow value changes with respect to certain factors like: topography, water resources, climatic and farming factors etc., Each nation would require distinctive minimal flow value corresponding to the above said factors. This research paper shall focus on the study of all the environmental flow methodologies including, Indian and International statuses and shall also include comprehensively various other methodologies associated with the environmental flow such as modelling, GIS applications etc.,

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The concluding part shall encompass various limitations, critical analysis of each methodology and overall review of the environmental flow methodologies. The critical review of all the methodologies of international and Indian status facilitated in preparing a methodology for evaluating and validating the environmental flow requirements.

Keywords Ecological flow methods · Hydrology · Hydraulic · Hydropower dam · Literature review

63.1 Introduction

Standards in respect to the products of all the industries are generally set and established by the concerned Government for the industry of each field to maintain and retain its quality. In doing this, the Government doesn't alone turn to one's advantage but also builds up goodwill to the industry. One such service of the Government is the conveyance of electricity by the Hydropower method and it is a known fact that Himachal Pradesh is famous for its Hydropower generation. River degradation is one of the major concerns which took the attention of the numerous researchers, lobbyist groups and the concerned individuals.

The attention had to be given as the water system became enfeeble due to the inability to maintain minimal flows. This inability may prompt weakening of the subordinate ecosystem's water condition. The general term used to depict the flow that is necessary to maintain river ecosystem's feature is minimum flow. Hydro power is a standout amongst the most economic and non-polluting wellsprings of energy. India ranks eighth in overall energy generation of hydroelectric power. Environmental flow goes about as a principal factor to anchor river ecological framework. Scarcely any nations have come to understand their regard as it helps in understanding and maintaining the health of the water subordinate ecosystem. Environmental flow evaluation changes with respect to some factors, namely, topography, water resources, climatic and farming factors. Every nation prescribes distinctive environmental flow methodologies corresponding to the aforementioned factors. A research work shows that there are up to 200 methodologies to regulate the presently existing e-flows and various mechanisms and the methods have also been suggested by the same. This review paper shall subsume the following:

Various aspects of environmental flow such as: Environmental flow assessment methodologies; Application of GIS; Environmental flow modeling; and Limitations in environmental flow assessment; Review analyzed from the period from 1970 to 2019 including both the Indian and International standards. Review papers on Decadal order; and Critical Review

63.2 Literature Review – Environmental Flow

There isn't a proper definition for the term "environmental flow" yet. The term "Environmental flow" at times is called as "Ecological flow"., both the terms demonstrate a closely comparable meaning as they are equally utilized by us Arthington et al. (1998). The generation of hydropower is done by tapping the water flow in the dam. But this causes an adverse impact on the environment as there is an optimum level of risk involved where river beds might dry up during the lean season due to exorbitant usage. Therefore, there is a greater need to evaluate the prerequisites of Environmental (Protection) Act, 1986 which states that 15% of the minimum flow of the stream must be discharged to the downstream of preoccupation structure for the assurance of greenery, fauna and aquatic life among intake and conversion point of tailrace and the stream Bhattacharjee et al. (2019).

According to Dyson et al. (2003): "An ecological balance is considered to be the necessary water management supplied inside a river, ocean or wetland to put up with the environment and the dependent points where flows are controlled and challenging water usages are present." Tharme (2003) stated that "the proportion of water that was left in the stream/river/dam to the water important for the water's biological system/ecosystem and to keep up the stream's health is called environmental flow." The term "Environmental flow" has various other definitions coined in different nations, for instance, instream flow, minimal flow etc., The present legal system has not yet provided a sensible, practical and legitimate course of water's action for the environmental flow in uniform regulations. A few nations have only understood the criticality of inefficient vocations of water and have created specific regulation to accommodate it. At present, there is no international understanding on the subject of environmental flow.

63.2.1 International Status

Bovee (1986) established the Instream Flow Incremental Methodology (IFIM) method referred to as the next level of EF assessment model depending on the physical as well as habitat parameters. It is based on the simulating the species' response using the response to the biological and hydraulic data is known as (HSM) Habitat Simulation Methods. Cavendish and Duncan (1986) used the IFIM by taking the fish as the indicator species of river habitat. Tharme (1996) surveyed various hydraulic simulation models and prominently used hydraulic rating methodologies to determine Environmental flow recommendations. Arthington et al. (2004a) reviewed the papers which are already researched and those which are under research now in environmental flow and discovered that over 200 methods for finding the ecological flows exists. These are used over 50 nations. Arthington et al. (2004b) also gave a short account of the progression of environmental flow methods and characteristics of the individual methodologies. The result shows holistic method as the prominent methodology. O'Keeffe and Quesne (2009) provided the need for river and environmental supplies. The foundation of environmental flow was complete with the hypothesis associated with it and its restrictions. The main issues such as selecting a methodology, setting aims were deliberated. Finally, the valuation methods were deliberated with the application of the indicators. This book gives a complete understanding of Environmental flow and its significance for the river.

Abbasov (2010), proposed a new methodology CREF (Co-efficient of Relative Ecological Factor of the water) by finding the ratio between the quantity of ecological flow to the observed flow in the river for the Kura basin river of Azerbaijan. This is conceivable to assess the Environmental flow for the entire time frame and also it is not assessed only for analyzing the water measure stations but also for analyzing the mouths of smaller water channels. Poff and Zimmerman (2010) studied 165 papers which were published over the last forty years, with an emphasis on latest papers targeting at determining if the common associations can be drawn from the dissimilar research present in the review of literature that might update on the administration of environmental flows. Of all the papers reviewed, about 92% detailed the qualities that were diminished for environmental measurements that were recorded in answer to a different sort of stream modification, while 13% announced the expanded qualities. Fifty-five of the research works had information reasonable for quantifiable investigation of the stream modification's ecological response. Dunbar et al. (2012) clubbed the two extensive methodologies of hydraulic approach and habitat modeling to estimate the needs of the Environmental flow for the Salmonids. The research work mentions that this modeling approach is trustable, on the progression of habitat suitability approach, which has chances of transferability, doubts, and relation to appliances at the population level.

Karakaya and Evrendilek (2013) measured the idea of Environmental flow for Big Melen project of water transfer project as a case study. Generally, environmental flow requirement method was applied to economically significant rivers where intensive fisheries take place and was defined as the sum of flow requirements that fish stocks demand. Of late, more solid techniques for the necessities of ecological stream have been built up that includes different natural components like other life forms' requests, the structure of the environment and its capacity. Poff and Matthews (2013) highlighted the evolving challenges that e-flows involves its difficulties. For a powerful commitment of the e-flows to a viable freshwater on a worldwide scale, it must, fundamentally, move from a rebuilding center to one of the climatic adjustments, other natural variety stressors, increment in its scale from single destinations to entire waterway bowls, and expand its gathering of people to hold the social-biological manageability that balances out the requirement for freshwater protection. This also aids in prosperity of people in creating a better condition in economy. Pastor et al. (2014) tried and applied Tessmann, Tennant, Smakthin, Q90, the Variable Monthly Flow method (VMF) in several places around the world. The outcome demonstrates that the Environmental flow 37% of yearly discharge on average is essential and around 46% for short flow periods and 17% for the large flow periods are assessed as the mandatory Environmental Flows.

Acreman et al. (2014) specified that the environmental flow can be attained in numerous ways, maximum of which are grounded by either restricting the alteration from the baseline of natural flow to uphold the biodiversity and the integrity of the ecology or designing the flow regimes to attain definite service results which serve beneficial to the ecosystem. Botelho et al. (2017) critically examined the impacts on the environment due to the advancement of the technology and also co-related its effects to the hydropower generation. He further examined the ratio of hydropower usage for a specific hydropower plant by the Contextual Analysis Method and established that excess utilization of resource had as adverse impact on the environment. The paper determines the noteworthiness of the Contextual Analysis Method, by defining significances concerning the alternate hydropower manufacturing offices. Ultimately, the paper determines that decision tests are mainly appropriate for estimating the perceived environmental impacts, related to planning the arrangements. Yasi and Ashori (2017). Increased the environmental flow range from 9% to 35% of the Mean Annual Flow after assessing the Environmental flow requirements for the Bukan Dam using nine eco-hydro methodologies for Urmia Lake from the Bukan Dam.

Ceola et al. (2018) claimed that these E-flows must be identified on the basis of the regional and quantitative valuation of Central Italy; and Valuation of the two threatened fish species namely Barbel and Chub due to the suitability hitch. The result evidently displays that the regional scale calculations which were done quantitatively were feasible even when the observations of streamflow were completely missing at the study sites. It also reveals that the flow policies which are aprioristic may enforce releases that surpass the natural stream flow for long time intervals significantly (weeks or months). This unduly tightens the flow policies which might in turn create a huge impact on the productivity of hydro-power which is regional (15% and 42% losses on annual and seasonal basis, individually), yet resulting in marginal or avoidable enhancements of fluvial ecosystem. Operacz et al. (2018) exhibited the method of environmental flow estimations which is separated as water areas. The calculation path was additionally exhibited along with the plausible inconveniences that resulted from the operative legal guidelines from Poland. It was regarding the chances of carrying out the undertakings that exploit the surface waters that are flowing. Volchek et al. (2018a, b) did a relative analysis on the rate of the environmental flow by the instance of the Yaselda River in its Bereza section with the usage of diverse methods of environmental flow valuation. The exceedance probability transfer technique seems to be the most capable one. It was concluded by the authors that to make it most effective, it is essential to do the zone checks of the areas by taking the parameters of exceedance possibility. Volchek et al. (2018a, b) finished a five diversified Environmental flow rate analysis for the Yaselda River. The even Environmental flow esteems are given by the edge methods across the year. The features of the approaches change consequently as these were formed in diverse economic and social circumstances. Książek et al. (2019) analyzed the hydraulic and hydrological methods and determined the logically adequate and financially savvy approach to Environmental flow of a mountain river with the high lack of pretension, on the case of the Wisłoka. The results show that the hydraulic methods gave a lower environmental flow value than the hydrological method. Praskievicz and Luo (2020). Albeit EFR can be evaluated by utilizing an assortment of strategies. Majority of these techniques require setting up connections among the stream and living space of types of concern. Owusu et al. (2021). Reviewed sixty-nine case studies on implementation of the environmental flow into practice via dam operations and legislations. Changing the dam operations can be tedious in restoring the ecosystem, hence integrating the environmental flow maintenance while designing the dam is suggested. The results suggest that environmental flow legislations are more successful than working on the dam operations to release the environmental flow. Belmar et al. (2019). Presented the relationship between the average flows at different temporal extent and the habitant population of the birds, shelly fish in the lower Ebro River. The healthy ecosystem can be attained by taking the habitat characteristics into consideration for modelling the environmental flow in addition to altering the discharge in the river. The discharge and the habitant have direct relationship. Virkki et al. (2021). Environmental Flow Envelopes (EFE), a novel method to evaluate the environmental flow was introduced for 4400 sub basins globally. The method is an envelope of variability bounded by discharge limits within which riverine ecosystems are not seriously compromised. The method typically identifies the values such as higher flow, quantification of the environmental flow violations etc., which the traditional methods fail to do. It requires more fine tuning towards the practicability and implementation. Yue et al. (2021). Inherent uncertainties in water resources management and potential variations in environment water requirements should both be considered to obtain desired water allocation strategies under changing climatic conditions.

63.2.2 Indian Status

In India, the Environmental flow assessment showed up in the late 1980s. The term "Minimum Flow" in the Indian strata was first coined in 1992 by the Center Water Commission. Smakhtin et al. (2004) first made an attempt to assess the amount of water which was vital for the good health of freshwater ecosystems. It contains environmentally applicable high and low-flow components for 128 river basins. It suggests that the Environmental flow should be a part of global water evaluation. Kumara et al. (2010) attempted to evaluate the present health status of the water flow in the Bhadra River at Lakkavalli, Karnataka and scrutinized the depth of the ecosystem services through E-flows. Over 60% of the downstream occupants have changed their vocation occupations and additionally migration level has increased in the fishermen networks. Rai et al. (2011) represented the various Environmental flow estimation techniques for a river along with the pros and cons of their methodologies. In addition, a comparison was made between several hydrology approach techniques along with their habitat and water requirements for various contributing factors. Dubey et al. (2013) calculated the Environmental flow using Tennant and Lookup Tables at 4 gauging sites in the upper part of Narmada River. Modified

Tennant method is used to estimate on a monthly basis resulting in a variation from 50.6 to 73.5 cumec for Sandia etc. Sundaray (2013) environmental Flow (Doctoral dissertation) assessed the Environmental flow for the downstream side of the Mahanadi River by analyzing the daily discharge (24 years) using the FDC and RVA methods. FDC method includes 1-d, 3-d, and 7-d flow. The RVA is analyzed by IHA and calculates 33 IHA, 34 EFC (Environmental Flows Component), i.e., 67 statistical parameters. Bhattacharjee (2014) assessed the Environmental flow using the RVA, FDC, and Tennant method, etc., for the Mahanadi River Basin. The low flow values were calculated using the Q95, 7Q10, Q90, etc. methods for 8 stations covering the Mahanadi River basin. Verma et al. (2015) used three hydrological methods FDC, Tessman, Tennant for Damodar river basin and sub-watersheds in West Bengal and Jharkhand resulting in the minimum flow varying from 1.04 to 16.08 m^3/s as required to maintain the health of various watersheds in that river ecosystem. Kawde et al. (2016) did a literature paper and elaborated about the environments that prompt the phenomena of ecological flow to be developed and then particularizes on developing ideas, and defining the concept. Johnson et al. (2017). Recommended a 26% of Environmental flow as a requirement across the Godavari River below the Polavaram dam. The Physical Habitat Simulation Model (PHABSIM) was utilized to understand the impact of the low flow upon the fishes and for this purpose, five fish species were chosen. The Environmental flow estimation was done for these species by deriving a habitat suitability curves (HSCs). Dutta et al. (2017) combined the Environmental flow theories and designed a new framework for the Environmental flow assessment. This research was in a way connected to the Ganga River. The outcomes demonstrate a relationship between the flow profiles, ecological impacts & physical habitat. Bhattacharjee et al. (2018) did an analysis for the Middle Oconee River on how various model of habitat models like instream flow and various scenarios of water drawing influences habitat in the Athens, Georgia. Historical release data are coupled with water drawing simulations for every withdrawal plan to examine exchange offs among ecological and social results. Hydraulic models are connected to translate hydrologic simulations into habitat appropriateness for the following three conventional habitat types: shallow-quick, profound quick, and shallow-moderate. Dubey et al. (2019a). – Calculated the required Environmental flow as 46%, 45.1% and 36.1% of the percentage of Mean Annual Runoff at the Barman, Sandia and Dindori stations respectively of the Narmada Basin using (GEFC) Global Environmental Flow Calculator developed by (IWMI) International Water Management Institute, Sri Lanka. Sharma and Dutta (2020). Stated that for a vigorous and all-encompassing appraisal of environmental flow, there is a requirement for refinement of existing strategies. The future investigations on environmental flow assessment should involve different requirements of aquatic ecosystem during extreme events. Surface–groundwater communications to represent base flows in keeping up lean streams, and river water quality to check the impact of contamination stacking and water reflection on the aquatic system. Hairan et al. (2021). reviewed the environmental flow conditions for the rivers flowing through the South East Asian countries such as India, China, Indonesia etc., The construction of hydropower projects in these rivers has increased. The results show that the environmental flow is unsatisfactory in most of the rivers.

Basin (2019). the concept of environmental flows has mainly remained on paper with limited implementation in practice. Dash et al. (2021). Evaluated the hydraulic regime of the Brahmani river basin for the base period and future scenario using the SWAT model. The increase in the environmental flow about ten times is expected in the future scenario. A little changeability in the precipitation pattern may cause a significant effect on agribusiness and associated areas by modification of the inventory request situation in horticulture with changes in streamflow and dregs yield. Prakasam and Saravanan (2021). Evaluated the environmental flow requirement using the wetted perimeter method and validated through GIS applications for the Binwa Basin, Himachal Pradesh. The resultant environmental flow is 0.7724 m^3/s which is less than the maintained environmental flow in the basin 0.9 m^3/s.

The National Green Tribunal (NGT arrange) passed a law that 15% of the Environmental flow needs to be sustained in the stream/dam/water resources during the lean period for preserving the health of the ecology after the “Ministry of Environment, Forest and Climate Change” with the reference to the present order passed River Ganga had guided 20% minimum condition flow to be maintained from Haridwar onwards in perspective of the ordinary lean season flow adjacent to the nation shall maintain minimum 15–20% of water flow of that river during the ordinary lean season State of India’s Rivers for India (2016).

63.3 Environmental Flow Methodologies

The Environmental flow assessment method can be categorized into four based on the input as

- Hydrological;
- Hydraulics;
- Habitat simulation; and
- Holistic methods (Palau and Alcázar 2012).

63.3.1 Hydrological Method

Caissie et al. (2007) employed the Flow Duration Curve (FDC) method to outline the extent of time taken to or surpassed to a certain flow limit level in a specific river or area. The curve duration is evaluated based on the data which is obtained ideally using records over more than 20 years. Flow limits are then identified from the field data based on various expert knowledge that portrays the flow levels that supports biotic integrity. Mathews and Richter (2007) used the (IHA) Indicators of Hydrologic Alteration which was established by The Nature Conservancy on the Green River during the 90s at Washington using the combination with models of ecology, water formulation and preservation/renewal goals of the land. Jha et al. (2008) used the Low Flow Frequency to estimate the low flows under diverse climate scenarios in the Basin of the River Brahmani, located in Orissa, India. To comprehend and forecast the probable effects of change of the climate upon the river flow and water resources it is essential to fathom the multifaceted nature, the non-linearity of the associations that happens in the atmosphere and the land surface. Mandal and Cunnane (2009) explored the FDC method, a regression-based model for Irish rivers. It was established and utilized for predicting FDC ungauged catchment based on watershed's climatology and physiography data. Desai (2012) used the Desktop Reserve Model (DRM) for the study area in South Africa. There is likewise a suggestion that a future variant of the pressure driven sub-model may incorporate the stream routine change that might have an impact on the channel geomorphology and sedimentology with the goal that the stream board can be proficiently assessed. Fuladipanah and Jorabloo (2015) used FDC which was based on the hydrology data to assess the Environmental flow in Gharasou River, Iran. Using FDC, Q90 and Q95 the diverse return periods were designed. The scale was fixed as 1-d, 3-d, 7-d and 30-days' time period to arrive at a minimum everyday discharge of 0.7 m^3/s^{-1} using the Q95 index. Herrera and Burneo (2017) assessed the impact of 10% minimal flow discharge as a rule in the Machangara and Chulco rivers using the Base Flow Methodology (BFM) which has been blocked by the hydroelectric project. For the Machangara river, during the rainy season, the minimal flow is evaluate data 27–51% of the (MAF) annual flow and 29–42% in the arid season for the river Chulco, the minimal flow of 15–45% of MAF during the rainy season, and 15–36% in the dry season. Hydrological methods such as Range of Variability Analysis, FDC, Tennant, DFM, Tessmann, 7Q and Q50 flow approaches are the most widely recognized ones. The hydrological method has an unusual state of result precision in the examination compared to the other three strategies. Hydrological strategies, which rely on the logged data methods are considered as delicate for environmental information, as it lacks to clear up the ecological hydrological relationship. Suwal et al. (2020). State that the hydrological methods are simple and used for preliminary analysis of environmental flow. When there are a few accessible answers for a similar issue, there is no assurance of the best arrangement from both fixed and logical viewpoints.

63.3.2 Hydraulic Method

Gippel and Stewardson (1998) employed the most common hydraulic method i.e., the Wetted Perimeter Method. This methodology identifies a point where there is a break in the condition of the bend and marks the respective discharge that is corresponding to the bending point called the breakpoint in the environmental flow. Extence et al. (1999) used the LIFE (Lotic-invertebrate Index for Flow Evaluation) method which employs 20 years' data of the ecological survey. This method was developed in the UK that evaluates the biotic response to the flow which is dependent upon the species-level and the family-level inclinations for flow speed conditions, recognizing that a few families include taxa with variable Environmental flow necessities. Procedure for utilizing this data in the administration of stream flows are still a work in progress yet the procedure is accepted to be comprehensive. Liu et al. (2011) employed the Adapted Environmental Hydraulic Radius Approach in Huvai River. This method applies the hydraulic sweep as the surrogate for the hydraulic habitat. The Manning Flow Obstruction Equation is engaged to determine the hydraulic span where the concerned habitat is surveyed and the "minimum ecological speed" is obtained. Efstratiadis et al. (2014) investigated the minimal flow norms from the most downstream dam by measuring the wetted perimeter and coupling it with the Basic Flow Method (BFM), appropriate for Mediterranean rivers, whose streams show robust erraticism through periods. The work shows the combination of these two would possibly produce a consistent result irrespective of the river flow data. Hydraulic rating methods utilize the river geometry parameters such as wetter perimeter, depth and width to shape of the e-flow. Calculating the geometrical parameters for each cross-sectional area marks as a disadvantage as it consumes a lot of data and time.

63.3.3 Habitat Simulation Method

The extension of hydraulic methods (depth and flow-related data such as velocity) along with the habitat details (flora, fauna, and habitual data) are the Habitat methods- Jowett, I.G. (1989). Leclerc et al. (1995) illustrated the IFIM methodology by learning the habitation of the Moisie River (Quebec) and comprehending the fish habitat at two sites which have a wide range of accessible discharge measurements. Palau and Alcázar (2012) presented the BFM as a real-time application for the Silvan stream, a natural river stream flowing through mountain which was being obstructed by a hydroelectric project. The final result is reflected with respect to the physical habitation generated and compared with IFIM, using RHYHABSIM for physical habitat modeling. Koutrakis et al. (2019) applied (MesoHABSIM) Mesohabit at Simulation Model to measure the environmental flow in Nestos River, Northern Greece. The outcome of the habitat suitability after scrutinizing the fish samples and hydro-morphological units were 10–15 m^3/s of the Ecological flow. Lester et al. (2019) applied the Murray Flow Assessment Tool, a situation-based habitat suitability model to evaluate the Environmental flow by correlating the monitoring data of explicit key species (fish) against the model data. The author states that using the simple, consistent combination procedures and constant weightings and re-examining the quantity of fish functional groups results in the improvement of the comparative habitat. Habitat Simulation methodology is an easy and a less labor implement method which would give a quick information. It gives the results by relating the discharge and accessible habitat conditions. Broad data collection and utilization of specialists, surprising expense makes this method an inquiry for using. Acuña et al. (2020). Presented that mesohabitat methods are more effective to describe the complex habitat dynamics during lean period by evaluating the environmental flow needs for European eel. The discharge, dry period relationship, habitat suitability, wet area, and connectivity were studied and shown that there is a relationship between these parameters.

63.3.4 Holistic Method

King et al. (2000) developed a holistic approach called Building Block Methodology (BBM) for the Rusape River's E-flow, a Save River's tributary, in Zimbabwe., This methodology has helped to administer the advance the Environmental flow assessment methodologies in a different and advanced approach as it focuses not particularly on a specific factor but on a wider factor from the bottom to the top approach. In other words, it paves way for evaluating the Environmental flow system from the descending standards to the ascending standards. Arthington et al. (2003) utilized the DRIFT for the Lesotho Highlands Water Project, Southern Africa. It offers an organized procedure for anticipating the bio-physical, social and financial results of changing a waterway's stream routine. This is a unique method where there is no need to hustle with the system but just to network with an administration system which is of a versatile nature that renders the real pledge to the age and also feeds a vast knowledge. King et al. (2003) states that the BBM, stimulated the driving force to the advancement of a few options like natural stream approaches. Strikingly the DRIFT which is an interactive and situation- based methodology intently used in exchanges that contains solid financial parties significant while measuring the subsistence utilization of waterway assets by riparian people groups. In a holistic methodology, all the three other methods are used and exceptionally vital flow attributes (high surges, base-flows and so on.) are recognized. Bahukandi and Ahuja (2013) recommended and provisioned the development of a BBM for Suswa river of Dehradun district. It works on the principle of drawing post-examination suggestions from pro gatherings, for example, hydrologists, geo-morphologists, water quality specialists, sociologists, earthy people, and data innovation specialists. The given data sources help the learning-based framework in advancing the aggregate discoveries (evaluation), in drawing the key suggestions, in advising with measures to be taken; and also, to maintain the actual standards of river stream in respect of both quality and quantity.

These methodologies give an immense strength to the administrative system as it helps in the following ways classification of the biotic and a-biotic division, formulates a good ecological system; and streamlines the complete scope of flow with their communal/spatial variance.

63.4 Limitations in Assessing the Environmental Flow

The data deficiency regarding the routines of the flow are essential for supporting the natural abilities at both scales which are close and bowl, speaks a massive hazard to the practical water the board. Chen et al. (2013) applied the models of static eco-path to estimate the Environmental flow, as the reason of time series data lack the ecology data. This was dispersed for many years in the past and was studied and fashioned according to the typical ecological data based on the standards such as quality of water, its level, and information on the fishery was used for the Baiyangdian study area in North China. Esselman and Opperman (2010) made an analysis which was contextual for Patuca River of how the assets and data restrain were expected to be in the advancement of the natural flow's proposals in Honduras under which a hydroelectric dam was proposed. The flow proposal was generated by connecting a procedure which has multiple steps such as hydrological examination and demonstrating, the accumulation of traditional ecological knowledge (TEK) amid field trips, master counsel, natural flow workshops for researchers, water supervisors, and network individuals. Junguo et al. (2016) used the information of the simulated stream for the appraisal of the Environmental flow. The proper strategy choice is compelled principally by the availability of data for a district, just as the nearby limitations as far as the time, the funding, capability, and intended help. Moore (2004) specified that even though there was a lack of information for a few regions, it can be told that it is acceptable assets, knowledge, and engrossment in the ecological flows that prevail in these locales, which in all probability makes it easier to develop the idea into innovative zones in the area. In any case, the number of assets, knowledge, and experience predicted to achieve this cannot be depreciated. Recollecting the constraints of the data, the degree of connecting to this idea varies over the important areas. Pastor et al. (2013) restricted the decision for EF techniques choice, for the inquiry was restricted to hydrological techniques in light of lack of information on reactions of the biological system to changes of the flow for world's maximum waterway bowls. The Eco hydrological information's absence leads to the trouble in deciding the minimum natural flow edges and tipping purposes of the numerous biological systems across the world in freshwater. Patsialis et al. (2014) recommended that this time series data lack can be fought over by making use of the simulated discharges which are resultant from the IHA hydrology model for Western Macedonia. Penas et al. (2013) outlined a methodology for estimating the environmental flow similar to Europe's water framework directive for the estuaries which are of heterogenous nature inclusive of the hydrologic and climatic pattern. The hydrologic and the climatic pattern are coupled with arithmetical modeling of the catchment area's salinity. The capacity for repeating this for a large portion of these methods is on an agonizing state due to the lack of required information and variance in the considered estuaries.

Tharme (2003) Accessibility issues are being analyzed using the lack of data which is accessible in certain cases and its vulnerabilities which are technically accessible. Yue et al. (2018) Hydrological method is utilized and it has been reviewed that due to the low-level usage of lower fundamentals, computations being straight, the actual result ends up very unpleasing though suitable for the streams. Schillinger et al. (2020). Debated the importance between the environmental flow maintenance for sustainable environment and hydropower production under global market. The implementation of the environmental flow with novel economic models that suits both the cause will maintain the balance between the hydropower production and sustainable environment.

63.5 Critical Review

A massive collection of familiar methods exists for suggesting the Environmental flow needs. Therefore, there is no particular method which is recognized as an overall method for EFA. All methods are evolving by a step-by-step process. Varied strategies were integrated into the International and Indian status to the extent of determining the Ecological stream. This review had a mandate analysis of Environment influence studies and fish habitat inspects. Diverse procedures should be and are used for various purposes depending upon the interest points of the relevant analysis and the kind of issue intended to. However, a single natural stream evaluation strategy does not suit all social, economic, hydrological and ecological zones of a nation. Various factors must be measured for the use of individual strategies. Evidently, various features are put into thought for determining the e-flow, in light of which one best method would be selected. The Long-term or Historical Data Flow is applied for calculating the Environmental flow in terms of hydrological methods. A wide range of data flow is collected in terms of range from day-to-day for 30 years and their mean-data flow is suggested as Environmental flow value to conserve the biodiversity. Hydrological methods such as Range of Variability Analysis, FDC, Tennant, DFM, Tessmann, 7Q and Q50 flow approaches are the most widely recognized ones. The hydrological method has an unfamiliar state of precision of the result in the examination with the other three strategies. The Hydrological techniques, which depend on methods of logged data, are measured as frail with respect to environmental information and are lacking to clarify the relationship of the ecology hydrology. The wetted perimeter technique is an outstanding method of all the other hydraulic approaches. With the help of a hydraulic rating approach, Environmental flow is shaped through numerous hydraulic variables of width, profundity, and wetted perimeter. An inspection of each cross-sectional area is a disadvantageous consequence concerning the time and the Habitat Simulation procedure is an easy and less labor implementation method which could give fast information. It provides the results by connecting the habitat conditions which are discharge and accessible. Wide-ranging data collection and application of specialists and the astounding expense makes this technique an inquiry for using.

In a complete procedure, all the three other approaches are utilized and exceptionally vital flow attributes (high surges, base-flows and so on.) are recognized. The Fig. 63.1 shows the methodology framed from the review of the literatures. This

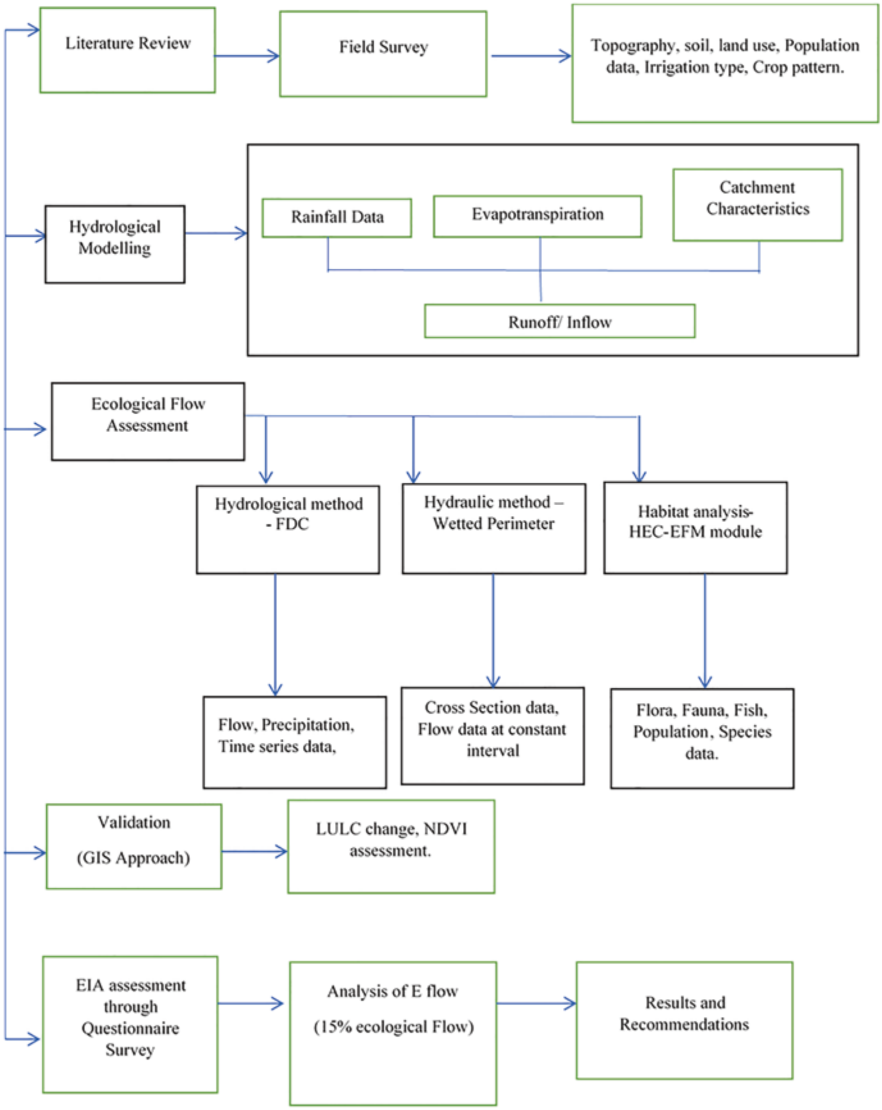

Fig. 63.1 Environmental flow assessment and validation

method needs huge logical ability, mind-boggling expense and not functioning makes one point in the side of weakness. Out of the four systems, the Hydrological technique has an uneven state of result accuracy in the inspection with the other three strategies. Next is the hydraulic technique which reduces in light of the monotony in assessing the cross area of the waterway, with which the Environmental flow is managed. Hydrological techniques, which depend upon the logged data, are censured for being slightly alike to environmental information and are inadequate to explain the ecological hydrological relationship. Regarding the Hydraulic strategy, a cross-sectional area estimation at each cross section prompts the negative results similar to the time and cost. Natural surroundings broadcast frameworks located second to hydrological EFMs at an overall scale, be that as it may, by virtue of Indian dimension, it positions third by water driven as a result of awkwardness in the examination of the earth in the different area. The points of interest and difficulties of the strategy oscillate concerning various parts and factors. Hydrological and hydraulic strategies, for example, the Tennant Method and wetted perimeter strategy are pertinent for setting up minimum environmental demands for water resources management. It should be seen that these approaches give a fundamental low confidence|| measure. These methodologies can be intertwined to render the primary check of the possible water measure required to upkeep with the natural circumstances. The Building Block Methodology (BBM) can be used for quick assessments. Nevertheless, in order to use this strategy for quick Environmental flow assessments, month to month naturalized stream course of action is required. The Instream incremental methodology strategy using PHABSIM (Physical Habitat Simulation System) is a largely used technique for more intricate decisions e.g., the development of a hydropower plant or the setting the deliberations limits from an environmentally touchy conductor. In total, there is no single logical solution to edifice the e-stream. To develop the basic Environmental flow the expert should take into the account the history and motivation behind the various strategies existing and need to utilize this information to settle on a sophisticated decision of the finest strategy to utilize.

63.6 Conclusion

Different strategies were incorporated in International and Indian status as far as deciding the Ecological stream required as part environment affect studies and fish habitat studies. Diverse techniques ought to be and are utilized for various purposes relying upon the specifics of the contextual analysis and the kind of issue to be tended to. Be that as it may, no single natural stream evaluation strategy suits all social, economic, hydrological, and ecological inside a nation. Various factors must be considered for the usage of distinctive strategies. A generally utilized basis for the usage of strategies depends on a hazard-based approach, implying that for stream choices with more noteworthy ecological, social or monetary dangers more complex techniques will be connected. It is obvious that numerous factors are mulled over for deciding the biological stream, in light of which the technique is chosen. Out of the four techniques, Hydrological method has an abnormal state of result exactness in examination with other three strategies. Next is the hydraulic method which shorts because of the monotony in estimating the cross area of the waterway, with which the e-flow is computed. Hydrological techniques, which depend on recorded data methods, are condemned for being frail as far as environmental information, and are deficient to clarify the ecological hydrological relationship. Regarding Hydraulic strategy, an examination of each cross-sectional area prompts negative outcomes as far as time and cost. Natural surroundings reproduction systems positioned second to hydrological EFMs at a worldwide scale, however, on account of Indian level, it positions third by water driven because of trouble in the investigation of the environment in various area. The points of interest and impediments of the strategy vary concerning numerous components and factors. Hydrological and hydraulic techniques, for example, the Tennant Method and wetted perimeter strategy are relevant for setting up the least environmental demands for water resources management. It ought to be noticed that these methods give an underlying —low confidence gauge. These procedures can be connected quickly at countless to give a first gauge of the possible amounts of water required to keep up nature in a given condition. The Building Block Methodology (BBM) can likewise be utilized for fast appraisals. Be that as it may, so as to utilize this strategy for fast e-flow evaluations, month to month naturalized stream arrangement are required. The in-stream incremental procedure strategy using PHABSIM (Physical Habitat Simulation System) is a generally utilized technique for more intricate choices e.g., the development of a hydropower plant or the setting deliberations limits from an environmentally touchy conduit. In conclusion, there is no philosophy that ought to be utilized for setting up the e-stream request. To build up the fundamental e-flow the specialist ought to consider the history and motivation behind the different strategies accessible and must utilize this learning to settle on an educated decision of the best strategy to utilize. This efficiency level is based on the research conducted upon river flow and fish habitat estimation. In terms of Hydropower usage upon the water present in the dam and their impact upon the ecosystem, the study is limited.

63.7 Recommendation

The minimal flow isn't maintained in the river of the hydropower extends in Himachal Pradesh, latest news on the Hydropower ventures. Currently, the government is aiming to increase the production of the hydropower potential overviewing the environmental effects upon the ecosystem and also the mountain communities depending upon it. Hence as a role of government, it should keep an eagle's eye in maintaining the e-flow in the dam while planning, executing the hydropower projects. Our study area Beas River basin in Himachal Pradesh comprises of hydropower ventures possessed by both the public and private corporations understood that owing to inadequacy in maintaining the minimal flow. These organizations subsequently met up intentionally and tried to shape a water basin level association. Regardless of power production, the private sector must run hand in hand with the administration sector in preserving the ecosystem of the mountain networks.

With the reference of many contextual analyses of healthy environmental communities' close hydropower projects, the key is that the approach of the project is bottom up, starting at the network level. The people group can't simply depend upon the legislature and private institutions at all conditions subsequently the network individuals must assume up the liability in preserving the ecosystem.

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Chapter 64
Sustainable Development of Scheduled Caste and Scheduled Tribes' Population in Select Villages of Himachal Pradesh, India: A Cross Sectional Study

Varinder S. Kanwar, Hitakshi Dutta, Ishwar Dutt, Jafar Ali, and Ashok Kumar

Abstract The current research reviews socioeconomic status of Scheduled Caste and Scheduled Tribes communities residing in select villages of Solan district of Himachal Pradesh in northern part of India. The research work includes evaluation of current socioeconomic status including population, housing, literacy, education, occupation, livestock land and income status. The awareness about various government schemes and digital services is Also, analyzed. The above information's are found satisfactory based on the recorded responses except computer literacy, financial status and digitization. Therefore, more emphasis is required to raise awareness, skill and income by transferring latest technology in the villages. More efforts are required from government and other institutions to sustain the initiative being implemented and further help in commercialization of products so produced so that sustainable growth of the villages where such population is there in large scale can take place. Majority of villagers are either matric or lower qualified in both the villages. Their literacy rate is low where % of illiterates is 22.39% in first village and 24.79% in second village. The condition of literacy beyond matric is worst in both villages due to large number of dropouts from school i.e 37.8% in Village 1 and 21.9% in Village 2. The results of the present paper provide valuable insights for the design of suitable framework to overcome some of the highlighted problems of both the villages though technology transfer and digitization.

Keywords Sustainable development · Community resilience · Socioeconomic · Technology transfer

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64.1 Introduction

In the recent years, numerous researches are being carried out on the socioeconomic development of rural communities across the globe due to advancement in technology and availability of sophisticated techniques. Socioeconomic position is a broad and multidimensional concept that covers social, financial and material circumstances (Lallukka et al. 2010) It includes resource and prestige-based measures, that can be measured at three levels i.e., individual, household, and neighborhood (Krieger et al. 1997). Hence, socio economic studies (SES) should be systematically measured at the individual level (education, income, and occupation), as well as at the household and neighborhood levels (Gonzalez et al. 2016).

The SES indicates the possession of economic and social resources of an individual, family, or other social group. It is assessed by occupation, education, income, or a combination of all. It is a general finding that the SES of a family is associated with children’s academic achievement and their highest educational degrees (Spinath 2012). These studies focus on the improvement of people's lifestyles through improved education, income, skill development, awareness, and employment and highlights the issues of the disadvantaged groups like Scheduled Castes (SCs), Scheduled Tribes (STs) and women based on cultural and environmental factors prevailing in those areas.

The SCs in India are sub-communities who are defined within framework of the Hindu caste system facing oppression, deprivation, and extreme social isolation in India on account of their perceived ‘low statuses’ since ancient times. They represent the most backward and deprived class in the society and referred to as Dalit or Harijan. According to the Constitution (Scheduled Caste) order 1950, only certain Hindu communities can be deemed as SC (CoI 1950). Similarly, Scheduled Tribes (STs) are the tribes in India, who have been living in various ecological and geo-climatic conditions ranging from plains and forests to hills and other inaccessible areas. (Kotresha 2019). They are geographically isolated with their own culture, and dependent on environmental conditions as available resources for livelihood (Jayakumar and Palaniyammal 2016). Socio and Economic stabilization of SC/ST people can Also, be brought by introducing various clean energy based harvesting and practice of traditional knowledge (Acharya and Sadath 2019; Agoramoorthy et al. 2009).

SCs constitutes 16.6% of the total population in India with a maximum in Uttar Pradesh. Whereas in Nagaland, Lakshadweep, and A & N Islands, no SC is notified (Census 2011). Most of them are dependent on low wage works, agricultural laborer and have very few assets (Raghavendra, 2020). Himachal Pradesh constitutes approximately 25.19% of SCs distributed across all the 12 districts with maximum population of SC in Sirmaur i.e. 30.34% and minimum in Lahaul & Spiti i.e. 7.08%. The present study focuses on Solan district with highest SC population of 28.35% in the state. (District census Handbook 2011). Two villages have been selected for the study. The first village consists of about 79% of SCs population and located in close proximity of our institution (Data as per our survey). STs constitute 8.6% of the country's total population of which 89.97% live in rural and 10.03% in urban areas. In Himachal Pradesh ST, population is 5.71% and Solan district constitutes 4.42% of total STs in state (District Census Handbook 2011). The second select village constitutes 73.01% of STs population.

Since independence, the Government of India has put emphasis on the development and planning towards enhancement of human well-being, reduction in equities along with growth of per capita income of SC and ST communities with focus on improvement in the areas of education, health and amenities like electricity, water supply and sanitation, housing, etc. However, the developmental schemes/programmes of the various Ministries/Departments are not invariably aimed for the benefit of the SCs and STs separately. If benefited, there is hardly any provision to monitor the progress in terms of reach to SCs and STs because there no collection of data by categories.

Hence the study aimed to collect and analyze the current status of SC and ST communities with an effort to improve their capacity by doing activities as per their requirements and adoption of more effective processes or recent available technologies.

64.2 Previous Work

Asia-Pacific Socio-Economic Research institute, (APSERI 2000) conducted an Impact assessment study of Socio-Economic development programmes. Assessment was quite widespread so we will stick to development profile of Solan District. They quoted Solan district as a non-tribal district and agriculturally advance district. Solan ranked in the middle of 12 other districts of state, in terms of poverty. The main occupation of rural people was agriculture. Around 66.68% of them were engaged in agriculture and labor activities. They harvested off season vegetables like tomatoes, cauliflower, hill capsicum, peas etc. Also, due to creation of education institutes, the district literacy rate has increased to 63.3% and Also, health facilities were satisfactory. They found that economic and social developments were primarily dependent on transport and communication. The road transport was the major means of travel and transport. Further a number of socio-economic development programmes by Government is under implementation in the district.

Kusuma and Das (2008) conducted a cross sectional study between tribal, rural and urban people for the estimation of hypertension and High BP. Data were collected from 803 people belonging to Cuttack, Khurda and Anugul district of Orissa. Tribal, Rural and Urban people were selected at random. The results were concluded based on the recommendation of seventh annual report of United states national committee on detection, evaluation and treatment of High Blood pressure. The results conclude that more than 60% of the target group belong to Obese and Overweight category.

Suryawanshi and Dhande (2012) studied about Socio Economic development among SC on Mahatma Phule Backward Class Development Corporation in selected district of Maharashtra (MPBCDC). They found that performance was not up to mark for success. The majority of respondents were among age group 30–40, which was not matching the expected age group of 20–30 from development point of view. Hence, they believe if scheme is opted by groups at proper age, the results can be improved. The average age was found to be 35. The study revealed that 40% of peoples are illiterate and only 15% are graduates. Nahar and Nav Buddha castes were in majority (60%) among all. Further, they found that financial and economic performances were very poor as 42% of people weren't earning and that only 4% of beneficiaries were able to save some amount of money. Average monthly salary was found to be Rs 236 and that only 4% of them are taxpayers.

Kumar and Kamal (2013) studied about education and cultural diversity of tribal population in Himachal Pradesh, India. Their findings present a conceptual framework that is focused on incorporation of culture and diversity among tribal population. They believe that it will help in promoting traditional validity through integration of cultural and diversity consideration at each phase with focus on the importance of tribal population. It is actually involving people in small focus groups who are sharing beliefs, perceptions and attitudes about tribal population. Lastly they intended on how best can they incorporate cultural consideration and conserve cultural, traditional and educational diversity.

Singh (2014) has conducted a similar study on socio economic status of SC people of Kangra of Himachal Pradesh, India. In this study he found that social and economic deprivation among SCs had been most common during Pre and Post independence. He found that most of SCs were not able to get good quality education for their children. Also, he found that most of peoples were involved in agricultural activities for their livelihood and that most of them lived in Semi-Kaccha house. The only rural employment scheme that villagers knew about was MGNREGA and that most people weren't aware about Government schemes. Further, the reservation for SC in many sectors has helped them a lot socially and economically.

Jayakumar and Palaniyammal (2016) studied about the socio-economic status of the ST of Kalrayan hills of Tamil Nadu, India. In this work they found that most of the households were involved in agriculture and cultivation. They found that more than 83% of villagers doing agriculture have income below Rs 5000–10,000 and further have put more attention on educational aspects. They Also, found that infrastructure like road, communication, sanitation etc were poor.

Biswas and Rao (2016) studied about socio-economic status of Gaddi Tribe in Himachal Pradesh. The study is focused on Gaddi tribe who are semi-agricultural, semi-pastoral and sei-Nomadic tribe. Gaddi tribes rear sheep and goats of Kangra and Chamba districts. They keep moving with their herds throughout the year in search of grazing land. They usually live-in high altitudes ranging around 4000–8000 ft. The main occupation of Gaddi tribe was found to be shepherding. Majority of them were found to be property owner and practice agricultural activities apart from herding sheep. They had to get a yearly permit for grazing their sheep's and goat and had to pay Rs 1 and Rs 1.25 respectively for them. Women in the Gaddi tribe are given very importance and they believe "God reside where woman is worshipped'. Gaddi women are skilled craftswoman and Also, the modern Gaddi women are educated too. The result showed that the Gaddi tribe has absorbed many customs and traditions of local and that they prefer well settled and comfortable life. Hence it is found that Gaddi tribe is on verge of extinction from old occupation and lifestyle.

Jha et al. (2017) studied about various tribal development programmes of India and their usefulness in mitigating the climate change. The tribal people in most of the region are vulnerable to climate change due to their combined effect of poverty and their dependence on agriculture throughout the year. He necessitated the importance of developing programs that simultaneously address their economic vulnerability and climate change. He concluded that the development of action policies based on traditional practices combined with the national framework will help promote climate changes at national scale.

Kotresha (2019) conducted a sociological study in problems and prospects of SCs and STs current status. He found that tribal peoples have been living in different ecological and climatic conditions from plains to hilly regions. As per study, various problems faced by SCs were Also, due to Varna system that existed in ancient period. Further author briefed about education and civic disabilities, economic status including owning property, occupations, etc. In addition, he found about the laws and regulations for welfare of SCs and STs. He concluded with a note that privileges given to SC and ST creates political tension and that these privileges cannot be the permanent feature of a polity.

Lakshmi and Paul (2019) reviewed Socio-Economic condition of tribal communities in Telangana and Andhra Pradesh. According to them the tribal groups are mostly disadvantage due to their status in the section in Indian society, where they are ranked as lowest. Reasons for them being disadvantaged include various factors like inability to satisfy basic amenities, geographic isolation, lack of education and many more. Further they reviewed about various Government welfare schemes including economic support schemes, skill development programmes, impart training and construction of various infrastructure for education like hostel buildings for degree colleges, high school etc. Therefore, the results showed that both Telangana and Andhra Pradesh government are performing well towards the welfare of tribal lives.

Priyadarshini and Abhilash (2019) suggested the potential of indigenous knowledge of tribal communities coupled with modern technologies as a way of promoting sustainable development. They have identified that 8.6% of total tribal communities in India has a vast knowledge in traditional practices. These practices can be used, modified and enhanced with adequate modern technologies for the sustainable development of the country. This knowledge's would aid in the benefit of better climate policies as well as betterment of social empowerment of women, child health and alleviation of economic poverty.

Raghavendra (2020) studied about Literacy and health status of SC in India. He found out that population of SC was steadily increasing. About 71% of SC are agricultural laborers, low-income wagers with a very few assets. Their literacy level is only 66.1% as compared to that of India which is 73%. Talking about female literacy, it is as low as 56.5% as compared to that of India which is 64.6%. Also, he found as per reports that half of school drop outs in primary were always Dalits. Talking about health status, he found that according to a study 46.5% of Dalit women never received required Antenatal and Postnatal visits to doctor. Also, the institutional birth percentage was found to be 78% for SC, 68% for ST and that of Other Backward Class (OBC) and General to be 80% and 84% respectively. He Also, found that SC and ST children were suffering more nutritional problems and Also, percentage of underweight children below 5 years were more in SC and ST.

Thamminaina et al. (2020) studied about the lack of opportunities and border control on women education in certain particularly vulnerable tribal groups (PVTG) of India. Her results conclude that the reduced female literacy rate is due to lack of female teachers, parents' engagement with the children's. Language barrier and poor infrastructure in the region Also, contribute to the lack in female literacy. She suggested that increased traditional knowledge and national framework for such problems would prove to be fruitful for the increase of female literacy rate.

From above discussion, it can be concluded that significant improvement is observed among SC and ST communities in different parts of India. Since India has a huge population (2nd position in the world), therefore, such type of study is Also, required in other parts of the country. This will help the government to implement more schemes/plans for their social as well as financial upliftment.

64.3 Study Areas

The present research work is being carried out in the Solan district of the state of Himachal Pradesh in northern part of India. Solan district is nestled on the lap of the Shivalik ranges and extending from 76.42° and 77.20° East longitude and 30.05° and 31.15° North latitudes (Fig. 64.1).

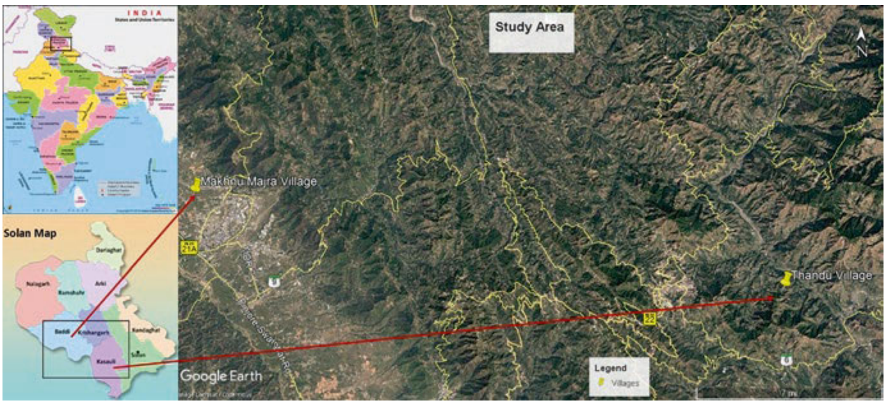

Fig. 64.1 Study area i.e., two villages represented by red arrow

We conducted our study in two villages which have been chosen out of 2544 villages located in close proximity to our Institute. The first village is situated 60 km towards west from district headquarters Solan, 45 km from block office and 110 km from State capital Shimla. Another village selected is located in Baddi tehsil of Solan district and is approximately 70 km away from district headquarter Solan. As per 2011 stats (District Census Handbook 2011), the total geographical area of villages are 93.08 ha and 124 ha. The local inhabitants of these villages are depended on agriculture for their subsistence and adopt several traditional practices conducive for farming in sloping terrains. The two study sites share similar development challenges but differ in important cultural attributes. Out of both the villages, one is remotely located on hills which make it difficult for villagers to avail basic facilities and hence make life difficult over there.

64.4 Objectives

Based on the related work reported in the literature, the objective of the study is to understand the socioeconomic status including population, housing, literacy, education, occupation, livestock, land and financial status of SC and ST communities belonging to the select villages of Solan district in Himachal Pradesh, India. Further, to study the extent to which these communities are aware about various government schemes and digital services available. Finally, based on the survey finding, a suitable solution will Also, be proposed to uplift their social as well financial status.

64.5 Methodology and Study Design

In order to analyze the current information, a detailed survey was designed and conducted using 5-broad categories questionnaire to check their social and financial status including population, housing, literacy, education, occupation, livestock, land and income status. In addition, awareness about various government schemes and digital services were Also, addressed. The detail of survey questions is presented in Table 64.1 below. These questions were in line with previous literature (APSERI 2000; Singh 2014; Pondorfer 2019).

The design of our survey was set up in such a way that we could collect respondent's socioeconomic status as well as demographic status in a detailed manner. Besides collecting general demographic characteristics such as gender, age, educational & occupational status, the questionnaire Also, sought information on wealth and awareness. To assess the financial status of selected villages, we considered various set of parameters like land records, monthly income and saving of individual households and assets like vehicle, cow, buffalo etc. These are the assets most common across the selected villages.

Table 64.1 Survey questions

Variable	Survey questions	Response categories
1. Respondent's Profile		
Gender		(1) Male; (2) Female
Age		In which year were you born?
Relationship with Head of Household		
2. General Household Information		
Household ID	House number if provided from concerned authority?	Yes/No (Specify)
Category	Which Caste/Category do you belong to?	General/SC/ST/OBC/None of these
Religion	Which religion do you belong to?	Hindu/Muslim/Sikh/Christian/ Others
Ownership Status of House	What is the status of house in which you live?	Owned/Rented/Other (specify) (Mention Monthly Rent Amount, if paid)
3. Household Income		
Average Monthly Household Income	What is the gross total income of your family?	Income from all Sources (Approx): In Rs. Below Rs 4000 Rs 4000–8000 Rs 8000–12,000 Rs 12,000–16,000 Above Rs 16,000
Income Sources	What is the source of income inyour family? If Possible, write the monthly income. Wages/ Salary Agricultural Income Animal Husbandry Income Tourism Income Business Income Rental Income Assistance from Relatives Pension Government Aid/Grant (Specify) Assistance from NGOs Others (Specify)	Amount in Rs.
4. Status of Facilities available at household:		
House Type	What is the type of house you are living in?	Kachha, Semi-Pakka, Pakka
Kitchen	Is the house you living have kitchen?	Yes/No
Water Supply	Is the house you living have water supply?	Yes/No
Electricity Connection	Is the house you living in connected to electricity?	Yes/No

(continued)

Table 64.1 (continued)

Variable	Survey questions	Response categories
Toilets in House	Is the house you living have toilets?	Yes/No
Solar Power	Is the house you living have solar power?	Yes/No
Rain Water Harvesting	Is the house you living have rain water harvesting?	Yes/No
Waste Disposal Management System	Is the house you living have waste disposal management system?	Yes/No
Segregation of household waste	Is the house you living have segregation of household waste?	Yes/No
5. Socio-economic and demographic characteristics and connectivity		
Level of education	What is your highest completed level of education?	(1) No school (2) Class 5 (3) Class 8 (4) Class 10 (5) Class 12 (6) Graduation (7) Above Graduation (8) Computer literacy
Occupation	What is your main activity in terms of work?	(1) Laborer (2) Farmer (3) Driver (4) Government Job (5) Private Job (6) Business (7) Does not work (8) Other (Specify)
Status of livestock Details Available	Do you have any of these animals?	If yes, please specify. Cow Buffalo Sheep Goat Hen
Status of Cultivable land	Do you have agricultural Land?	If yes, please specify. Below 0.5 acre 0.5–1 acre 1–1.5 acre 1.5–2 acre Above 2 acre
Saving status per month	Do you save any amount of money per month?	If yes, please specify. Below Rs 500 Rs 500–1000 Rs 1000–1500 Rs 1500–2000 Above Rs 2000
Awareness about various Government Schemes	Do you know about amy of these government schemes?	Pm KisanYojana Pm Jan DhanYojana Kisan Credit Card Pm UjjawalaYojana Pm AwasYojana Atal Pension Yojana Swachh Bharat Mission

(continued)

Table 64.1 (continued)

Variable	Survey questions	Response categories
Other facilities and services	Do you have these facilities and services at your home?	Bank Accounts Ration card LPG connection Two-wheeler vehicle Four-wheeler vehicle
Digital Gadgets and facilities	Do you have these Digital gadgets and facilities?	Mobile Computer TV Internet Online Services

Table 64.2 The number of households along with population of different categories gender wise

Village name	No of households	Gen (M)	Gen (F)	Gen Total	SC (M)	SC (F)	SC Total	ST (M)	ST (F)	ST total	Grand total
Village 1	195	130	103	233	25	24	49	410	353	763	1045
Village 2	110	45	53	98	210	176	386	0	0	0	484

The survey was conducted from November 2020 to December 2020. A total of 110 people from first village (80 men, 30 women) and 195 people from second village (155 men, 40 women) voluntarily participated in the interviews across two villages. Thus, information from a total of 305 people is analyzed in this study.

The research team went to the villages and did door to door survey of each household. Each respondent was given the questionnaire in a face-to-face interview. The interviews was carried out in the local language of the two villages by local research helpers who again were supervised by the researchers. To instruct the helpers on how to conduct the interviews, we organized a 2-day workshop prior to the survey.

64.6 Results and Discussion

The recorded responses are presented and analyzed below:

Demographic Status

- ***Population status:***

Firstly, the information compiled on the basis of survey conducted related to population of villagers is tabulated in Table 64.2.

Based on the demographic data it was found that village first villagehas 195 households out of which schedule tribe (ST) population is 763 i.e. 73.01% of total population. Similarly, in the second village, schedule caste (SC) population is 386 i.e. 79.7% of the total population of 484.

• ***Status of facilities in households*:**

The recorded information about facilities is plotted in Fig. 64.2.

From Fig. 64.2, it is clear that majority of peoples are living in Pakka and Semi pakka house in both the villages. Besides Government providing AwasVikasYojana, peoples are not fully benefitted from it, as some percentages are not having Pakka or Semi pakka house. Facilities like % of separate kitchen are very low in these two villages i.e., 27.17% in first village and 29.09% in second village of total household in both the villages. Also, some of houses are not having latrine although

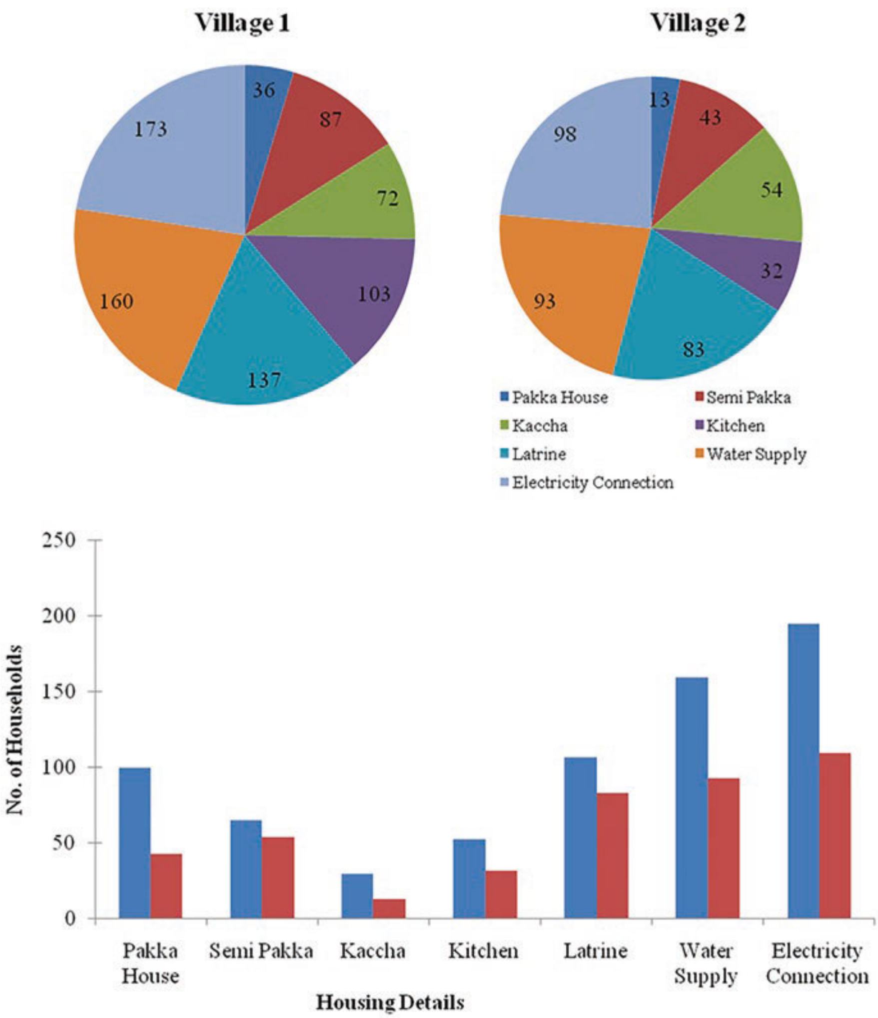

Fig. 64.2 Housing details and facilities in house in selected villages

government is providing facilities to build one under Swachh Bharat mission. Most of the houses have proper facility of water and electricity except few in the second village.

- ***Literacy status:***

Response recorded related to literacy status are presented in Fig. 64.3.

Figure 64.3 shows that majority of villagers are either 10th pass or below in both the villages. Also, majority of peoples are illiterate in both villages i.e. 22.39% in the first village and 24.79% in the second village but % of illiteracy is more in case of second village than the first one. Condition of primary education is good in case of first village but in case of second village % goes on decreasing as students reaches 10th. Talking about secondary and higher education i.e. above 10th, percentage as depicted in graph goes on decreasing drastically for both villages which clearly

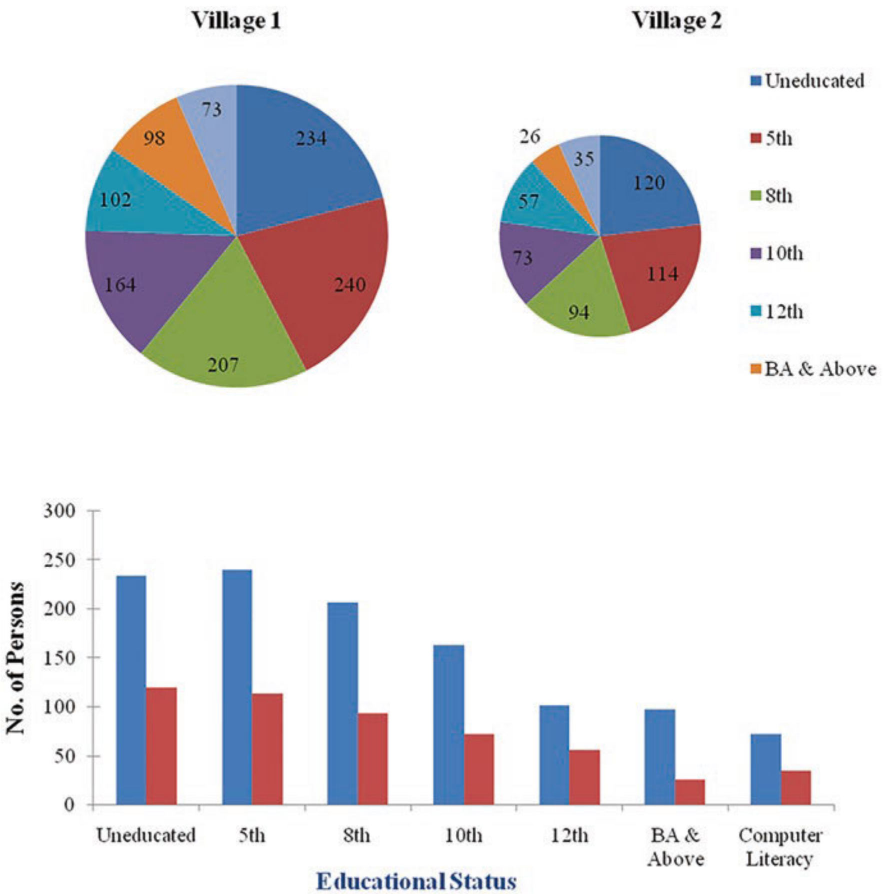

Fig. 64.3 Educational status in the selected villages.

shows that peoples are dropping out of school after high class schooling. In addition, computer literacy and digital literacy is Also, quite low which may be strengthened.

- ***Occupation status:***

  The response recorded related to occupation status is shown in Fig. 64.4.

  Figure 64.4 shows that majority of villagers are either working as laborer, farmer or are in private jobs which further denotes a poor financial status of villagers. Less % of Government jobs depict that villager are not able to avail the reservation provided to them in various government organization due to which they are not much into Govt. Jobs. Also, less % of business person shows that they are less aware about Ministry of Micro, Small & Medium Enterprises (MSMEs).

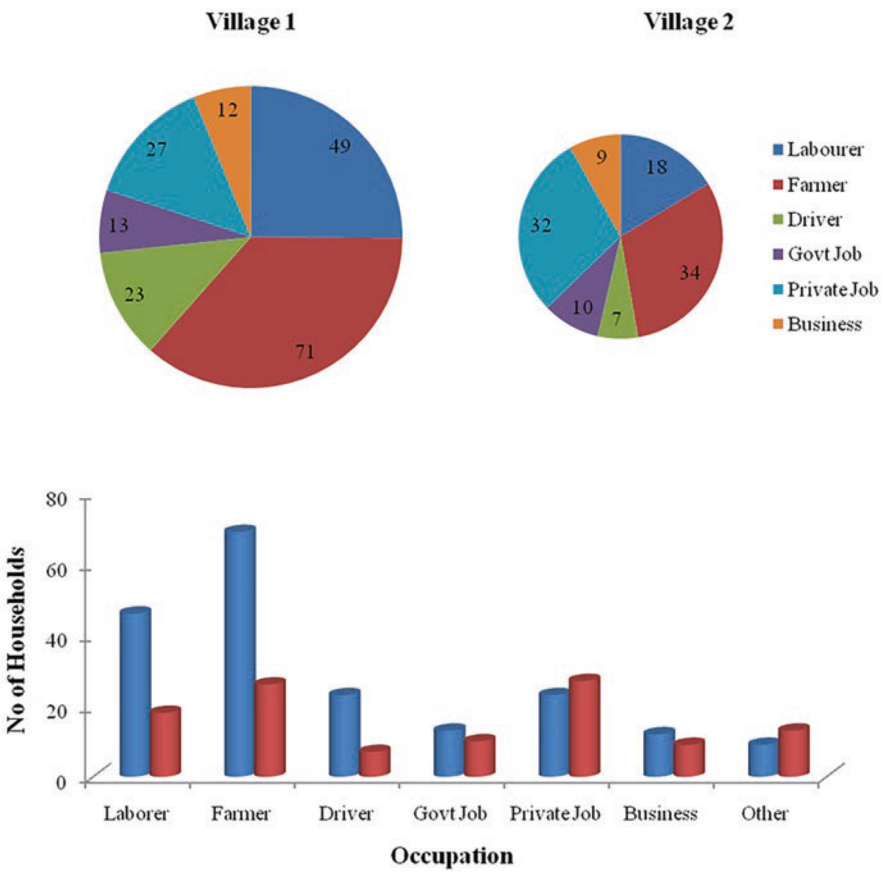

Fig. 64.4 Current occupation status in the selected villages

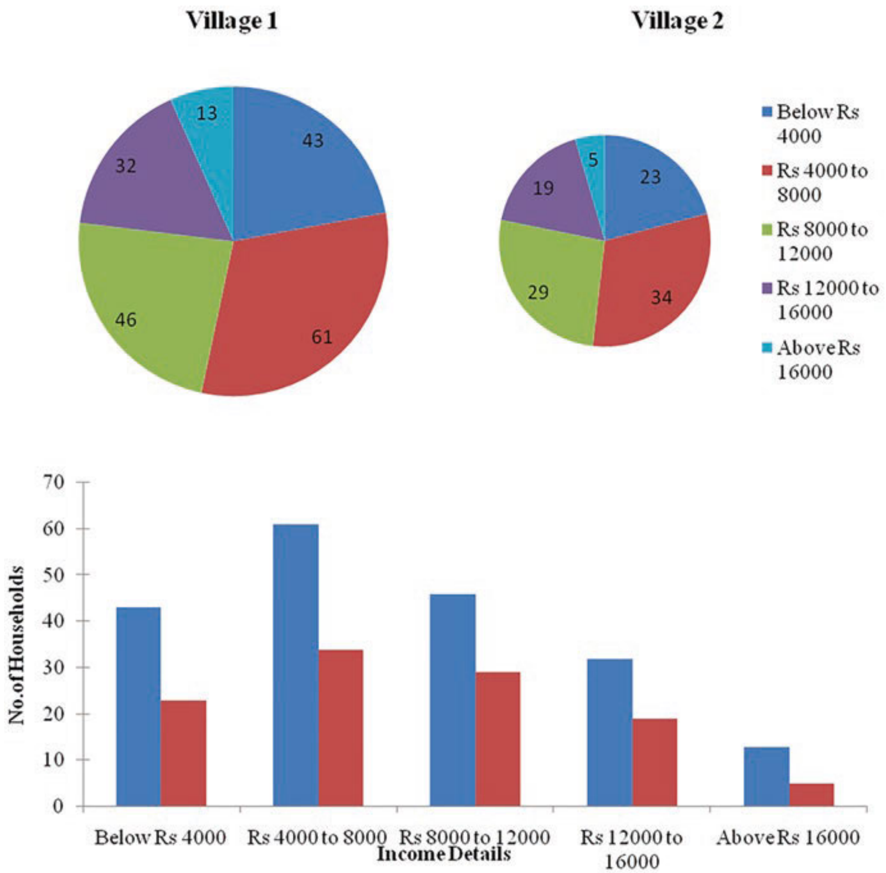

Fig. 64.5 Income analysis of households in two selected villages.

- ***Financial status:***

The response recorded regarding income is shown in Fig. 64.5.

It is very clear from the Fig. 64.5, that majority of income of both village lies under Rs 12,000. Peoples who are working as a laborer, farmers, drivers etc. mostly have income below this range. Peoples who are particularly in business and government jobs have income more than Rs 12,000 in both the villages. Also, some of private sector employees are above this mark.

- ***Status of livestock details available:***

The details of livestock were collected and are shown in Fig. 64.6.

From Fig. 64.6, it is clear that in both the villages, almost every household are having either cows or buffaloes. Out of these, most of them are very dependent on cows and buffaloes for their source of income and rest are raising for personal use. Percentage of sheep and goats raised is Also, very high in the two villages. Raising

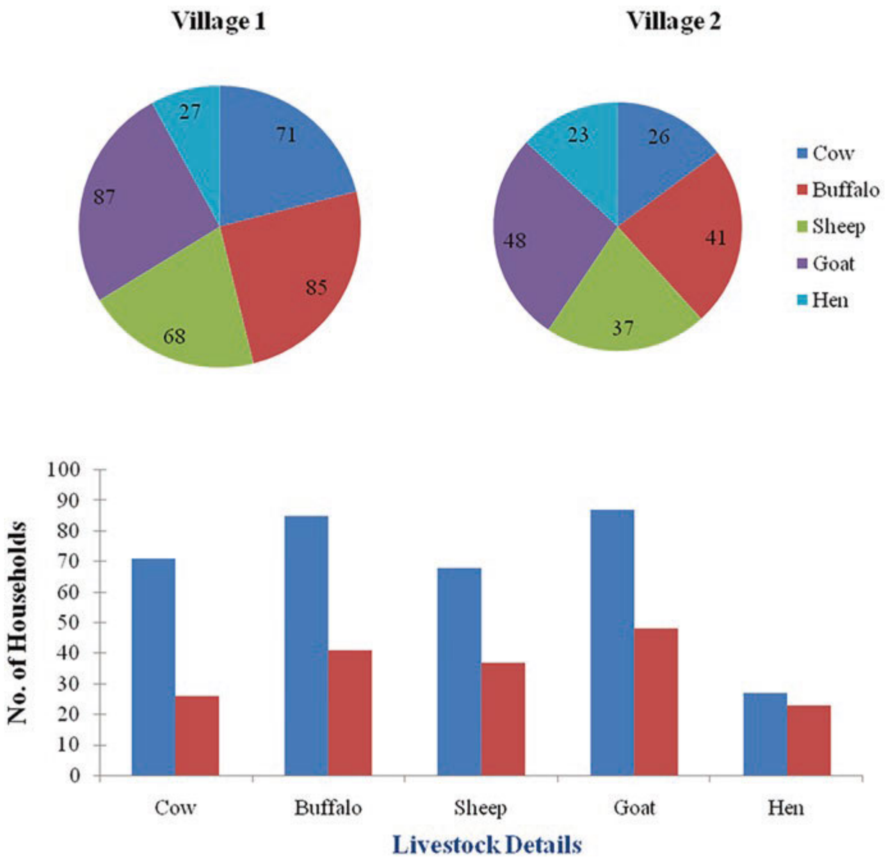

Fig. 64.6 Livestock details in both villages

Cattles, sheep, goats etc. are tradition of SC and ST people which they are following it today also. Apart from these some households are raising hens too either for egg or for meat.

- ***Status of cultivable land:***

The details of land possessed by villagers were recorded and are shown in Fig. 64.7.

From Fig. 64.7, it is clear that most of households in both the villages are having lands less than 1.5 acre. Peoples are having more land in first village compared to that of second village. Most of peoples possessing land in both villages are dependent on farming as their only source of income. First village being a plane area as compared to that of second makes it suitable for villagers to cultivate various types of crash crops and seasonal vegetables. Also, number of households possessing lands below 0.5 acre in both villages is quite high and that of above 1.5 acre is very low, which reflects the economic status of the villagers.

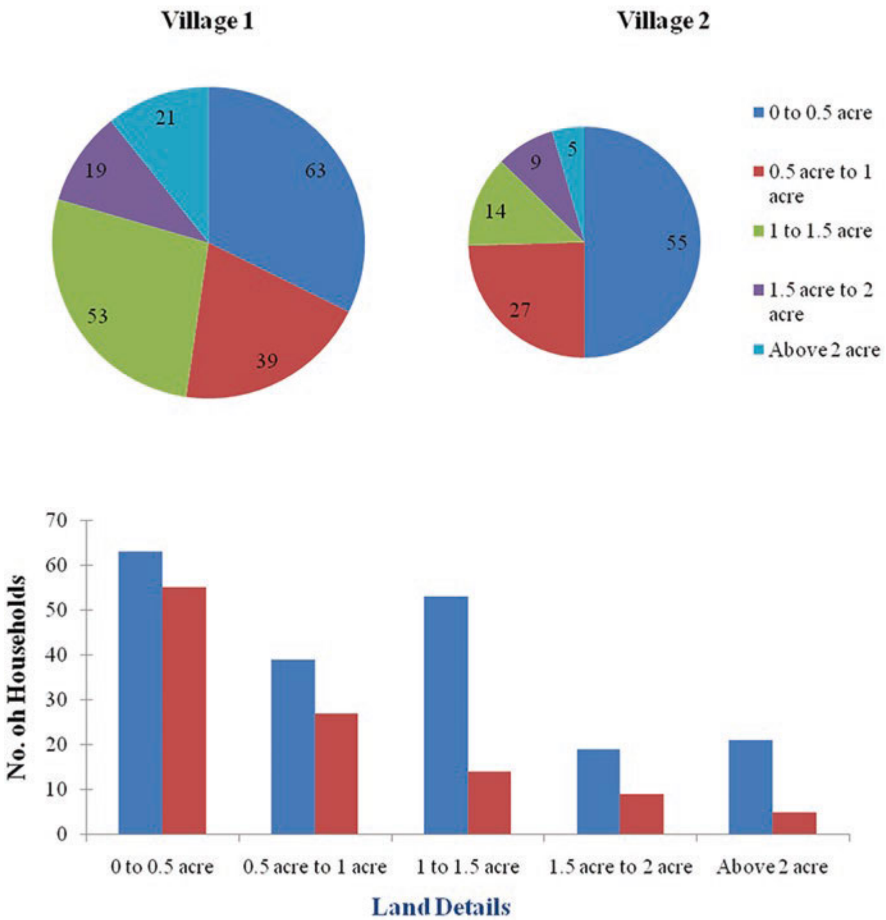

Fig. 64.7 Land holdings by peoples in two selected villages

- ***Saving status per month:***

Savings of villagers were found out in both the villages and are represented in Fig. 64.8.

From Fig. 64.8, we can say that majority of peoples are not able to save more than Rs 2000 a month in both the villages. This may be due to the maximum number of them working as a laborers, farmers and drivers etc and have very less income. Also, due to their low income and higher expenditure, they are hardly able to save. Peoples saving more than Rs 2000 mainly are either Government employee or are into some business. Also, some of farmers and others are able to save above Rs 2000.

- ***Awareness about various Government Schemes:***

Awareness about various Government schemes was found out amongst peoples of both the villages and is shown in Fig. 64.9.

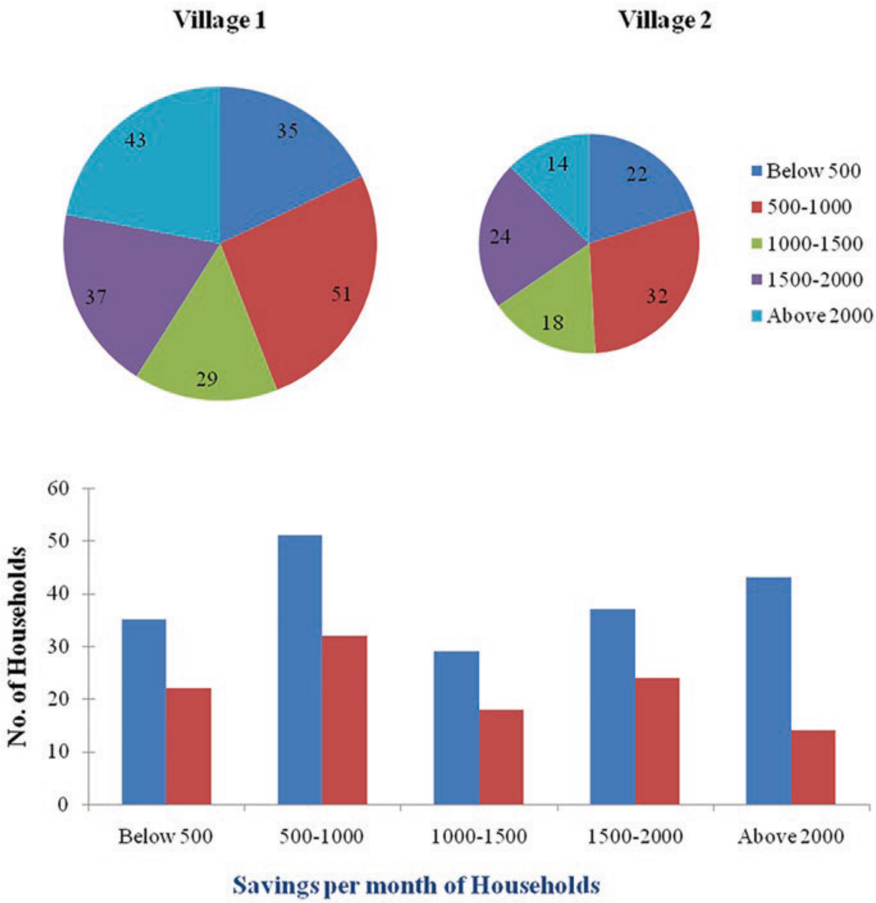

Fig. 64.8 Savings per month of households of two selected villages

From Fig. 64.9, it is very clear that majority of peoples in both the villages are lacking behind in awareness about various schemes and facilities provided by the government. The most famous schemes known to the villagers include PM Jan DhanYojana, Swachh Bharat Mission and PM KisanYojana. Yet each and all households are not having a toilet hence, it depicts lack of implementation of schemes in these villages. Also, PM Ujjwala Yojana is not availed by most of the peoples in both villages as only around 50% of them are using LPG.

- ***Banking and other facilities availed:***

The status of Bank accounts, Ration card, LPG connection and vehicles possessed was found out which is shown in Fig. 64.10.

As from Fig. 64.10, we can conclude that maximum number of peoples have availed PM Jan Dhan Yojana, as percentage of Bank accounts are more in both the villages. Also, number of ration card is more which means they are getting rations

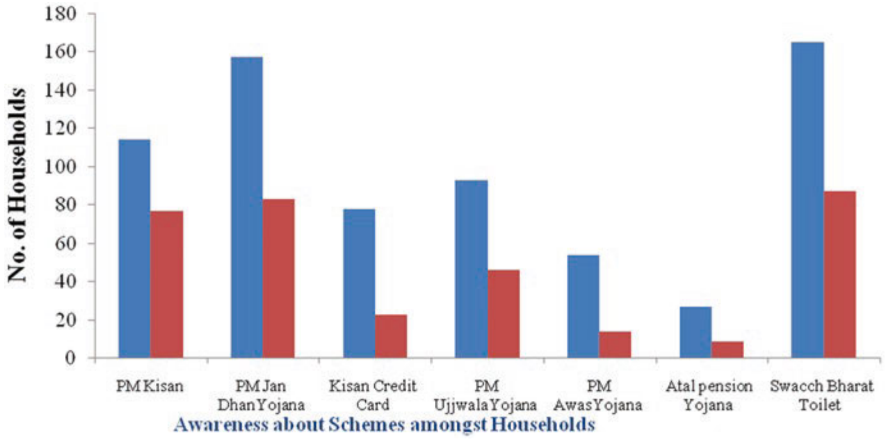

Fig. 64.9 Awareness about various schemes amongst villagers

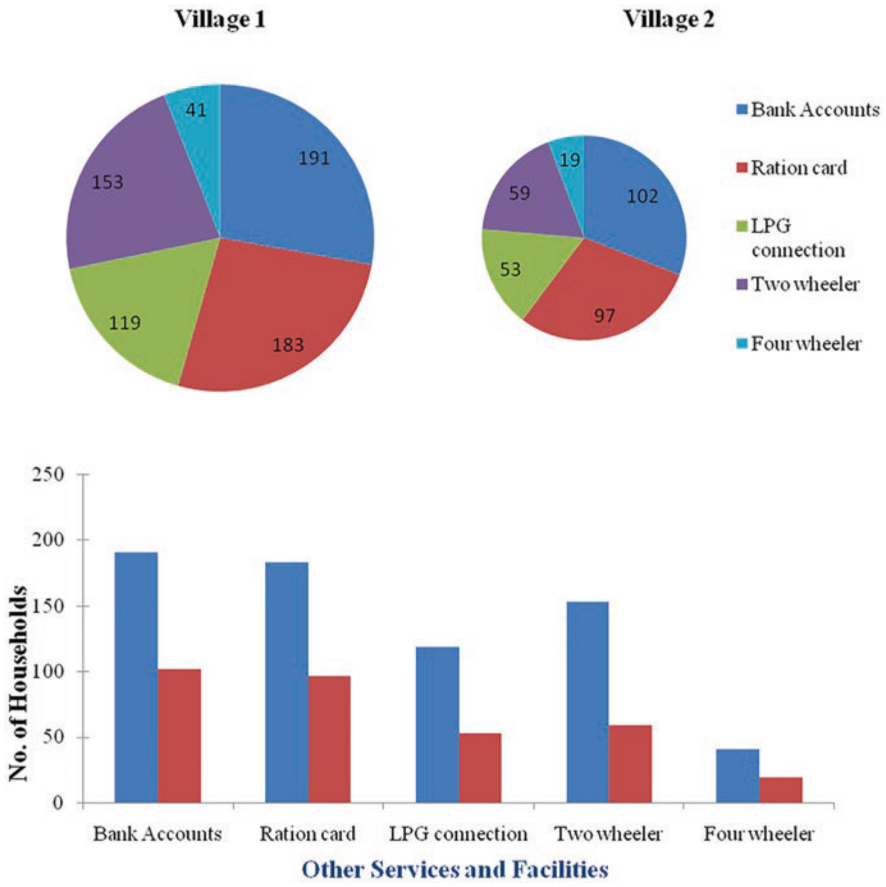

Fig. 64.10 Other facilities and assets availed by villagers

provided by the government. Both the villages are dependent on transportation via Road networks. Still due to low income, majority of peoples in both the villages are not able to afford two wheeler and four wheeler vehicles.

- ***Digitization and online faculties availed:***

Usage of mobile phones, computers and internet along with online facilities were found out which is shown in Fig. 64.11.

From Fig. 64.11, it is clear that maximum number of households is having mobile phones. Number of households having computer is very low in both the villages due to which computer literacy is Also, affected. Internet facilities availed by peoples are good in numbers and most of the users are youngsters which they mostly use it for social media. TV is present in maximum number of households in both the villages. Online services are yet to be availed by most of the households as they are unaware of the services like online billing, recharge, updating of Aadhar etc.

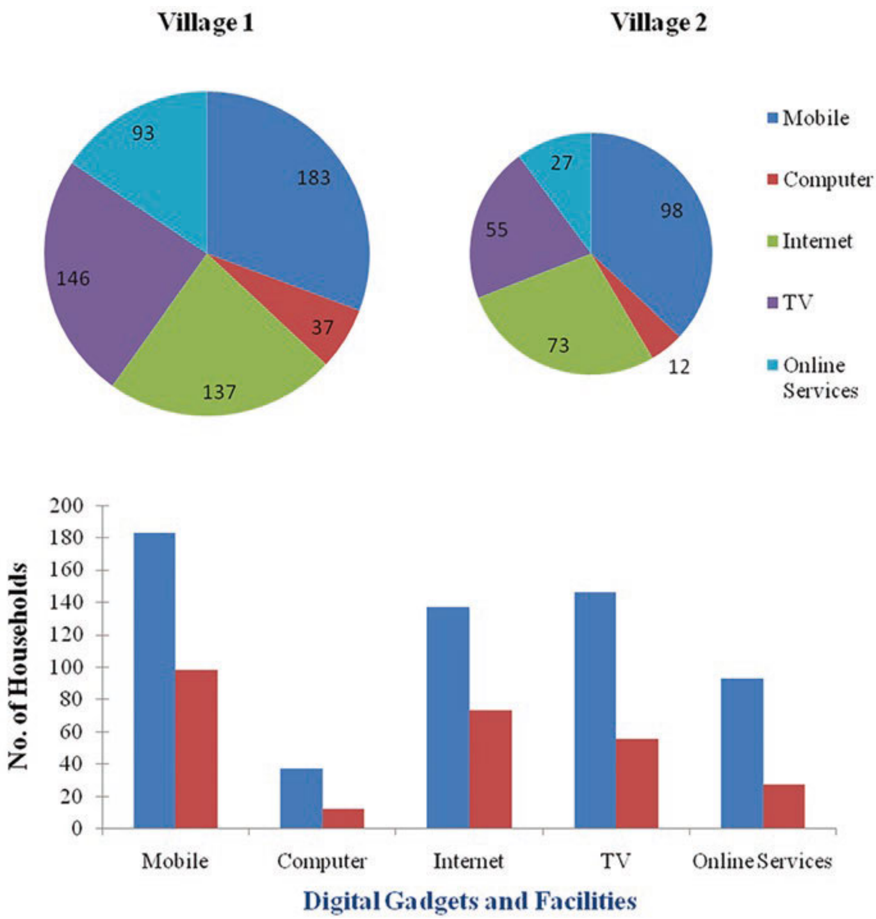

Fig. 64.11 Digital services and online facilities.

64.7 Conclusion

The motivation for this research comes from the problem that is arising due to unavailability of resources and facilities to some groups of SC & ST all around Himachal State. Although a small number of studies of other districts exist, highlighting some similar issues, well-defined profound empirical research including statistical analysis is still missing. Quantitative findings are the valuable tools to complement qualitative work with respect to reliability, accuracy, and creditability of findings. In the area under investigation, quantitative studies enable identifying both common and local factors that help us to analyze the socioeconomic conditions of SC & ST households in both the villages.

Previous studies on similar area concluded about issues faced among SC & ST peoples across the state and Also, says about their socioeconomic status, but show insufficient knowledge on in-depth analysis of quantitative studies about their conditions. Comparing two villages - we show the ground reality of these communities and that how factors such as education, occupation, housing etc. are affected due to lack of proper facilities and services and ignorance from the societies.

The results of the present paper provide valuable insights for the design of suitable framework to overcome the problems of literacy, occupation and other services in both the villages. In this paper, the socioeconomic status of Scheduled Caste and Scheduled Tribes communities residing in two villages i.e., in first village with 73.01% ST of total population and in the second village with 79.7% SC of total population, of Solan district of state Himachal Pradesh belonging to northern part of India is reviewed and presented, with the help of assessment survey.

Majority of villagers are either matric or lower qualified in both the villages. Their literacy rate is low where % of illiterates is 22.39% in first village and 24.79% in second village. Even as most of the people are illiterate in both villages, the percentage of illiteracy is more in second villages compare to first village. The condition of literacy beyond matric is worst in both villages due to large number of dropouts from school i.e 37.8% in Village 1and 21.9% in Village 2. Moreover, computer as well as digital literacy is Also, quite low and required to be taken care of.

Due to low educational conditions, most of villagers are spending their lives with minimal source of incomes and are working as laborer, farmer or are in private jobs. Moreover, low awareness about the government schemes like Swachh Bharat Mission and PM Kisan Yojana, PM Ujjwala Yojana etc. villagers are not able to avail benefit of the facilities provided to them. Most of the households depend on cows and buffaloes for their source of income but some are still following their traditional ways of raising sheep, goats, hens etc. to meet their both ends meet.

Occupational status is Also, poor as majorities are laborers and farmers. Large number of farmers in both the villages have cultivable land less than one acre and as farming being major source of income, they are not able to earn a lot. Villagers from plane area of village1have more options of cash crop and seasonal vegetables as compared to that of village 2. Also, From the above figures it can be concluded that the SC and ST people of both the villages have low level of income i.e. below Rs

12,000 due to which all of them are not able to afford Pakka house and other facilities like latrine and kitchen etc. People are not able to save more than Rs 2000 a month in both the villages. As road is the only mean of transportation, but due to low income, majority of people in both the villages are not able to afford two-wheeler and four-wheeler vehicles.

Besides all these, maximum number of people have availed PM Jan Dhan Yojana, as percentage of Bank accounts are more in both the villages. Also, number of ration card is more which means they are getting rations provided by the government. Maximum number of households is having mobile phones but in case of computers, this number is low in both the villages and consequently low computer literacy is observed. Internet facilities availed by peoples are good in numbers and most of the users are youngsters which they mostly use it for social media. TV is present in maximum number of households in both the villages. Online services are yet to be availed by most of the households as they are unaware of the services like online billing, recharge, updation of Aadhaar etc.

The results of the present paper provide valuable insights for the design of suitable framework to overcome some of the highlighted problems of both the villages though technology transfer and digitization.

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