Lecture Notes in Civil Engineering

Arvind Kumar Agnihotri
Krishna R. Reddy
Ajay Bansal *Editors*

Recycled Waste Materials

Proceedings of EGRWSE 2018

Springer

Lecture Notes in Civil Engineering

Volume 32

Indexed by Scopus

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ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-13-7016-8 ISBN 978-981-13-7017-5 (eBook)
https://doi.org/10.1007/978-981-13-7017-5

Library of Congress Control Number: 2019933908

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

The ever-increasing population growth has resulted in a tremendous load on the natural resources. Added to this, the rapid industrialization and urbanization activities are making the situation grim. All these developments have been at a heavy cost in terms of deteriorated environmental conditions. An adverse impact on the environment has drawn the attention of technocrats and researchers to look for technologies that are sustainable. As a consequence of a huge domestic and industrial waste and deteriorating environmental conditions in general, statutory regulatory bodies have become more active and the pollution-related norms have become more stringent than ever before. We are running a race against time to look for technologies with sustainable viability. The recycling of waste materials is one of the key features of sustainability.

The growing quantities and types of waste materials, shortage of landfill spaces, and lack of natural earth materials highlight the urgency of finding innovative ways of recycling and reusing waste materials. Additionally, recycling and subsequent reuse of waste materials can reduce the demand for natural resources, which can ultimately lead to a more sustainable environment. The construction industry is a massive consumer of natural resources and a huge waste producer as well. The high value of raw material consumption in the construction industry becomes one of the main factors that causes environmental damage and pollution to our mother earth and the depletion of natural and mineral resources.

Waste material has been defined as any type of material by product of human and industrial activities that has no lasting value. The amount of waste material is increasing day by day with an increase in population. It is a general practice to dump these waste materials on lands, which creates environmental and social problems. The reuse of these waste materials is one of the effective ways of minimizing such problems. The bulk use of wastes like pond ash, rice husk ash, fly ash, and tire wastes as admixture is now becoming popular in the construction of geotechnical structures. Researchers have shown that these materials can be used in the subgrade of roads, embankments of roads, as fill materials in retaining walls, etc.

The greatest challenge before the processing and manufacturing industries is the disposal of the residual waste products. Waste products that are generally toxic, ignitable, corrosive, or reactive have detrimental environmental consequences. Thus, the disposal of industrial wastes is a major issue for the present generation. This major issue requires an effective, economic, and environment-friendly methods to tackle with the disposal of the residual industrial waste products. One of the common and feasible ways to utilize these waste products is to go for the construction of roads, highways, and embankments. If these materials can be suitably utilized in the construction of roads, highways, and embankments, then the pollution problem caused by the industrial wastes can be greatly reduced.

Recycling waste materials is beneficial in many ways.

- Recycling helps protect the environment. This is because the recyclable waste materials would have been burned or ended up in the landfill. Pollution of the air, land, water, and soil is reduced.
- Recycling conserves natural resources. Recycling more waste means we do not depend too much on raw (natural) resources, which are already massively depleted. Recycling saves energy.
- It takes more energy to produce items with raw materials than from recycling used materials. This means we are more energy efficient, and the prices of products can come down.
- Recycling creates jobs. People are employed to collect, sort, and work in recycling companies. Others also get jobs with businesses that work with these recycling units. There can be a ripple of jobs in the municipality.

This book covers a variety of such multidisciplinary articles which will be very useful for students, working professionals, practitioners, and researchers.

Jalandhar, India — Arvind Kumar Agnihotri
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About the Editors

Arvind Kumar Agnihotri is Professor of Civil Engineering at NIT Jalandhar. He completed his Ph.D. from University of Roorkee (1998), M.Tech. from NIT Kurukshetra (1989) and B.E. from Panjab University Chandigarh (1987). He possesses a work experience of around 29 years in research, teaching and academic administration, with several years spent holding key leadership positions. His areas of interest are Geotechnical and Geo-Environmental Engineering, Reinforced Earth (Geo-Synthetics and Geofibers), Ground Improvement and Soil-Structure-interaction. He has supervised nine Ph.D. Thesis and seven more are in progress. He has guided 45 M.Tech. dissertations. He has published more than 100 papers in international and National journals and conferences. He served as Head of Civil Engineering, Dean Academic, Dean (Planning and Development) at prestigious Dr. B. R. Ambedkar National Institute of Technology, Jalandhar. He is fellow/member of many professional organizations like ASCE, IGS, ISTE, Institution of Engineers, International Society of Soil Mechanics and Geotechnical Engineering and Indian Roads Congress. He is reviewer of many international journals of repute.

Krishna R. Reddy is a Professor of Civil and Environmental Engineering, the Director of Sustainable Engineering Research Laboratory and also the Director of the Geotechnical and Geo-Environmental Engineering Laboratory in the Department of Civil and Materials Engineering at the University of Illinois at Chicago. He is the author of three books: (1) *Geo-Environmental Engineering: Site Remediation, Waste Containment, and Emerging Waste Management Technologies*, (2) *Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater*, and (3) *Sustainable Remediation of Contaminated Sites*. He is also author of 182 journal papers, 15 edited books, ten book chapters, and 170 full conference papers. Dr. Reddy has given 160 invited presentations in the U.S.A. and 15 other countries. He has served or currently serves as an Associate Editor or Editorial Board Member of over ten different journals, including the ASCE and ASTM Journals, among others. He has received several awards for excellence in research and teaching, including the ASTM Hogentogler Award, the UIC Distinguished Researcher Award, the University of Illinois Scholar Award, and the University of Illinois Award for Excellence in Teaching. He is a Fellow of the American Society of Civil Engineers, a Diplomat of Geotechnical Engineering, and a Board Certified Environmental Engineer.

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Evaluation of Compressibility and Drainage Characteristics of Highly Plastic Clay Stabilized with Fly Ash and Stone Quarry Dust

Himanshu Yadav, Haidar Ali and V. P. Singh

Abstract Approximately, one-fifth parts of the soil deposit in India is covered with high compressible clay (i.e., Black cotton soil); due to high volume change behavior on changing moisture and poor drainage condition, such soil is classified as problematic soil and requires suitable modification before using it as a soil support. In this study, fly ash and stone quarry dust were used as stabilizing admixture to improve the mechanical behavior of soil, which reduce the waste disposal problem and the environmental pollution, and save the natural material (soil). Here, soil sample was collected from SH 102, B.P. Road, Allahabad and classified as CH. Fly ash was collected from Prayagraj Thermal Power Plant, Bara Allahabad (660 MW), and stone quarry dust was obtained from Shankargarh crushing unit, Allahabad. Three different types of samples were prepared in which soil was mixed with fly ash, stone quarry dust, and both in equal proportion in different percentages (i.e., 4, 8, 12, 16, 20, 25, and 30%) by dry mass separately. After proper mixing and aging of samples, standard consolidation test was carried out on each sample. The calculated values of compressibility characteristics (c_c, c_v) and permeability (k) have reflected considerable and justified results, in which coefficient of compressibility decreasing, coefficient of consolidation, and permeability increase with increasing mix proportion of differently used admixtures with different rates. The optimum percentages for all three different mixes have been determined and compared by considering a triple bottom line of the sustainability.

Keywords Consolidation · Compressibility characteristics · Stabilized soil · Fly ash · Quarry stone dust

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_1

1 Introduction

High volume change behavior on changing moisture content and poor drainage of expansive soils caused severe damages to the foundation and the structure over it. Aim of the study is to improve the volume change behavior and drainage behavior with the utilization of waste materials. Soil stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to commercially available admixtures that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (IRC: SP: 89-2010). In this study, fly ash and quarry stone dust are used as stabilizing material. Fly ash itself has little cementitious value but in the presence of moisture it reacts chemically and forms cementitious compounds and attributes to the improvement of strength and compressibility characteristics of soils (Bhuvaneshwari et al. 2005). Stone quarry dust is a waste material produced from aggregate crushing industries, disposal of which involves high cost and proper knowledge. Various researchers have reported significant improvement in properties of expansive soil when mixed with fly ash and stone quarry dust. Compression index, c_c, decreases with increase in various percentages of admixtures (i.e., Rice husk ash, fly ash, and quarry stone dust). Coefficient of consolidation c_v decreases with increase in loading for various percentages of admixtures (Jain and Puri 2013a). Coefficient of consolidation also increases with increase in the fly ash content. Compression index decreases appreciably with addition of fly ash indicating improvement in consolidation characteristics (Mir and Shridharan 2014).

2 Materials

2.1 Soil

The proposed site location for collection of soil, B.P Road, SH-102, Allahabad belongs to one of the deposits of expansive soil in Northern India. Soil sample was collected at a depth of 1.5 m from a borrow pit to avoid the organic matter.

2.2 Fly Ash

The sample collection of different types of ashes such as fly ash, bottom ash, and pond ash has different procedures. The sample of fly ash was directly collected from the storage point through a sampling pipe. Fly ash for the study was taken from Prayagraj Thermal Power Plant, Bara Allahabad (660 MW). The fly ash collected from the plant was light gray in color.

Table 1 Properties of materials (Singh et al. 2017)

Property	Natural soil	Fly ash	Stone quarry dust
Specific gravity	2.73	2.01	2.78
Liquid limit (%)	51	NA	NA
Plastic limit (%)	21	NA	NA
Plasticity index	30	Nonplastic	Nonplastic
Soil classification	CH	–	SP
Maximum dry density (gm/cc)	2.25	1.227	–
Optimum moisture content (%)	11.56	20.41	–

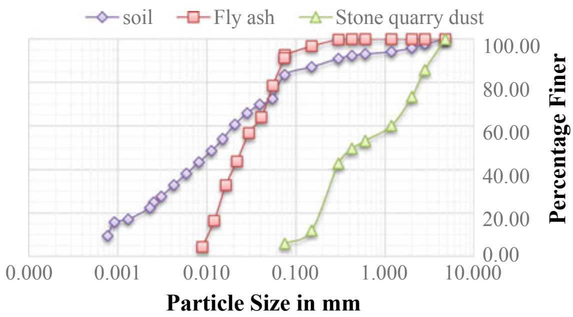


Fig. 1 Grain-size distribution curves for soil, fly ash, and stone quarry dust

2.3 Stone Quarry Dust

Stone quarry dust is a waste material produced from aggregate crushing industries. It was collected from the crushing units located in Shankargarh area of Allahabad which is about 10 km from the proposed site SH-102, B.P. Road, Allahabad. Index properties of the stone dust were determined as per IS codes. The stone dust is classified as SP.

The properties of materials are given in Table 1, and grain size distribution curves for materials are shown in Fig. 1.

3 Methodology

For this study, three different types of samples were made in which soil was mix with fly ash, stone quarry dust, and both in equal proportion (i.e., 4, 8, 12, 16, 20, 25, and 30%) by dry mass separately. Totally, 21 types of samples were prepared.

Table 2 Experimental program

Soil–fly ash mixes			Soil–stone quarry dust mixes			Soil–fly ash, stone quarry dust mixes			
Soil (%)	Fly ash (%)	Notations	Soil (%)	Stone quarry dust (%)	Notations	Soil (%)	Fly ash (%)	Stone quarry dust (%)	Notations
100	0	SF0	100	0	SQ0	100	0	0	SFQ0
96	4	SF4	96	4	SQ4	96	2	2	SFQ4
92	8	SF8	92	8	SQ8	92	4	4	SFQ8
88	12	SF12	88	12	SQ12	88	6	6	SFQ12
84	16	SF16	84	16	SQ16	84	8	8	SFQ16
80	20	SF20	80	20	SQ20	80	10	10	SFQ20
75	25	SF25	75	25	SQ25	75	12.5	12.5	SFQ25
70	30	SF30	70	30	SQ30	70	15	15	SFQ30

Standard consolidation tests were conducted on each sample, and consolidation characteristics and permeability of each sample were calculated. Here, admixture content is defined by the ratio of weight of admixture to the dry weight of natural clay soil expressed as a percentage, e.g., SF20 means soil with 20% fly ash by weight; and SFQ30 means soil having equal fly ash and quarry stone dust (15% fly ash and 15% stone quarry dust) (Table 2).

Sample Preparation: Heavy compaction for each mix was done as per IS 2720 (Part 8) (1987). Air-dried soil samples were compacted at maximum dry density (MDD) and corresponding optimum moisture content (OMC) in mold. The consolidation ring was penetrated into the compacted soil mold, and it was taken out and trimmed from both sides. Then specimen was assembled in consolidation cell, and test was performed for each sample similarly (IS: 2720 Part 15 1986).

4 Results and Discussion

4.1 Compressibility Characteristics

Compressibility characteristics, compression index, c_c, and coefficient of compressibility, c_v, are determined by standard procedure. Compression index determines the magnitude of settlement, while other tells about the rate of settlement.

4.1.1 Void Ratio and Compression Index

Figures 2, 3, and 4 show the void ratio (e)—effective pressure p curve for various mixes of soil with admixtures. It is also known as “e–log p curve.” The compression

Fig. 2 *e*–log *p* curve for soil mixed with fly ash

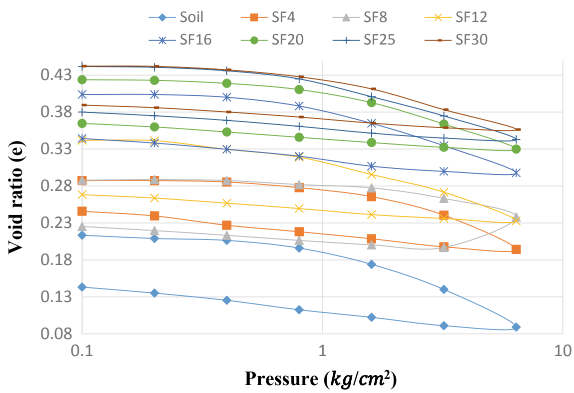
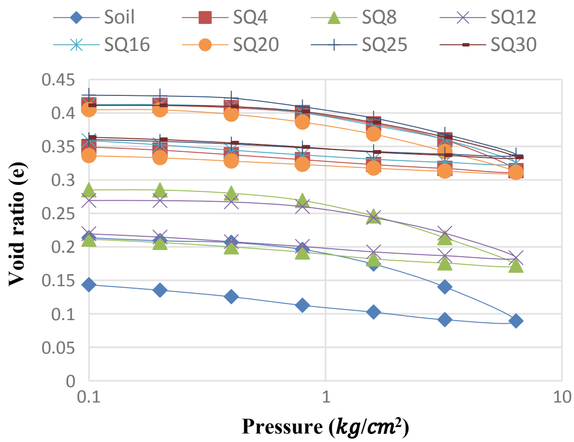


Fig. 3 *e*–log *p* curve for soil mixed with stone quarry dust



index, c_c, is the slope of linear portion of "*e*–log *p* curve" which indicates amount of settlement of soil or soil mix.

Compression index decreases with increase in admixture content and variation of compression index with different percentages of admixture (as shown in Fig. 5). The compression index, C_C, decreases with increase in percentage of fly ash and bottom coal ash (Jain and Puri 2013b).

4.1.2 Coefficient of Consolidation, c_v

Coefficient of consolidation, c_v, has been determined for different percentages of admixtures at different loading pressures (1.6, 3.2, and 6.4 kg/cm^2). Casagrande's logarithm of time fitting method was used for the calculation of t_{50} which was further used to calculate the value of coefficient of consolidation, c_v. Its value increases with increase in percentage of admixture because the soil is moving toward the courser

Fig. 4 *e*–log *p* curve for soil mixed with both fly ash and stone quarry dust

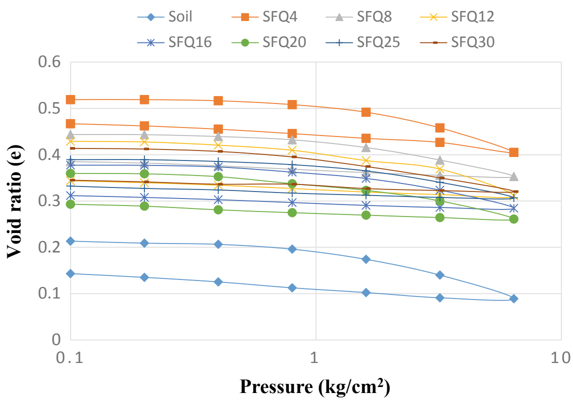
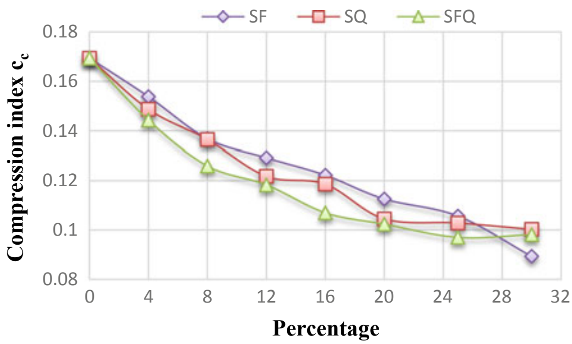


Fig. 5 Variation of compression index, c_c, with different percentages of admixture



material or turns to more granular. This will make the process of consolidation faster. Coefficient of consolidation decreases with increase in loading. It means time required for the soil to reach a given degree of consolidation will increase with increase in loading. Variation of coefficient of consolidation, c_v, is shown in Figs. 6, 7, and 8. The coefficient of consolidation, c_v, decreases with increase in loading

Fig. 6 Variation of coefficient of consolidation with percentage of fly ash

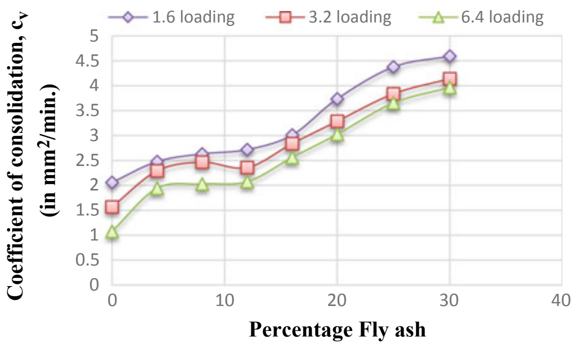


Fig. 7 Variation of coefficient of consolidation with percentage of stone quarry dust

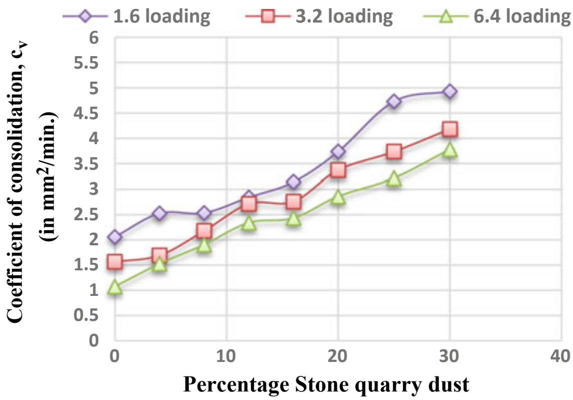
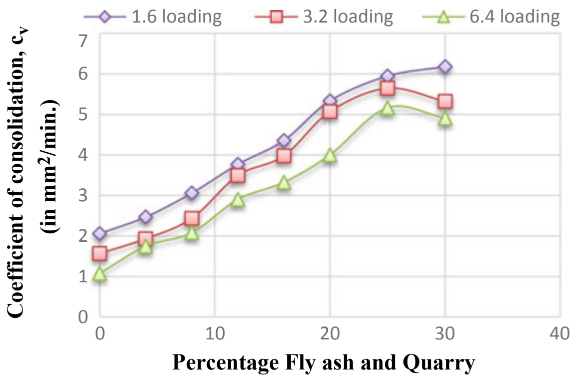


Fig. 8 Variation of coefficient of consolidation with percentage of fly ash stone quarry dust



pressure (Eberemu and Sada 2013). The coefficient of consolidation, c_v, increases with percentage of admixture increases (Narsihmarao et al. 2014).

4.2 *Coefficient of Permeability, k*

The coefficient of permeability, *k,* was calculated for soil with different percentages of admixture at different loadings. Its value was evaluated using formula $k = c_v m_v \Upsilon_w$.

The value of coefficient of permeability increases with increase in the percentage of admixture because soil is getting converted into granular when mixed with admixture and its value decreases with increase in loading. Drainage properties, i.e., coefficient of permeability, *k,* of soil increase by 102% with the increase in the fly ash content to 30% and increases by 120% with the increase in the dolochar content to 30% (Mohanty et al. 2016). Coefficient of permeability, *k,* is directly proportional to the coefficient of consolidation, c_v. The variation of coefficient of permeability, *k,* with respect to percentage of admixture is plotted in Figs. 9, 10, and 11.

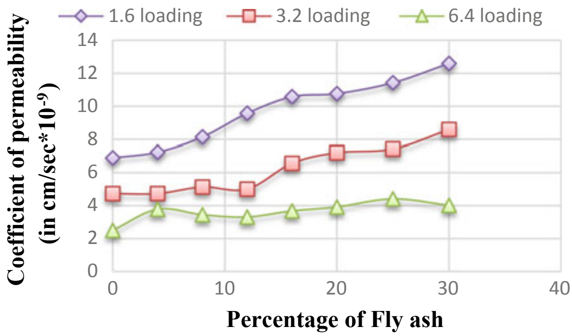


Fig. 9 Variation of coefficient of permeability, *k*, with percentage of fly ash

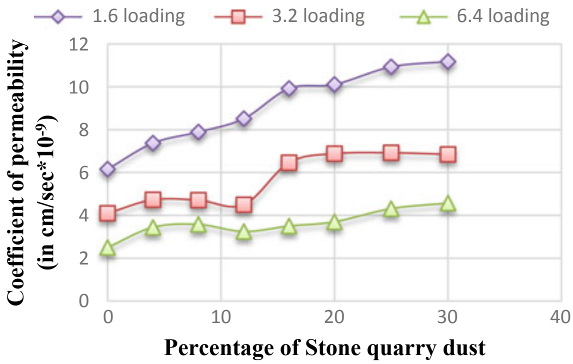


Fig. 10 Variation of coefficient of permeability, *k*, with percentage of stone quarry dust

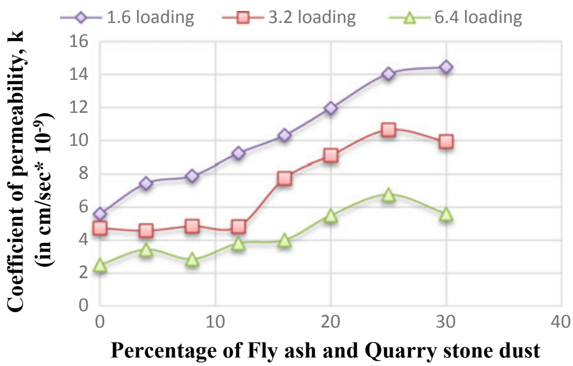


Fig. 11 Variation of coefficient of permeability, *k*, with percentage of fly ash and stone quarry dust

5 Conclusions

1. Compression index C_C decreases from **0.1694** to **0.08936** when fly ash added up to 30% and its value decreases to **0.1003** for 30% quarry stone dust. For mixture of both fly ash and quarry stone dust, its value decreases to **0.09815**.

2. SQ25 and SQ30 are also having less value of compression index Cc than SQ20, but reduction in compression index Cc is quite lower and addition of higher percentage of mixture will require more cost.
3. So, **SQ20** is better than SQ25 and SQ30. Similarly, SFQ20 and SFQ25 also have less value of compression index Cc than SFQ16, but reduction in compression index Cc is very less. So, we will prefer **SFQ16** over SFQ20 and SFQ25.
4. So, SQ20 and SFQ16 are two alternatives for reduction in compression index C_C.
5. Reduction in compression index C_C increases in percentage of waste material which means there will be reduction in the settlement of soil after stabilization.
6. Coefficient of consolidation, c_v, increases with increase in percentage of admixture added and decreases with loading. It represents the rate of consolidation which means for higher percentage of admixture rate of consolidation is higher.
7. Coefficient of permeability, *k,* increases with increase in the percentage of admixture because soil is getting more granular with addition of admixture. It decreases with increase in loading pressure.

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Strength Characteristics of Clayey Soil Stabilized with Nano-silica

Abhay Malik, Shiv Om Puri, Neeru Singla and Sanjeev Naval

Abstract Due to rapid growth in urbanization and industrialization, waste utilization becomes an important aspect of the conservation of the environment. With the progression in the field of Geotechnical Engineering, waste materials like rice husk ash, fly ash, agro-industry waste, silica fume, etc. find their way in soil improvement techniques. Soil, in its natural state, at a construction site may not always be suitable for supporting structures. The constructions at a site composed of clay possess great challenge due to settlement. This research is intended to study the effect of adding nano-silica on the strength characteristics of clayey soil. A series of laboratory experiments have been conducted on the virgin soil and the soil blended with nano-silica content at 5–20% by weight of dry soil. The experimental results showed an increase in optimum moisture content with the increase in nano-silica content. It was found that unconfined compressive strength also showed an increase in the addition of stabilizing material. From the investigation, it can be concluded that nano-silica particles have a potential to improve the engineering properties of the clayey soil along with its proper utilization from the environmental point of view.

Keywords Clayey soil · Soil stabilization · Nano-silica · Compaction · UCS

1 Introduction

In India, annually huge quantities of wastes are produced and dumped at open sites or discharged into rivers which are not treated and mishandled. Consequently, available land resources for the construction of civil engineering structures are reduced. The

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_2

remaining sites where constructions are carried on clayey soils may not always be totally suitable for supporting structures in its natural state. The usage of local soils in construction schemes is currently in limelight due to rapidly increasing prices of premium materials. These situations lead to the development of ground improvement techniques such as soil stabilization. With the development in engineering and technology, researchers have utilized the waste materials to stabilize the soils for better and improved engineering properties (Singh and Mittal 2014; Rastogi and Sharma 2012; Bachchhas and Soni 2017). The engineering properties of soils and their strength characteristics are of great concern to engineers engaged in design and construction. The improvements in parameters like Proctor compaction, shear strength, unconfined compression strength, and swell characteristics are likely to be expected for the construction of structures on unfavorable soil conditions. Recent studies define the use of waste materials like rice husk ash, sawdust ash, fly ash, coir fiber, agro waste, and even rubber tire waste for the improvement of said parameters (Butt et al. 2016; Raj and Kumar 2017; Kumar and Preethi 2014). Advancements in nanotechnology have made its way in geotechnical engineering by studying the soil structure in nanometer scale to gain better understanding of soil nature (Hareesh and Kumar 2016). Nanoparticles are used as an additive to the soil and after effects on their engineering properties are studied. A better understanding of these characteristics will enhance the usage of these materials in geotechnical engineering works, thereby making clays suitable for structures (Alireza et al. 2013). For satisfactory performance of a structure, the soil beneath must possess high strength to prevent the structure against failure. The clayey soil has high shrinkage and swelling potential; thus, the strength of the soil is relatively low. It has been witnessed by several studies that addition of nanomaterial had a positive influence on the expansive and shrinkage behavior of the soil (Taha and Taha 2012). The quality of soil has a huge effect on the structure and design of a foundation of a building or roads or earth dams. At present, development of infrastructure will encompass the areas with the types of soil which may be unsuitable for construction. The clayey soil undergoes volume changes when they originate in contact with water. Hence, it has become necessary to modify the properties of clayey soil. The improvement in engineering properties of clayey soil such as increase in shear strength, stiffness, and durability, and reduction in swelling potential of wet clayey soils can be done by soil stabilization (Puri 2012). Materials such as lime and silica fume are also being used to stabilize weak soils. These materials too had positive effects on the permeability, swelling, and compressive strength characteristics of the clayey soils (Pham and Nguyen 2014; Kalkan and Akbulut 2004; Fattah et al. 2014; Alrubaye et al. 2016; Pashabavandpouri and Jahangiri 2015). In the present work, strength characteristics have been studied for clayey soil treated with nano-silica by conducting a series of experimental test procedures (Prakash and Jain 1999).

2 Materials and Methodology

For better understanding of previous trends and methodologies, an extensive review of literature was carried out. Soil stabilization paves way for improving the engineering properties of soils unsuitable for construction purposes. The materials collected from the respective sites for determination of different engineering properties are as follows.

2.1 Clayey Soil

The clay used in the experiments was collected from Samani, Traffic Police Post, GT Road, Kurukshetra, Haryana. The soil was classified as CLas per Indian Standards (IS: 1498-1970). The soil properties are given in Table 1.

2.2 Nano-silica

Nano-silica was purchased from Adinath Industries, Ajmer, Rajasthan, India. Nowadays, nano-silica has its application in various industries such as paint, plastic, ceramics porcelain, gypsum, batteries, adhesives, fiber, glass, and many other fields. The specifications of nano-silica are reported in Table 2.

2.3 Laboratory Tests

Virgin clayey soil was mixed with nano-silica at various percentages, i.e., 5, 10, 15, and 20% by weight of dry soil. Experimental tests such as Atterberg limit, specific gravity, compaction test, and unconfined compressive strength were conducted as per relevant IS code.

Table 1 Geotechnical parameters

Grain size distribution	Gravel (%)	0
	Sand (%)	7.65
	Clay + Silt (%)	92.35
Specific gravity		2.48
Liquid limit		51
Plastic limit		28
Plasticity index		23
IS classification		MH
Optimum moisture content (OMC) (%)		21.8
Maximum dry density (MDD) (kN/m^3)		14.8
Unconfined compressive strength, q_u (kN/m^2)		132.1

Table 2 Specifications of nano-silica

B.E.T. surface area	200 m^2/g
PH (4% aqueous slurry)	3.7–4.3
325 mesh residue (44 μ)	0.02% max.
Bulk density	3.0 lb/ft^3 max.
Pour density	50 g/L tap density
Loss on heating	<1.5% max.
Loss on ignition (at 1000 °C)	<2 wt%
Specific gravity	2.2 g/cm^3
Wt. per gallon	18.3 lb
Refractive index	1.46
X-ray form	Amorphous
Assay (% SiO_2)	>99.8
Oil absorption	~350 g/100 g oil
Average particle length	0.2–0.3 μ

2.4 Composition of Specimens

Specimens of parent clay and clay treated with 5, 10, 15, and 20% by weight of nano-silica particles were prepared at maximum dry density and optimum moisture content as per Indian Standards (IS: 2720-Part VII) (1974).

2.5 Compaction

Oven-dried sample at approximate water content was mixed thoroughly with and without additive at different moisture contents to determine the optimum moisture content. Soil was placed in the Proctor mold and compacted in three layers giving 25 blows per layer with 2.5 kg rammer uniformly distributed over the surface of each layer. The collar was removed, and the compacted soil was trimmed. This series was continued until a decrease in wet unit weight of compacted soil was observed.

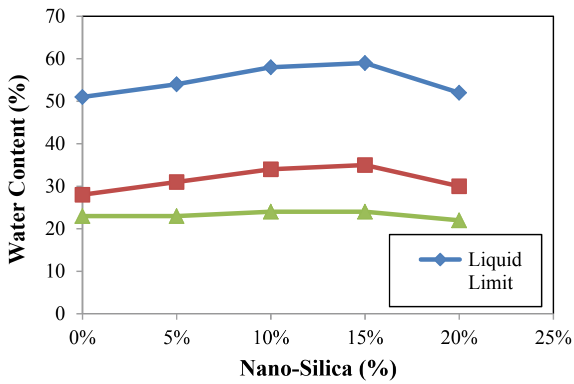
2.6 Unconfined Compressive Strength

Specimens prepared at optimum moisture content and maximum dry density were used in unconfined compression testing machine, where a provided ring is used to measure the compressive force. There were two plates, having a seating arrangement for the specimen. The specimen was placed on the bottom plate such that it makes contact with the upper plate. The dial gauge and provided ring are set to null. Compressive load is applied to the specimen by turning the handle.

3 Results and Discussions

With the increase in percentage of nano-silica, increase in liquid limit was observed up to 15% of the stabilizer, after which it decreased as shown in Fig. 1. Also, Fig. 2 shows the decrease in specific gravity of the soil from 2.4882 to 2.4476 with the increase in the percentage of the stabilizer. The compaction tests were carried out on virgin soil and soil treated with nano-silica. The variations of optimum moisture content (OMC) and maximum dry density (MDD) are shown in Fig. 3. OMC showed an increase with the increasing silica content, whereas MDD decreased with increasing silica content. The unconfined compressive strength increased from 132.1 to 174.6 kN/m^2 with the increase in nano-silica content, i.e., 0–20% as observed in Fig. 4.

Fig. 1 Effect of nano-silica on Atterberg limits



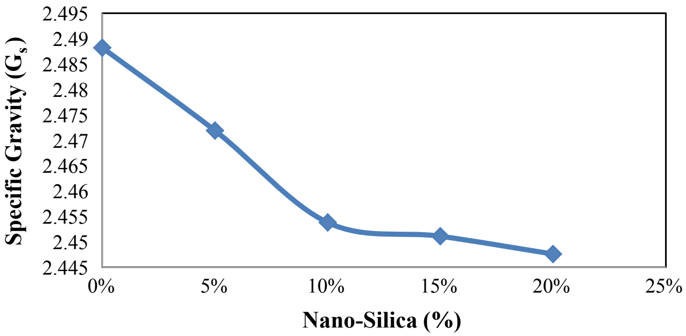


Fig. 2 Effect of nano-silica on specific gravity of soil

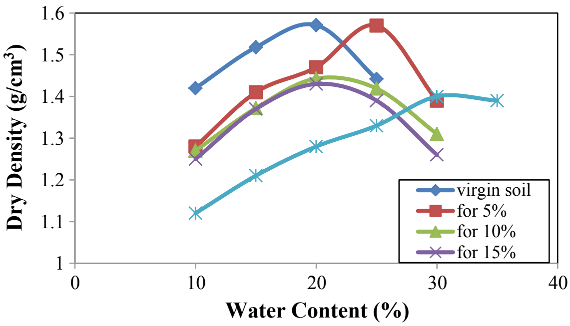


Fig. 3 Effect of nano-silica on compaction characteristics of soil

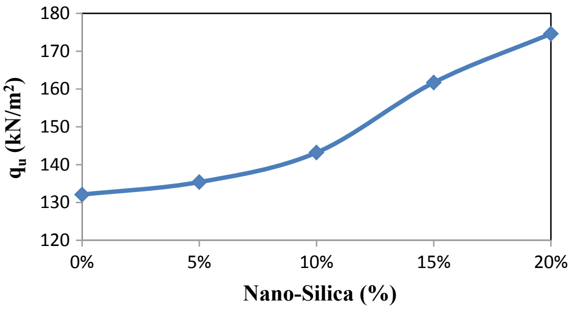


Fig. 4 Effect of nano-silica on unconfined compressive strength (q_u)

4 Conclusions

The study shows the influence of nano-silica on the strength characteristics of the locally available clayey soil. The following conclusions have been drawn on the basis of experimental work carried out in this study:

1. An increase in liquid limit and plastic limit was observed on addition of nano-silica particles.
2. Increase in percentage of nano-silica content showed a decrease in specific gravity of the soil.
3. The addition of nano-silica particles to the parent clay resulted in an increase in optimum moisture content and decrease in maximum dry density with the increase in nano-silica content.
4. The unconfined compressive strength was the clayey soil increased significantly with the increase in the percentage of the stabilizer.
5. From the investigations, it can be concluded that nano-silica has the tendency to modify the engineering properties up to certain extent. But on the other hand, cost is the concern.

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Chemical Analysis Procedures for Determining the Dispersion Behaviour of Red Mud

N. Gangadhara Reddy, B. Hanumantha Rao and Krishna R. Reddy

Abstract The present study deals with evaluating the dispersion characteristics of red mud by adapting to chemical analysis methods. For this purpose, the leached aqueous solution has been extracted by suitably diluting the red mud particles with distilled water. The parameters like sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP), which are strong indicators of flocculation or dispersion stability, pH, zeta potential and electrical conductivity, have been measured and employed to assess the dispersive nature of the red mud. The values of SAR and ESP are measured as 54.9% and 98.3%, respectively. The very high values of SAR and ESP demonstrate that the red mud tends to exhibit moderate to high dispersive behaviour. Usually, dispersive soils are not selected as a source material for the construction of earth structures, without adequately stabilizing or treating with chemical additives. As such, the results emphasize that there is a need for treating the red mud with additives like gypsum or alum for mitigating the dispersion behaviour, before its intended use.

1 Introduction

Minimization and utilization of industrial wastes, as a substitute for natural materials, is essential to safeguard the geoenvironment and to avoid the excessive exploitation of nature. Red mud could be one of the potential resource materials for constructing roads, pavements, embankments, or levees, as its geotechnical properties resemble that of conventional soils. Red mud is a slurry waste left behind after extracting alumina from bauxite ore and it is strongly alkaline, with a pH ranging from 10.5 to 13 (Rao and Reddy 2017). Due to the high alkalinity, its consumption in geotechnical engineering applications is almost negligible. As against natural soils, in which the presence of divalent cations (Ca^{2+} and Mg^{2+}) are generally dominant, the red mud

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_3

primarily contains monovalent Na^+ ions. The dominance of monovalent ions, instead of other cations (divalent cations) in the red mud, makes it susceptible to dispersion and thus, tends to erode in the presence of flowing water.

Usually, soils having inadequate attractive forces, i.e. weak van der Waals forces, between the particles and excess sodium ions are the most vulnerable to dispersion and the erosion phenomenon under saturated conditions (Sherard et al. 1976; Ouhadi and Goodarzi 2006; Parameswaran and Sivapullaiah 2017). Many earth dams, hydraulic structures, roadways, embankments, etc. have suffered serious erosion problems, and consequently, failed (Bell and Maud 1994). As such, the magnitude of the erosion phenomenon can become intense with the use of dispersive kind of soils. Therefore, prevention of failures caused by the dispersibility of soils has become one of the major concerns in the geotechnical engineering field.

The extent of dispersion depends on mineralogy, clay chemistry as well as the total dissolved salts (TDS), exchangeable sodium percentage (ESP), sodium absorption ratio (SAR) and electrical conductivity (EC) (Bhuvaneshwari et al. 2007; Harmse and Gerber 1988). Studies carried out by Gore (2015) and Rout et al. (2012) on the red mud waste found that it is intermediate to highly dispersive in nature. These studies further also reported negative-free swell index (N-FSI) for the red mud waste. Generally, conventional soils yield positive-free swell index values, which indicate an increase in the volume of the deposited sediment with respect to its original volume. Contrarily, the red mud exhibited N-FSI value, indicating that the material can be characterized as dispersible (Rout et al. 2012).

Generally, the routine geotechnical characterization studies do not reveal the dispersive behaviour of a soil/waste. Therefore, researchers have developed physical tests such as crumb test, double hydrometer test and pinhole test and chemical analysis procedures to assess the dispersivity of a material (Volk 1937; Umesh et al. 2011). This paper focuses on evaluating the dispersion behaviour of the red mud waste, following the chemical analysis methods. Details of the various chemical analysis methods used in the study are given in the paper. Though many researchers report geotechnical properties of the red mud, investigations pertinent to understanding other important properties such as dispersion and erosion are very limited. Understanding of these properties is essential and often becomes critical when asserting the suitability of a material for constructing earthen structures or as a substitute for natural materials.

2 Materials and Methods

2.1 Physical Properties of Red Mud

The red mud samples used for the study were collected from the red mud pond of NALCO, Damanjodi, India. The physical properties of the waste were determined as per ASTM standards. The specific gravity was measured as 3.05, and the gradational characteristics show that the material is dominated with silt fraction (i.e. 72%), followed by clay and sand fractions at 23 and 5%. The liquid limit, plastic limit and plasticity index were found within the range of 41–43%, 36–38% and 3–7%, respectively. As per Unified Soil Classification System (USCS), red mud can be classified as inorganic silt of low plasticity (ML).

2.2 Chemical Properties of the Red Mud

2.2.1 Oxide Compositions

Table 1 shows the chemical compositions, established using XRF technique, of the waste used in the study. The proportion of Fe_2O_3 is found to be around 48%, which is significantly higher than the remaining chemical compositions. Al_2O_3 and SiO_2 are the major chemical oxides after Fe_2O_3 composition. Other oxides like Na_2O, TiO_2, CaO, etc. are also detected in small to trace levels.

2.2.2 pH and Electrical Conductivity

pH and EC measurements were made on aqueous solutions prepared with a liquid to solid ratio of 1:1, as per the guidelines of ASTM D4972. All measurements were made at an ambient temperature of 25 ± 2 °C. The values of pH and EC measured are reported in Table 2.

2.2.3 Measurement of TDS, ESP and SAR

The dispersion behaviour of red mud can be assessed using the chemical parameters like TDS, ESP and SAR. These measurements are made on the aqueous solution

Table 1 Oxide compositions and constituent analytes in the red mud waste

Oxide composition	% by weight	Analyte	Concentration (Mg/L)	Concentration (Meq/L)
Fe_2O_3	48.90	Calcium (Ca)	3.1	0.155
Al_2O_3	18.96	Magnesium (Mg)	0.32	0.0256
SiO_2	18.35	Potassium (K)	1.5	0.107
TiO_2	3.69	Sodium (Na)	380	16.5224
Na_2O	4.80			
CaO	1.52			
Others	3.37			

Table 2 Chemical analysis of extracted aqueous solution

Property	Value
pH	10.8–11.4
Electrical conductivity, EC (mS/cm)	8.43–8.45
TDS (meq/L)	16.81
SAR value	54.9
Exchangeable sodium percent, ESP (%)	98.3
Zeta potential, ζ (mV)	−45

extracted by adding 70 g of oven-dried sample to 1400 mL of distilled water (i.e. 1:20 ratio), by agitating the suspension for a period of 18 h in accordance with the ASTM-D3987 standard. The analyte extracted further analysed using ICP-MS in order to determine the concentration of cations such as Ca, Mg, K and Na. The elements analyzed with respective concentrations meausred are listed in Table 1.

Based on the cations present in the red mud aqueous solutions, TDS, ESP and SAR values were calculated using the following equations:

$$\mathrm{TDS} = \left(\mathrm{Na}^{+} + \mathrm{Mg}^{2+} + \mathrm{K}^{+} + \mathrm{Ca}^{2+}\right) \tag{1}$$

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}}} \tag{2}$$

$$\mathrm{ESP} = \frac{\mathrm{Na}^{+}}{\mathrm{Na}^{+} + \mathrm{Mg}^{2+} + \mathrm{Ca}^{2+} + \mathrm{K}^{+}} \tag{3}$$

Using the concentration of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} as reported in Table 1, the values of TDS, SAR and ESP are calculated and listed in Table 2.

2.2.4 Zeta Potential Measurements (ζ)

Zeta potential measurements have been performed using Zetasizer Nano ZS90 (make, Malvern, UK) and in aqueous solutions extracted at a liquid to solid ratio of 100. The value of zeta potential measured is listed in Table 2.

3 Results and Discussion

Generally, pH of a soil is said to be master variable. As such, the same for the red mud waste is measured above 10, which is remarkably high as compared to natural soils. The high value of pH is attributed to the presence of NaOH, which is added during the extraction of alumina from bauxite ore. Many studies report that pH is one of the parameters that strongly influence the dispersion or flocculation behaviour of particles. It can be noticed that the measured EC is also quite high, i.e. above 8 mS/cm for the red mud. The high EC might be due to the greater concentration of Na^+ ions, which might be presented in the solid phase. The contribution of other cations such as Ca^{2+} and Mg^{2+} does not seem to contribute significantly to the EC, as their solubility is very low at pH above 10 (Grafe et al. 2011). Chemical analysis on solution evidently shows that Na^+ is substantially higher than their counterpart cations (i.e. Mg^{2+}, Ca^{2+} and K^+).

ESP for the waste used in the study was measured as 98.3%. The considerably high value of ESP may be due to high soluble monovalent cations (i.e. sodium ions) and at the same time low levels of divalent cations (i.e. Ca^{2+} and Mg^{2+}). Knodel (1991) has proposed a scheme to classify the dispersive nature of a material based on the relationship between ESP and TDS, as depicted in Fig. 1. According to this method, soils in which ESP is found above 60% can be categorized as dispersive soils. From Fig. 1, it can be observed that the values of ESP and TDS for the red mud waste fall in Zone A, classifying it as dispersive material. This finding well corroborates with the results of Courtney and Timpson (2005), who have reported the value of ESP greater than 60% for the red mud belonging to a different source. Similarly, Northcote and Srene (1972) highlighted that the soils with ESP above 6% are dispersive in nature, while Gerber and Harmse (1987) also defined that the soils having ESP greater than 15% are highly dispersive soil. Incidentally, all the three methods categorize the red mud waste that is dispersive in nature.

Studies by Rengasamy et al. (1984) demonstrate that soils with SAR value of greater than three are dispersible, while that of by Aitchison and Wood (1965) shows

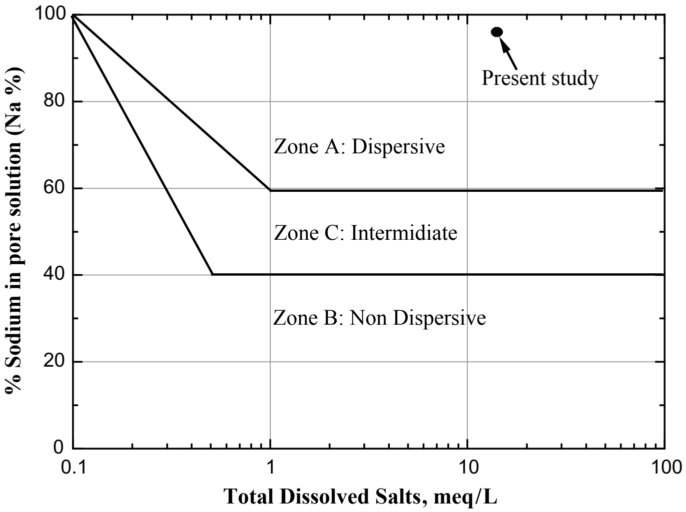

Fig. 1 Classification of dispersive nature of the red mud based on percent sodium versus TDS plot (Knodel 1991)

that soils with SAR value of greater than two are dispersive in nature. Incidentally, the SAR value for the red mud was measured as 54.9, which is appreciably higher than the values proposed by Rengasamy et al. (1984) and Aitchison and Wood (1965). This clearly again confirms a fact that the red mud is dispersive in nature.

Previous studies document that if Ca/Mg ratio of a particular soil is less than 1, it may be capable of dispersing (Premkumar et al. 2016). This phenomenon has been linked to potassium having monovalent cations with low flocculating power. It is important to note that the ratio of Ca/Mg for the red mud is found as 9.7, which is substantially greater than 1 and yet, it exhibited dispersion behaviour. The reason behind this may be linked to the significant amount of Na^+ monovalent cations, the dominance of which might be leading to very low flocculating power than other cations making the red mud tending to show the high dispersion. It is worth mentioned here that the flocculating power of Na^+ (i.e. 1.0) is quite close to that of K^+ (i.e. 1.7), while flocculating power for Mg^{2+} and Ca^{2+} is considerable high of 27 and 43, respectively.

As such, the various chemical analysis methods employed proved the fact that the red mud exhibits dispersion behaviour.

4 Challenges and Remediation

In practice, dispersive soils tend to exhibit low bearing capacity and low stability due to the presence of excessive monovalent Na^+ cations. Studies highlight many varieties of wastes (e.g. fly ash) even in the scenario of falling into the category of dispersive material, but extensively being used in the construction of earthen structures. In several instances, it becomes indispensable to use such materials as resource materials substitute to natural materials, however, after amending it with a suitable stabilizer(s) such as lime, cement, etc. Gypsum is another more effective additive than the lime for treating dispersive soils as it increases the electrolyte concentration and replaces Na^+ with Ca^{2+}, leading to flocculation effect, increased soil strength and hydraulic conductivity. Typical effects of treatment with gypsum include decrease in pH, electrical conductivity and soluble Ca^{2+} (Hardie 2009).

Alum has effectively been used for remediating the dispersion and erosion phenomena for some time. As the alum is acidic (pH 4–5), treatment of materials like red mud using it seems a promising and viable option for reducing the pH and mitigating the dispersion behaviour. Additionally, studies by Rout et al. (2012) and Gore (2015) have recommended covering the red mud with locally available soils to avoid dispersion.

It is, therefore, logical to devise an appropriate mechanism that could potentially avoid dispersion of the red mud waste to a degree where it becomes safe to use it in earthen structures. In addition, the embankment usually when made using fly ash, it is covered with natural soil to protect it from erosion. The same practice can also be implemented for the red mud waste, when it is used as a substitute to natural materials for constructing earthen structures, however, after treating it with alum or gypsum.

5 Conclusions

In the present study, dispersive behaviour of the red mud waste is investigated based on methods pertinent to chemical analyses. The various methods employed in the study clearly demonstrate that the waste exhibits dispersion behaviour. It has been noticed that the values of TDS (16.8 meq/L), SAR (54.9) and ESP (98.3%) obtained from the waste are extremely greater than those of natural soils. As such, the results recommend stabilization of the red mud with a suitable chemical additive, which would not only prevent the material showing dispersion but also safeguard the earthen structure. Alternatively, the beneficial utilization of the waste can be promoted by encompassing the red mud waste with a suitable natural soil.

Acknowledgements The authors are grateful to Science and Engineering Research Board (SERB), Department of Science and Technology (DST), Government of India, for the financial support (Grant No.: SB/FTP/ETA-0297/2013) to carry out this research work.

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Study and Analysis of Characteristics of Construction and Demolition Waste in Highway Pavements

Nupur Jain and Tripta Goyal

Abstract Recycled Concrete Aggregates (RCA) and Recycled Asphalt Pavements (RAP) are the most easily available "Construction and Demolition (C&D)" waste materials. Research work has established that the volumetric properties of bituminous mixes, i.e., bulk density, percentage voids in mineral aggregates, voids filled with bitumen, and the bitumen film thickness, are complementarily affected by the use of RCA & RAP. Studies have been conducted on dense bituminous mixes prepared with natural aggregates (NA) to analyze the effect of field compaction on the pavement life, using "Extended Marshall Compaction Test." However, the performance characteristics of RCA and RAP substituted bituminous mixes, so as to ensure that the pavement material does not undergo premature failure due to surface bleeding and plastic deformation, remain under-researched. In this study, the performance characteristics of "Dense-Graded Bituminous Mix" prepared by substitution of natural aggregates (NA) by RCA and RAP have been studied. Laboratory experiments have been done by preparing Marshall samples at various bitumen contents corresponding to different compaction efforts. The effect of variation in either of the factors on Marshall properties has thereafter been analyzed.

Keywords Recycled concrete aggregates · Recycled asphalt pavement · Extended marshall compaction test · Surface bleeding · Plastic deformation · Dense-graded bituminous mix · Marshall samples

1 Introduction

The "Construction Industry of India" has been growing rapidly at an annual growth rate of about 10% over the past decade. The vast amount of waste generated during the construction and maintenance activities, along with that produced during the demolition and renovation of structures, bridges, roadways, etc., is classified as "Construction and Demolition (C&D) Waste." TIFAC's estimates associate a value

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_4

40–60 kg of C&D waste generation per sq. meter of new construction, 40–50 kg/m^2 for a building repair, and 300–500 kg/m^2 for demolition-related activities. In accordance with these values, in the year 2013 alone, India generated 50 million tons (MT) of C&D waste due to new construction, 193 MT due to repair and refurbishment and a huge 288 MT due to demolition-related work, giving a total annual value of 531MT of C&D waste (Construction and Demolition Waste 2014).

In the current scenario, most of the C&D waste produced is being dumped in the landfills, or being washed away by the water bodies, majorly—the rivers. This has a huge negative impact on the environment and is a major contributor to land and water pollutions. The restrictions on extraction of minerals and other materials such as sand, and the hard pathway to clearances have converged into a one-point problem—the demand and supply gap in the availability of naturally sourced building materials. Technological research for development of cost-effective techniques is therefore of utmost importance. The potential of use of C&D waste in providing a solution to this grave problem is, therefore, immense.

Several studies on the use of RCA and RAP in pavements base courses and subbase courses have been conducted by Paranavithana and Mohajerani (2006), Saeed and Hammons (2008), Ye et al. (2009), Mills-Beale and You (2010), Chen et al. (2011a, b), Marantzidis and Gidado (2011), Lee et al. (2012), Verian et al. (2013), Ayan et al. (2013), Al-Humeidawi (2014), and by Motter et al. (2015). The results obtained by these researchers are quite encouraging and are indicative of the feasibility of reuse of RCA and RAP. In the comparison drawn between RCA and RAP substitutions, by Rafi et al. (2014), on the properties of mix design, RAP and RCA were shown to be having complementary effects on the volume properties and the strength characteristics. Also, it was seen that the percentage of air voids increases with an increased level of substitution by RCA, whereas a decrease is observed with an increase in the substitution by RAP. Similarly, the stability/flow ratio is found to be more for RCA substitution and less for RAP substitution. Hence, there is a possibility of replacement by RCA and RAP in such a proportion, so as to neutralize each other's effects in order to attain a mix design having properties very similar to those of the mix prepared without any addition of RAP and RCA.

Additionally, many studies have also been conducted to test the performance of pavements. Awanti et al. (2006) imitated the field conditions in the laboratory using a "Modified Marshall Compaction Technique," to study the impact of aggregate compaction and alignment achieved in the field conditions by the action of rollers during pavement laying and that of pneumatic tires during the service life of the road. The results showed that the "Modified Compaction Technique" resulted in lesser voids in the mix and thus higher specific densities and higher stability values. However, the greater compaction achieved by the kneading action of the indented hammer also resulted in an increase in the flow values, thus indicating the possibility of plastic failure of the pavement. Sridhar et al. (2006) studied the effect of field compaction on the pavement life using the concept of "Refusal Density." Laboratory tests using the "Extended Marshall Compaction Method" were carried out to find out the optimum binder content for a dense bituminous mix, using different bitumen binder grades (60/70, 80/100, CRMB-60, PMB-40). The "Refusal Density" design of the mixes led to a decline in the optimum binder content required for the mix, so as to prevent premature failure of the pavement due to permanent plastic deformation.

There are no studies to evaluate the feasibility of use of RCA and RAP together as substitute materials and their corresponding performance during the design life. The objective of this study is to evaluate the possibility of replacement by RCA and RAP in such a proportion, so as to neutralize each other's effects in order to attain a mix design having properties very similar to those of the mix prepared without any addition of RAP and RCA. This has been studied by employing the "Extended Marshall Compaction test."

2 Methodology

2.1 Materials

In this study, the material used includes natural aggregates of sizes 10 and 20 mm, RCA, RAP, sand, and bitumen of penetration grade 80/100. RCA was obtained by manually crushing reminiscences of plain cement concrete. RAP was obtained by manually crushing the wearing coat layer of about 75 mm thickness.

2.2 Aggregate Specification Tests

The following specification tests were performed to ascertain their fundamental and engineering properties of aggregates:

1. Sieve analysis and test for flakiness and elongation indices on NA, RCA, and RAP in accordance with procedure specified by IS 2386 (1963) Part-I.
2. Test for specific gravity and water absorption of NA, RCA, and RAP in accordance with procedure specified by IS 2386 (1963) Part-III.
3. Impact value test on NA, RCA, and RAP in accordance with procedure specified by IS 2386 (1963) Part-IV.
4. Asphalt content test on RAP using the Asphalt Content tester machine.

A summary of all the relevant specification tests on aggregates, and their results are shown in Table 1. From Table 1, it can be seen that all the properties of NA and RAP lie within the values stipulated by Specification of MoRT&H (2013). The water absorption and impact value of RCA are significantly higher than the recommended values. Thus, to use RCA and RAP in conjunction, they need to be proportioned so that the values of water absorption and impact value meet the Specification of MoRT&H (2013). The water absorption and impact values that would be theoretically obtained on mixing RCA and RAP at different proportions were calculated. From this, the proportion that reaches the limiting value of either of the two properties (which

Table 1 Result of aggregate specification tests on NA, RCA, and RAP

Specification	NA		RCA	RAP	MORTH recommendations
	20 mm	10 mm			
Flakiness index (%)	15.39	13.91	2.14	4.85	–
Elongation index (%)	13.96	15.81	8.20	8.03	–
Combined index (%)	29.35	29.72	10.34	12.89	<30
Specific gravity	2.58	2.59	1.93	2.27	–
Water absorption (%)	1.16	1.12	4.47	0.82	<2
Impact value (%)	23.5	24.10	40.50	11.65	<27
Cleanliness (% finer than 75 μ)	0.47	0.44	2.3	2.52	<5
Asphalt content (%)	–	–	–	3.27	–

Table 2 Proportioning of mix of RCA and RAP

RCA in %	RAP in %	Water absorption of mix (%)	Impact value of mix (%)
10	90	1.18	14.54
20	80	1.55	17.42
30	70	*1.92*	20.30
40	60	2.28	23.19

is water absorption in this case) is chosen for performing further investigation. This is obtained at a value of use of RCA and RAP in the ratio 3:7. This can be seen in Table 2.

2.3 Grading Curve of Aggregate Composition

Specification of MoRT&H (2013)—provides two gradings for dense-graded bituminous mixes. The grading used in the current study is for 75 mm wearing coat thickness. The sieve analysis results in NA, mix of RCA, and RAP in the ratio of 3:7, and sand were tabulated and the resultant grading of the mix obtained at different proportions was compared with the prescribed grading requirements, until the most-fit grading curve was theoretically obtained. They resulted in the grading requirement being most closely met at 12% RCA, 28% RAP, 21% 20 mm aggregates, 15% 10 mm aggregates, and 24% sand. Figure 1 shows the curves representing the maximum and minimum percentages of grading and the grading obtained after proportioning, both, experimentally and theoretically achieved.

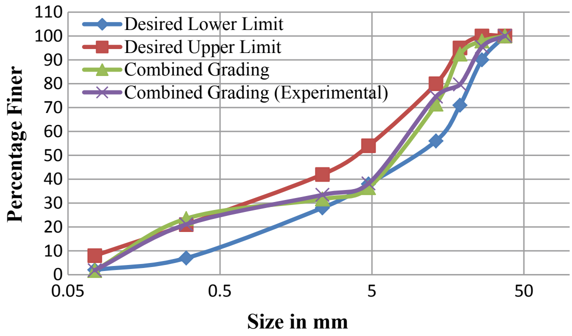

Fig. 1 Combined grading for DBM (75 mm thickness)

Table 3 Experimental setup

No. of samples	Compaction effort (no. of blows per face)				
	50	75	125	200	300
Bitumen content (%)					
3.0	2	2	2	2	2
3.5	2	2	2	2	2
4.0	2	2	2	2	2
4.5	2	2	2	2	2

2.4 Extended Marshall Compaction Test

Marshall samples were prepared at bitumen contents ranging from 3 to 4.5%, in increments of 0.5%. Corresponding to every bitumen content, two samples were prepared at compaction level of 50, 75, 125, 200, and 300 blows per face of the specimen. Thereafter, the volumetric properties, namely, "specific gravity," "percentage of voids filled with air (VFA)," and "percentage of voids filled with bitumen (VFB)" and specimen properties, i.e., "Marshall Stability Value" and "Flow Value" were evaluated. The experimental setup of the investigation showing the variation in the contents is given in Table 3.

3 Results and Discussion

3.1 Volumetric and Mechanical Properties of Marshall Mix Design

The requirements of mix design of dense-graded bituminous concrete as per Specification of MoRT&H (2013)—are presented in Table 4. The volumetric parameters to be checked include "percentage of voids filled with air in the mix" and "percentage

Table 4 Parameters of Marshall mix design

Characteristic	Unit	Range
Percentage of air voids in the mix	%	3–6
Percentage of voids filled with bitumen in the mix	%	65–75
Stability value	kN	>9
Flow value	mm	2–4

of voids filled with bitumen." The mechanical properties to be evaluated include the "Marshall Stability Value" and "Flow Value."

It can be seen from Fig. 2 that the specific gravity increases with an increase in the bitumen content as well as with an increase in the compaction effort. This was expected, as an increase in bitumen content results in filling of the voids in the mineral aggregates and an increase in compaction effort causes a decrease in the total voids in the mix. It can also be seen that, for compaction effort of 300 blows, the specific gravity increases up to a bitumen content of 4% and then decreases. This is known as the refusal density, beyond which an increase in the bitumen content or compaction effort would destroy the structure of the specimen and result in decrease in the specific gravity of the mix.

Figure 3 shows the effect of increase in bitumen content and compaction effort on VFA. An increase in both the parameters causes the air voids to decrease. The effect of increase in bitumen content decreases as the compaction effort increases. The effect of bitumen content and compaction variation on VFB, as shown in Fig. 4, is in full

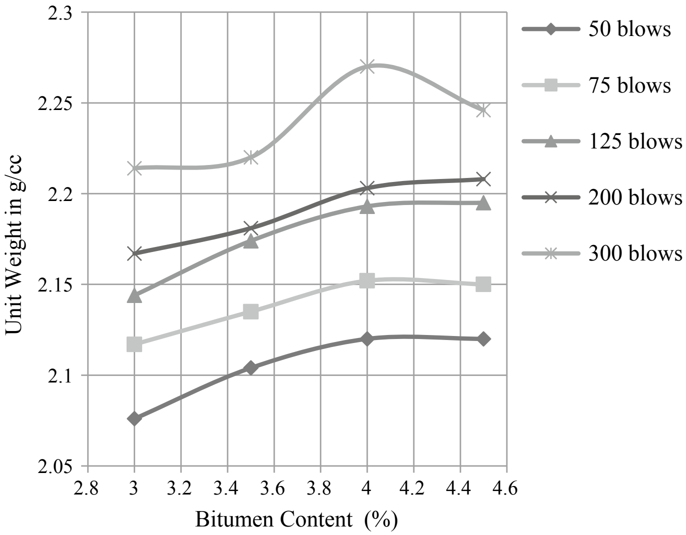

Fig. 2 Specific gravity curves characterized by Bitumen content

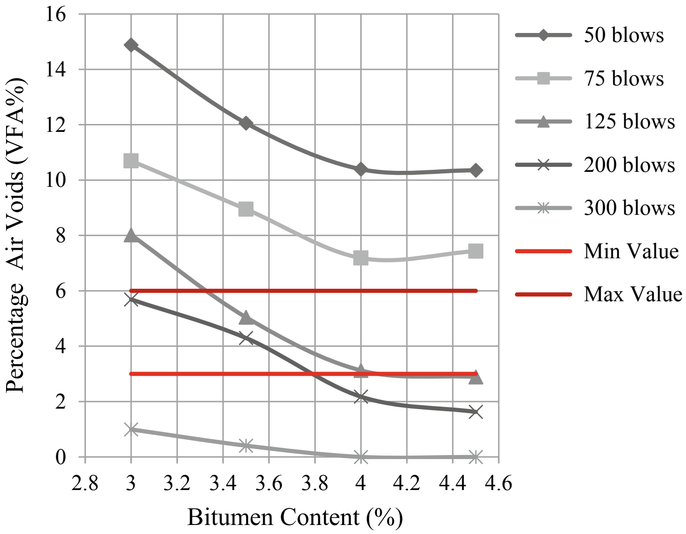

Fig. 3 VFA curves characterized by Bitumen content

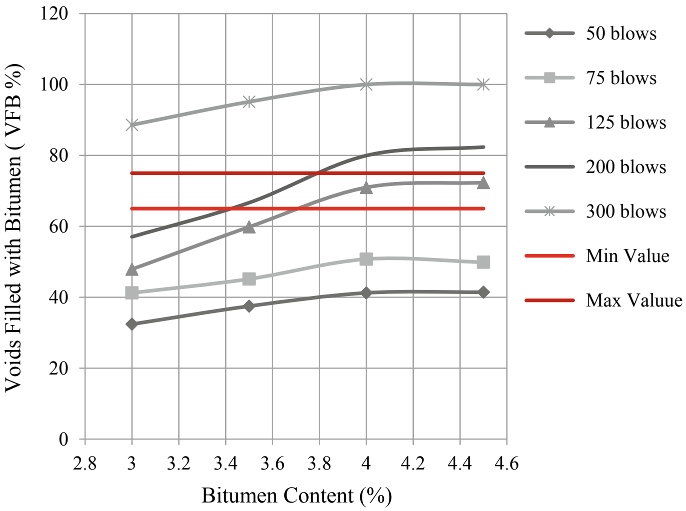

Fig. 4 VFB curves characterized by Bitumen content

contrast with the effect on the percentage of voids filled with air. This was expected, since an increase in VFB is associated with a decrease in VFA. The bitumen content and the compaction effort have to be restricted within ranges that would allow the specifications for VFA and VFB, as prescribed by MORTH in Table 4 to be met.

Figure 5 shows the effect of bitumen content and compaction effort on the stability value. The stability value remains higher than 9 kN, as suggested by Specification

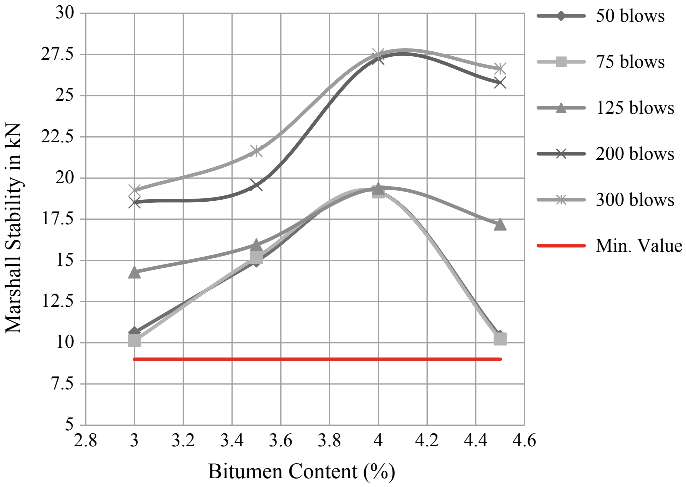

Fig. 5 Stability value characterized by Bitumen content

of MoRT&H (2013) for all levels of bitumen content and the compaction effort. However, the peak value is more clearly visible at lower compaction efforts. The increase in number of blows used for compaction from 75 to 125 is associated with a sudden increase in the stability value. This is suggestive of the fact that the optimum compaction level for RCA and RAP substituted mix could be at 125 blows, in lieu of the standard practice of using 75 blows per face.

Figure 6 shows that the flow value increases with an increase in the bitumen content. Its variation with the compaction effort is decreasing and then increasing,

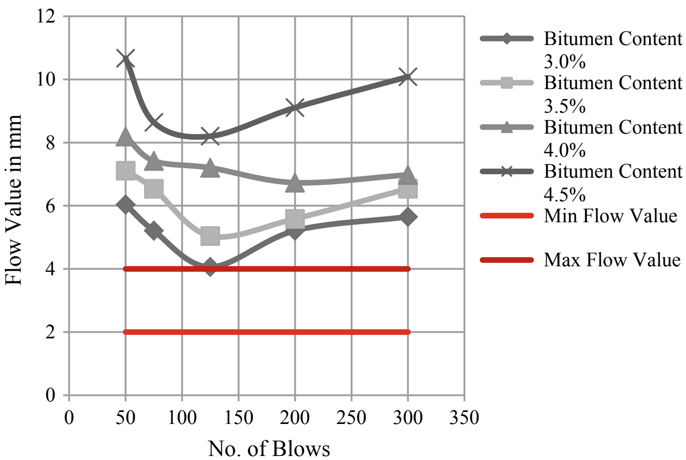

Fig. 6 Flow value characterized by Bitumen content

with a minimum value being achieved around a compaction effort of 125 blows. However, for all the mixes, i.e., for all bitumen contents and compaction efforts, the flow value exceeds the maximum prescribed value of 4 mm. Thus, to limit the flow value, the initial percentage substitution by RCA and RAP has to be reduced.

4 Conclusions

Analysis of the volumetric and mechanical properties of Marshall specimens by varying the bitumen content and compaction effort used for their preparation yielded the possibility of use of RCA and RAP in pavement wearing courses. The following conclusions have been drawn from the study.

1. In the current study, the properties of the Marshall samples, i.e., Stability value, VFA, and VFB meet the recommendations by Specification of MoRT&H (2013). However, the flow value remains higher than the maximum value of 4 mm, as suggested by Specification of MoRT&H (2013), for all values of bitumen content and compaction effort. Thus, to affect a change in the flow value, the percentage substitution has to be reduced.
2. The optimum bitumen range for construction of wearing courses is based on the average of the bitumen content for which the Marshall stability is maximum, bitumen content corresponding to air void content of 4.5%, and flow value of 3 mm. However, to ensure durability of the pavement, its behavior under increased load has to also be considered. This requires a change in the procedure for finding out the optimum bitumen content. Additionally, the optimum compaction range will also have to be determined such that the combination of the optimum bitumen content and optimum compaction effort meets the recommendations of Specification of MoRT&H (2013), as well as offers the maximum durability for the pavement surface. This can be achieved by establishing a regression model, and thereby finding out the compaction level and bitumen content offering good strength and durability characteristics, thus economizing the entire process.

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Effect of Cement Kiln Dust and RBI Grade 81 on Engineering Properties of Plastic Clay

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Abstract This paper deals with plastic clay (CH) treated with cement kiln dust (CKD) and roadbuilding international Grade 81(RBI 81). Geotechnical properties including consistency limits, compaction characteristics, unconfined compression strength (UCS), California-bearing ratio (CBR) and consolidation properties are investigated before and after treating the soil. The effects of CKD and RBI 81 on geotechnical properties are found to be very significant. The consistency tests result in the various mix proportions of CKD, RBI 81, with clay soils indicates the low plastic (CL) in nature. The maximum dry density significantly improved with these cementations materials. The UCS increases with increase in curing time and achieves maximum strength. The mix of CKD and RBI 81 with clay soils of the compression index reduced considerably. For pavements having high compressible subgrade especially in rural areas, these materials are very useful due to significant improvement in CBR values. They are durable in terms of maintenance of the pavements as well. Scanning electron microscopy (SEM) observations on original clay and treated mix presented. The SEM image shows the formation of impermeable CSH and CAH gel. The mix which was studied can be used for rural and low-cost construction road infrastructures.

Keywords Cement kiln dust (CKD) · RBI 81 · Plastic clay · CBR · UCS

1 Introduction

Expansive soils are those that experience significant volume changes associated with changes in water contents. It expands when water is added and shrinks when they dry out. An expansive soil expands due to the presence of highly reactive clay minerals such as montmorillonite and smectite. It is necessary to mitigate the problems posed by clayey soils and prevent cracking of structures.

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_5

CKDs are by-products of the cement manufacturing process. The Indian cement industry with current production capacity is around 366 million tons (MT). The problem of disposing and managing solid waste materials (CKD) in the industrial countries has become one of the major environmental, economical and social issues.

2 Literature Study

Stabilized soils exhibit enhanced mechanical properties such as strength, modulus of elasticity and CBR, durability in terms of water resistance, water sorptivity and shrinkage. The addition of CKDs decreased both the LL and the PI of the clay; large increases in compressive strength and stiffness were obtained for the clay by CKD. CKD stabilized soils show higher strength/elastic modulus/CBR/water resistance/shrinkage values and lower water absorption/sorptivity compared to their RHA counterparts (Hossain 2011). The inclusion of fibre reinforcement within soil and CKD soil mix caused an increase in UCS, shear strength and axial strain at failure (Heeralal and Praveen 2011). CKD stabilization improves modulus from 5 to 30 times depending on the CKD content and type of base material. The seismic young's modulus and resilient modulus of cement-stabilized material were 5 to 20 times higher than those of CKD stabilized material (Ebrahimi et al. 2012). Natural soil treated with CKD obtained UCS value of 381 kN/m^2 and 410 kN/m^2 upon 12 and 8% CKD content at 7 days of curing (Moses and Saminu 2012). The addition of CKD and CKD + Lime increases primary and secondary sonic wave velocities with increasing curing period. Examination of stabilized soil using SEM indicates that the microstructures of tested soil were changed due to CKD and CKD + Lime (Ismaiel 2013). At 2 and 4% of oil contents, the OMC and MDD values increase and then decrease with increasing amounts of CKD. The pavement thickness is substantially reduced with the use of CKD as a stabilizer to oil-contaminated sand (Nasr 2014).

Free swell index decreases as the addition of RBI Grade 81. Similarly, UCS and CBR reduce with increasing dosage of sodium silicate in soil pose limitation of sodium silicate used as stabilizer (Madurwar et al. 2013). RBI 81 and Pond ash help to reduce the swelling characteristics of clayey soil as the DFS index reduces, soaked CBR value of subgrade clayey soil and grade-III material improved by addition of Pond ash and RBI 81 and RBI 81 worked as a good clayey soil stabilizer (Patil and Patil 2013a, b, c). Soil shows appreciable improvement in UCS with the addition of stabilizer under the curing period of 3 and 7 days, and explains early reactions and formation of cementitious products in the mix (Gunturi et al. 2014a, b, c). XRF result presented the formation of cementitious compound C-A-H and C-S-H. SEM micrographs reveal the change in microstructure of the treated soil by the formation of cementitious material (Gunturi et al. 2014a, b, c). Designing of pavement on treated black cotton soil with 4% RBI 81, pavement thickness reduces by 37.50% to untreated black cotton soil and there by cost of the pavement reduced 18.50%.

Table 1 Basic properties of expansive soil

Physical properties	Value
Specific gravity	2.5
Liquid limit (%)	64
Plastic limit (%)	31.7
Plasticity index (%)	32.2
Optimum moisture content (%)	20
Maximum dry density (g/cc)	1.68
Unconfined compressive strength (kN/m^2	88.3
California-bearing ratio (%)	–
Unsoaked	1.65
Soaked	1
IS soil classification	CH

3 Materials and Testing Methods

3.1 Clay Soil

Clayey soil was collected from Sundernagar, Distt. Mandi (HP), India. Tests were carried out to determine the various properties of soil. Basic properties of expansive soil are given in Table 1. Soil was classified as CH.

3.2 Cement Kiln Dust (CKD)

Cement kiln dust (CKD) is a finely divided particulate material similar in appearance to Portland cement. During the manufacture of Portland cement, a large amount of dust is collected from kiln exhaust gases and disposed to landfills. Cement kiln dust was collected from ACC cement factory Barmana (HP). Chemical composition and physical properties of cement kiln dust (CKD) are tabulated in Tables 2 and 3.

3.3 RBI Grade 81

RBI Grade 81 is an odourless beige powder that is composed of number of naturally occurring compounds. It works by hydration reaction and it is insoluble in water, non-UV degradable, inert and chemically stable. It improves the structural properties of a wide range of soil. The chemical composition and particle size of RBI Grade 81 presented in Tables 2 and 4.

Table 2 Chemical composition of RBI Grade 81 and cement kiln dust (CKD)

Chemical composition	RBI Grade 81 (%)	CKD (%)
Oxide compounds	%	%
Cao	52–56	55.06
SiO_2	15–19	11.9
Al_2O_3	5–7	9.9
Fe_2O_3	0–2	3.4
SO_3	9–11	1.48
MgO	0–1	1.7
Na_2O	–	0.5
K_2O	–	0.1
Mn, K, Cu, Zn	0–3	–
Fibres (Polypropylene)	0–1	–
Additives	0–4	–
H_2O	1–3	–
Loss on ignition	–	4.7

Table 3 Physical properties of CKD

Property	Value
Maximum particle size	0.3 mm
Specific surface area (cm^2/g)	4600–14,000
Specific gravity	2.6–2.8

Table 4 Response spectrum for RBI G 81

Soil type	Fine clay	Coarse clay	Fine silt	Coarse silt	Fine sand	Coarse sand
Particle size (μ)	<1.5	1.5–2	2–10	10–60	60–500	500–2 mm
Volume stability	Very poor	Poor	Fair	Fair	Very good	Very good
RBI G 81	✓	✓	✓	✓	✓	✓

3.4 *Material Proportions for Testing*

Series of laboratory tests were conducted on clay soil mixed with various percentages of CKD and RBI 81. Atterberg Limits, Standard Proctor test, unconfined compression strength and California-bearing ratio (CBR) were investigated. The percentages used of CKD were 5, 10 and 15%, and RBI 81 of 2, 4 and 6% of total mass of the mixture. All tests were performed as for IS: 2720 (Part 7) (1983), IS: 2720 (Part 10) (1991) and IS: 2720 (Part 16) (1973) standards.

4 Results and Discussions

4.1 Effect of CKD and RBI 81 on Atterberg Limits

Based on the consistency limits, the selected soil classified as highly compressible (CH) in nature. Liquid limit and plastic limit of the soil was found to be 64 and 31.7%. Consistency limits tests were continued with soil mixed with CKD and RBI 81 under the consistency of CH soil.

The variation of liquid limit, plastic limit and plasticity index with CKD and RBI 81 content is shown in Table 5 and Fig. 1. The liquid limit decreases with the addition of CKD up to 10% and then increases slightly with further increase with the addition of CKD. While RBI Grade 81 is added with CKD, then liquid limit and plastic limit decrease. When RBI Grade 81 increases beyond 4%, it increases liquid limit and plastic limit again. The decrease in liquid limit is due to cation exchange of soil particles with calcium ions which decrease liquid limit due to suppression of diffuse double layer. The increase in liquid limit after increasing RBI 81 indicates flocculation of soil particles (Umesh et al. 2009).

The Atterberg limits are traditionally used for soil classification purposes, and the PI gives an indication of the expansive activity of a particular soil. Effective stabilization of clay with CKD should alter the Atterberg limits significantly. From Fig. 1, CKD and RBI 81 significantly decreased both LL and PI. The liquid limit (and PI) of the CKD 10–15% and RBI 81 4 and 6% are reduced. A further increase of the CKD and RBI 81 content did not find considerable reduction in LL and PI.

4.2 Influence of CKD and RBI 81 on Maximum Dry Density and Optimum Moisture Content

Standard Proctor test was performed on clayey soil. The OMC and MDD of the soil were found to 20% and 1.68 g/cc, respectively. Tests were prepared by mixing CKD with different percentages at an interval of 5% and with RBI 81 with increasing percentage as 0, 2, 4 and 6%. Influence of CKD and RBI 81 on compaction behaviour of various proportions is shown in Table 5.

The relationship between the OMC and MDD against % CKD addition for different soil proportions study is shown in Fig. 2. It is noted that, with increasing the CKD content, MDD decreases and OMC increases steadily. Flocculation of soil particles which has been indicated by Atterberg's limit should have decreased the maximum dry density and increased the optimum moisture content.

While RBI 81 is added with CKD, the MDD increases and OMC decreases. When RBI 81 increases beyond 4%, MDD decreases and OMC increased. The MDD obtained as 1.76 g/cc at 18.1% of OMC for the mix of 81:15:4 (clay:CKD:RBI 81), results presented in Fig. 2. Further addition of RBI 81 content MDD decreases. During compaction, the flocculated particles might have collapsed and fibre content present in the RBI 81 might be caused the higher density and lower moisture content.

Table 5 Experimental results

Designation	Soil:CKD:RBI	LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc	UCS (kPa)			CBR (%)
							7 days	14 days	28 days	
S	100:00:00	64	31.7	32.3	20	1.68	88.3	88.3	88.3	1.65
$(S + C)_1$	95:05:00	54.2	31.3	22.9	21.5	1.67	91.2	99.2	107.5	2.41
$(S + C)_2$	90:10:00	52.5	31	21.5	22	1.65	93.9	102.5	125.7	3.88
$(S + C)_3$	85:15:00	55.9	31.5	24.4	24	1.64	95.8	111.5	139.5	4.35
$(S + C+R)_1$	93:05:02	47	30.5	16.5	19.78	1.69	102.4	127.5	181.25	4.68
$(S + C+R)_2$	88:10:02	45.8	29.8	15.7	19.53	1.70	112.5	153.6	210.3	6.36
$(S + C+R)_3$	83:15:02	44.2	29	15.2	19.3	1.72	129.4	206	266.05	8.03
$(S + C+R)_{11}$	91:05:04	40	26.5	13.5	19.28	1.73	146	241.8	388.8	11.11
$(S + C+R)_{22}$	86:10:04	36.8	27.7	9.1	18.8	1.74	169.8	283.5	467.8	13.32
$(S + C+R)_{33}$	81:15:04	35.4	25	10.4	18.1	1.76	228.8	338.4	572.7	17.14
$(S + C+R)_{111}$	89:05:06	38.5	28.43	10.07	19.5	1.72	298	361	662.25	19.02
$(S + C+R)_{222}$	84:10:06	37.05	28.33	8.72	19.9	1.685	308.7	382	770.5	20.02
$(S + C+R)_{333}$	79:15:06	37.4	30.63	6.77	21	1.67	384	444.4	976	21.7

Note S = Clayey Soil; C = Cement Kiln Dust; R = Road Building International Grade 81. Numerics in the designation represent the percentage of stabilizer by total mass of mixture

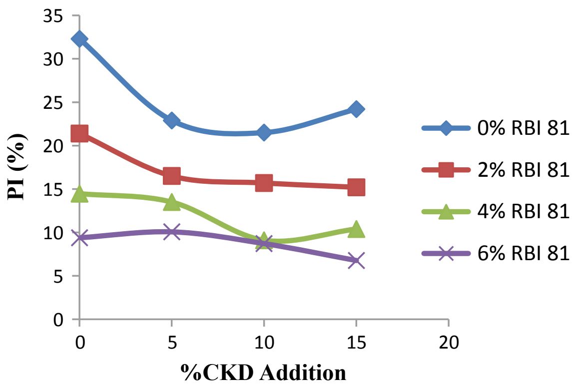

Fig. 1 Influence of the amount of CKD addition on the Atterberg limits of clay after mixing

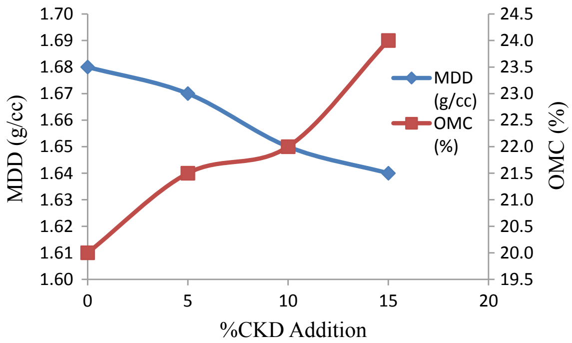

Fig. 2 Variation of MDD and OMC with %CKD addition

4.3 Unconfined Compression Strength

Cylindrical specimens (38 mm diameter and 76 mm length) were used for unconfined compressive strength. The specimens were wrapped in thin plastic film until testing at 7, 14 and 28 curing days.

Determined UCS values are shown in Table 5 and Fig. 3. The increase in UCS values is observed at 7, 14 and 28 days curing period. The 15% CKD content of UCS obtained is approximately 140 kPa (from approximately 88 kPa).

In addition to the CKD content RBI 81 mixed with the clay, the UCS is increased significantly as the study shown in Fig. 4. UCS is investigated for 2, 4 and 6% of RBI 81 in addition to CKD content for 7, 14 and 28 days. Study (Fig. 4) shows the steady increase of the UCS values. UCS increased to 976 kPa (from approximately 88 kPa) at 15% CKD and 6% RBI 81 for 28 days curing period. Similar kinds of results are published. It is due to the formation of pozzolanic compounds formed in the presence of water, and secondary process of soil stabilization took place (slow reaction). When CKD and RBI 81 are added to the clayey soil, calcium ions (high free lime) combine with silica and alumina to form additional cementitious material

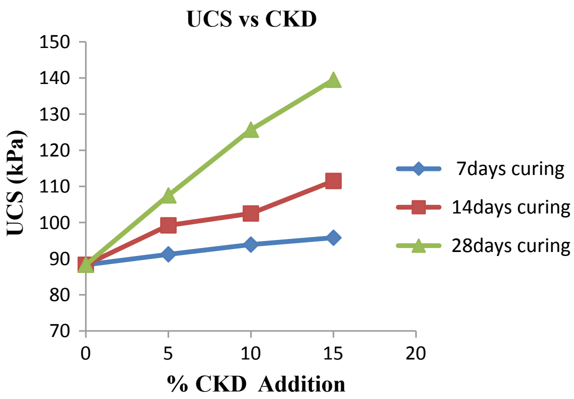

Fig. 3 Influence of % CKD addition on the UCS of clay cured at 7, 14 and 28 days

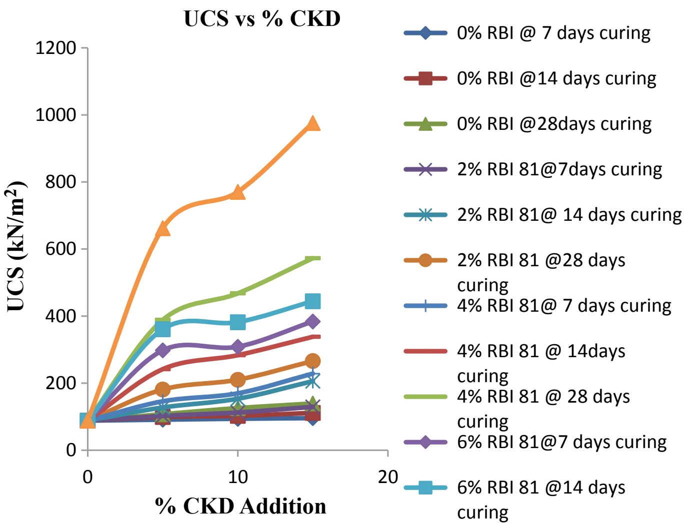

Fig. 4 Influence of RBI 81 on the UCS of clay cured at 7, 14 and 28 days

(C-S-H and C-A-H). Therefore, due to the pozzolanic reactions, UCS might have increased with time (Umesh et al. 2009).

$$Ca^{++} + 2(OH)^{-} + SiO_2 = \text{CSH (Calcium silicate hydrate) gel}$$
$$Ca^{++} + 2(OH)^{-} + Al_2O_3 = \text{CAH (Calcium aluminate hydrate) fibrous.}$$

4.4 Stress–Strain Behaviour

The stress–strain behaviours of the clay samples mixed with the CKD content alone and CKD and RBI 81 and cured at 28 days are presented in Figs. 5 and 6. The stiffness (secant modulus) of modified mix was calculated between 0 and 1% strain on stress–strain curve. The secant modulus values are 0.834 MPa, 3.84 MPa, 4.69 MPa and 5.96 MPa for 0%, 5%, 10% and 15% of CKD, respectively.

Variation of stress–strain can be observed from Figs. 5 and 6 at 28 days curing time, and original clay is observed low stress and higher strains. Treated soil samples increase the stress at lower strain rates with increase in curing time. There is an increment in stiffness that can be observed from study.

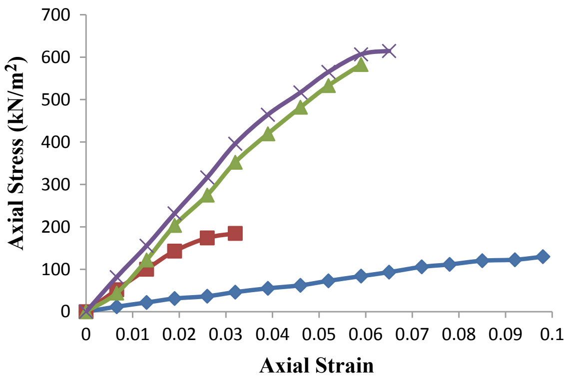

Fig. 5 Stress–strain behaviour of clay modified with CKD and cured at 28 days

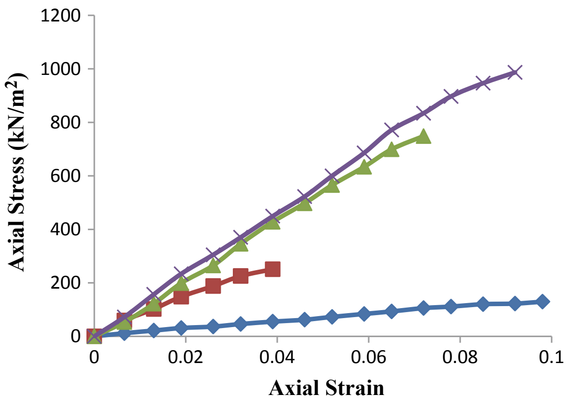

Fig. 6 Stress–strain behaviour of clay modified with CKD and RBI 81 cured at 28 days

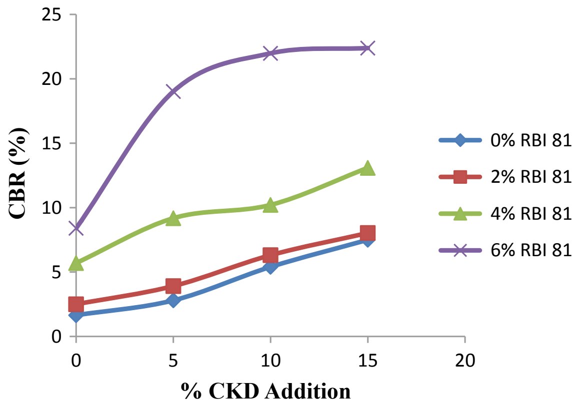

Fig. 7 Effect of CKD and RBI 81 on CBR of clay soil

4.5 California-Bearing Ratio

CBR value is one of the key parameters for designing the pavement and indicator for effectiveness of CKD and RBI 81 as soil stabilizers. Influences of CKD and RBI 81 on CBR values study are in shown in Fig. 7. By the test performed at unsoaked condition, study shows that CBR increases with increasing percentages of CKD content and RBI 81. The original clay has got the CBR value of 1.65%, while clay modified with CKD and RBI 81 is increased to 21.7%. RBI 81 has fibre content (less than 1%) due to which the CBR values may be increasing.

4.6 Consolidation Studies on Original Clay and the Mix of 81:15:4 (S:Ckd:RBI 81)

One-dimensional consolidation test was conducted to determine the consolidation characteristics of untreated and modified soil. The influence of CKD and RBI 81 is considerable on void ratio study as shown in Fig. 8. Study shows that void ratio decreases with increase in pressure. Compression index (Cc), which is the slope of the linear portion of the e-log σ' curve indicates the amount of compression undergone by the soil. The value of Cc is decreasing with increasing CKD of material as shown in Fig. 9. The value of Cc for original clay soil is 0.378 and for the mix of 81:15:4 is 0.117. The decrease in compression index implies that there could be a formation of pozzolanic impermeable products within the pore spaces of soil from physicochemical changes which leads to a reduction in compression index.

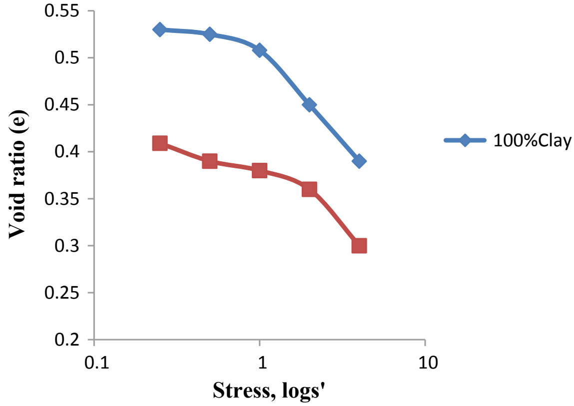

Fig. 8 Consolidation test on original clay and modified clay

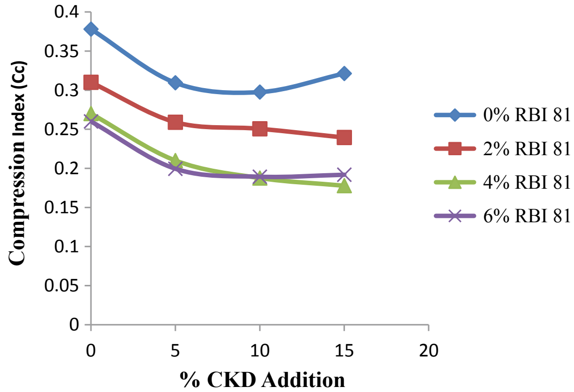

Fig. 9 Influence of CKD and RBI 81 on compression index

4.7 SEM Studies

Microstructure study was conducted on clay soil, CKD and RBI 81. In the 81:15:4 mix, morphology was studied by scanning electron microscopy (SEM) images taken using SEM equipment and the elemental compositions of the samples were analysed using energy-dispersive X-ray spectrometer (EDS).

Figure 10 illustrated the micrographs of the untreated and treated soil with 15% CKD and 4% RBI 81 at 28 days of curing period. The micrographs study show that the formation of cementitious compound from CKD and RBI 81 in the presence of water. The pores were partially filled with cementitious compound and relatively reduce the pore sizes. Micrographs of the CKD modified soil indicated the formation of new cementitious compound.

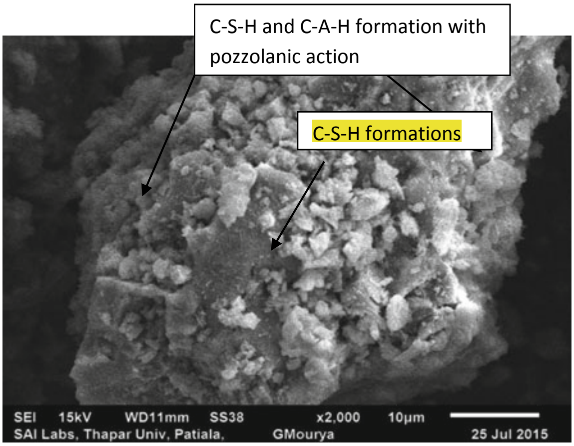

Fig. 10 Treated with 15% CKD and 4% RBI 81

5 Conclusions

The experimental investigation for the clay soil on the effectiveness of CKD and RBI 81 as stabilizers is presented. The effectiveness of the CKD is combined with RBI 81 improvement in engineering properties of the modified clay, including Atterberg limits, compaction characteristics, strength and CBR. Based on the study, the following conclusions can be drawn.

1. The selected clay soil exhibits highly plastic (CH) in nature, CKD and commercial material RBI 81 mixing with the original soil; the plasticity is reduced, and it becomes low compressible soils (CL).
2. Cement kiln dust and RBI Grade 81 are suggested to use up to 15% and 4%, respectively.
3. Maximum dry density (MDD) and optimum moisture content are giving the desirable results when mixing the CKD and RBI Grade 81 may be due to binding property of free lime presented in both the components.
4. The unconfined compressive strength of modified soil increases with increase in percentage of CKD, RBI Grade 81. Time of curing increases from 7 to 28 days, and the UCS increases from 88.3 to 976 kPa. Reason may be due to slow secondary pozzolanic reaction and fibre presented in the material.
5. Original clay soil observed low CBR values, but this investigation result indicates that CBR strength can be improved by adding these industrial dusts to CKD and RBI Grade 81 at significant levels. And it may be durable.
6. Consolidation properties of compression index (Cc) can be improved to the considerable levels by adding the CKD and RBI Grade 81. Settlements will be reduced in longer duration.
7. The SEM micrographs show the changes in microstructure of the treated soil and reduction in pore spaces by the formation of new cementitious compounds CSH and CAH due to pozzolanic reaction, which explains the increase in strength.

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Stabilization of Silty Soil with Marble Dust and Sugarcane Bagasse Ash

Priyanka Mishra and V. K. Arora

Abstract Soil with low bearing capacity requires stabilization to improve its engineering properties. In urban areas, to borrow soil from a long distance is time-consuming and uneconomical. Therefore, it is economical to use locally available industrial and agricultural waste for soil stabilization. In the present investigation, silty soil is used with various percentages of sugarcane bagasse ash and marble dust; various laboratory experiments have been performed, viz., unconfined compressive strength test and standard Proctor test to evaluate the effect of materials used to enhance the properties of parent soil. This stabilization technique is cost-effective and has an additional benefit of providing an environmental-friendly way to deal with industrial waste product. Results of Proctor test indicate that there was an increase in optimum moisture content and decrease in maximum dry density on increasing the stabilizer content, and unconfined compressive strength test result shows that there was increase in the strength value on increasing the stabilizer content.

Keywords Soil stabilization · Marble dust · Sugarcane bagasse ash · Compaction · UCS

1 Introduction

Soil is the cheapest and easily available construction material and supports the load coming from the superstructure. Although it the cheapest and easily available construction material, its properties vary from point to point across the country. Silty soils cause great engineering problems due to low strength and low bearing capacity. So it is very necessary to treat these soils. As silt exhibits certain undesirable engineering properties, they tend to have low shear strength and their shear strength decreases further upon wetting or due to some other physical disturbances. These

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_6

properties can be improved by the process of soil stabilization using different types of stabilizer. Stabilized soil proves to be very useful construction material, especially if locally available industrial or natural material is used as it will be cost-effective also. The choice of particular soil stabilization depends on many factors like type and nature of soil, type, and importance of project and economy of the project.

Rozhan Sirwan Abdulla and Nadhmiah Najmaddin Majeed (2014) investigated the soil from two spots: Bastora and Erbil Airport with Bastora soil as CH soil and Erbil Airport as CL soil. The marble waste powder was included in percentages of 10, 20 and 30% by weight of soil. The results demonstrate that an increase in the percentage of marble dust decreases liquid limit, plasticity index and plastic limit, and swelling potential.

Chayan Gupta and Ravi Kumar Sharma (2014) demonstrated the impact of waste materials, for example, marble dust and fly ash on the subgrade qualities of black cotton soil. They concluded that 15% of marble dust is adequate to increase the California-bearing ratio's soaked strength of up to around 200%.

M. Chittaranjan et al. gave a trial study of using sugarcane bagasse ash as a stabilizer to stabilize the clayey soil. Sugarcane bagasse ash (SBA) was used in different proportions (0, 3, 9, 12 and 15%) and compaction, and CBR characteristics were studied. The study shows that there is an increase in optimum moisture content (OMC) and decrease in maximum dry density (MMD) as there is an increase in SBA content. The result of CBR test shows increase in CBR value.

Alavez-Ramirez et al. worked on improving the durability and mechanical properties of compacted soil blocks by using sugarcane bagasse ash (SBA) and lime as a stabilizer. Different blocks having different percentages of sugarcane bagasse ash and lime were prepared and tested. In order to have better understanding, tests were done on 7, 21, and 28 days. Soil blocks having a combination of 10% lime and 10% SBA show better result as compared to the blocks in which only lime or only SBA was used. Also, the addition of SBA to stabilized soil solves the problem of disposal SBA up to a large extent. By the addition of lime and SBA in the soil, there was an increase in both optimum moisture content (OMC) and maximum dry density (MMD). CBR test results show an increase in CBR value by addition of SBA and lime to clayey soil.

Amu, O.O., Ogunniyi, S.A., and Oladeji, O.O. worked on a modification of geotechnical properties of lateritic soil using sugarcane straw ash to obtain a cheap and economical way of stabilization. There were three types of soil samples, namely, samples A, B, and C, and different tests were conducted on stabilized (by adding 2, 4, 6, and 8% of sugarcane straw ash) and unstabilized samples. Results show that OMC increases from 19 to 20.5%, 13.3 to 15.5%, and 11.7 to 17.0% for samples A, B, and C, respectively. There was an increase in CBR from 6.31 to 23.3%, 6.24 to 14.88%, and 6.35 to 24.88% for samples A, B, and C, respectively. Based on the result found, sugarcane straw ash was an effective stabilizer to improve the geotechnical properties of lateritic soils.

Table 1 Identification and physical properties of soil used

S. no.	Property	Typical value
1	I.S. classification	ML
2	P.L.	13.42
3	L.L.	23.55
4	P.I.	10.13
5	MDD, gm/cc	2.012
6	OMC %	10.98
7	Specific gravity	2.65
8	UCS (kg/cm^2)	1.125

2 Material Used

2.1 Description of the Soil

The soil used for this study is a predominantly silty soil, and around 150 kg of locally available silt was collected nearby NIT campus Kurukshetra, Haryana from a depth around 0.5–0.6 m below the ground surface, and then pebbles and the vegetative matter were removed. The soil was sieved through 4.75 mm sieve for the removal of gravels. The soil was oven-dried for 24 h before testing. All tests on soil were done as per Indian Standard Code (Table 1).

2.2 Marble Dust

Marble dust is the waste obtained during cutting and cleaning of marble. The rapid development of commercial enterprises of marble produces waste material. It becomes a major issue to the people surrounding them, and moreover, it goes about as a toxin so as to influence natural environment of the Earth. It has been observed that marble dust is a successful waste material in soil stabilization strategy which enhances the compaction qualities, subgrade characteristics, swelling characteristics, and compressibility characteristics. In the present study, marble dust is obtained from the local marble industry.

2.3 Sugarcane Bagasse Ash (SBA)

Bagasse is the fibrous matter that remains after the whole juice has been extracted from the sugarcane and deposited as waste and clutter the environment. This bagasse is used as a fuel in sugarcane mills for the generation of steam which eventually results in sugarcane bagasse ash (SBA); this SBA is a very good pozzolanic material as it contains a good amount of oxides of silica and aluminum, so can be used as a stabilizer in stabilizing salty soils. The bagasse ash used in the study was collected from the Shahabad Cooperative Sugar Mill Ltd. Shahabad Markanda of District Kurukshetra. It appears to be black in color on visual inspection and in fibrous form.

3 Methodology

3.1 General

Different tests were conducted on the soil samples prepared by mixing SBA and MD. Though field test is considered to be best, it is not possible to conduct field test all the time as they prove to be expansive and time-consuming, so model test is employed to obtain the useful result; as nowadays with modern technology and instrument, it is possible to maintain condition similar to that of field. Moreover, laboratory test has the advantage of better control over the conditions.

3.2 Testing Procedure

Soil collected from the site was pulverized in pulverizing machine and lumps were broken. It was sieved through 4.75 mm sieve initially. For each test, required amount of soil was taken from the bag and was oven-dried for 24 h. Following tests were conducted:

1. Grain size analysis,
2. Plastic limit,
3. Liquid limit,
4. Shrinkage limit,
5. Specific gravity,
6. Standard Proctor test, and
7. Unconfined compressive strength test (UCS).

3.3 Standard Proctor Test (IS 2720-Part 7-1980)

This test was conducted with the aim of finding the proper amount of mixing water to be used during the compaction of the soil in order to achieve proper denseness and maximum dry density (MDD). It was invented by R.R. Proctor for the construction of earth fill in the state of California. The Indian standard proctor apparatus consists of a cylindrical mold of volume 1000 cm^3 with a diameter of 100 mm and height of

127.3 mm (as per IS code 2720-Part 7-1980) collar of 50 mm height, removable base plate, rammer of weight 2.6 kg falling from a height of 310 mm. The dry density w.r.t. each trial is determined by knowing the mass of the compacted soil and its water content.

3.4 Unconfined Compressive Strength Test (IS 2720-Part 10)

The apparatus used consists of a load frame fitted with proving ring to measure the vertical stress applied to the soil sample. There is a dial gauge to measure the deformation of the sample. Cylindrical specimen has hollowed end in the form of a cone. This is done to reduce the tendency of the sample to become barrel shape by reducing the end restrains. In the test, load and deflection readings are taken and the graph is plotted. In case of brittle failure, proving ring indicates rapid downfall in the load as the strain is increased after the maximum load. However, in case of plastic failure load w.r.t, 20% of the strain is taken as failure load.

4 Results and Discussion

4.1 General

To investigate the compaction characteristics and strength characteristics of the silty soil treated with different combinations of marble dust, sand SBA is the main objective of the present study. It is done to make the soil suitable for desired engineering purpose by modifying its geotechnical characteristics. First, a series of standard compaction test confirming IS 2720-Part 7-1980 was conducted on all the samples to determine the OMC and MDD for parent soil and silty soil in the combination of marble dust and SBA. Then, a series of UCS test confirming to IS 2720-Part 10 was conducted on silty soil alone and with a combination of marble dust and SBA. The outcome of these tests is listed below.

4.2 Moisture Content and Density Relationship

Standard Proctor test has been done to determine the OMC and MDD. For the result of series of this standard, Proctor test is conducted on different samples. For sample no. 1 (Parent soil), MDD is found to be 2.019 gm/cc at 12% OMC; for sample no. 2 (Parent soil + 5%MD), MDD was 1.948 gm/cc at 12.399% OMC; for sample no. 3 (Parent soil + 10%MD), MDD was 1.91 gm/cc at 12.665% OMC; for sample no. 4

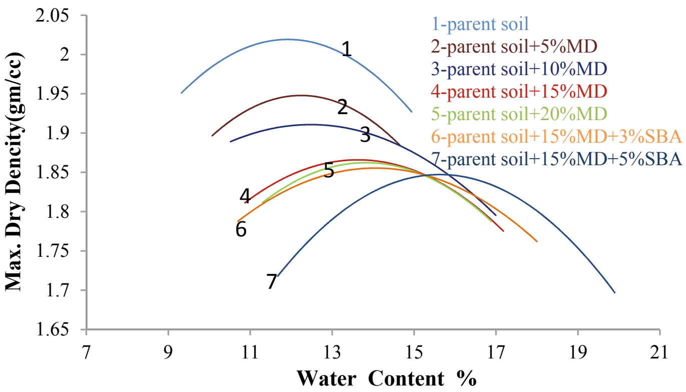

Fig. 1 Comparison graph for different moisture–density relationships

(Parent soil + 15%MD), MDD was 1.866 gm/cc at 13.468% OMC; for sample no. 5 (Parent soil + 20%MD), MDD was 1.863 gm/cc at 13.867% OMC; for sample no. 6 (Parent soil + 15%MD + 3%SBA), MDD was 1.856 gm/cc at 14.3% OMC; and for sample no. 7 (Parent soil + 15%MD + 5%SBA), MDD was 1.826 gm/cc at 17.09% OMC.

From the study, it is observed that there is a continuous increase in OMC and decrease to MDD value with increase in stabilizer content. The presence of MD and SBA having low specific gravity is the main cause of reduction in density (Fig. 1).

4.3 Unconfined Compressive Strength Test

As compressive strength is one of the most important properties as far as silty soil is concerned, hence, a series of unconfined compressive strength (UCS) confirming to IS 2720-Part 10 has been conducted on silty soil alone and silty soil mixed with different percentages of Marble dust. For sample no. 1 (Parent soil), maximum compressive strength found to be 1.125 kg/cm^2 and corresponding strain observed was 0.0278; further, for sample no. 2 (Parent soil + 5%MD), maximum compressive strength found to be 1.376 kg/cm^2 and corresponding strain observed was 0.0616; further, for sample no. 3 (Parent soil + 10%MD), maximum compressive strength found to be 1.702 kg/cm^2 and corresponding strain observed was 0.0411; further, for sample no. 4, (Parent soil + 15%MD), maximum compressive strength found to be 2.158 kg/cm^2 and corresponding strain observed was 0.0676; further, for sample no. 5 (Parent soil + 20%MD), maximum compressive strength found to be 1.191 kg/mm^2 and corresponding strain observed was 0.0357; further, for sample no. 6 (Parent soil + 15%MD + 3%SBA), maximum compressive strength found to be 2.277 kg/mm^2 and corresponding strain observed was 0.0479; and further, for sample no. 7 (Parent soil + 15%MD + 5%SBA), maximum compressive strength found to be 2.496 kg/mm^2 and the corresponding strain observed was 0.0486 (Fig. 2).

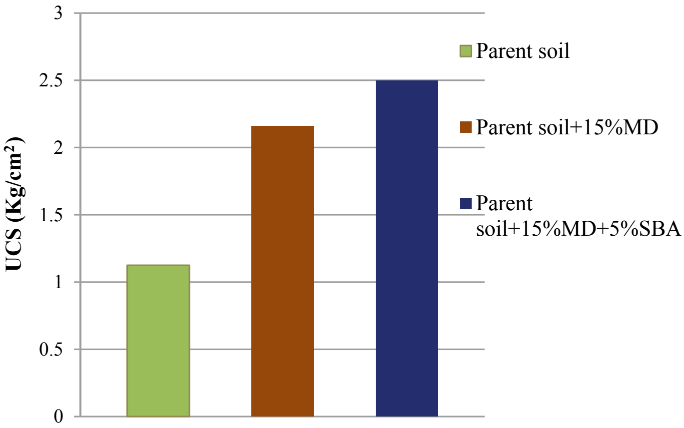

Fig. 2 Effect of increasing stabilizer on UCS value

5 Conclusions

- From the study, it is been observed that there is a continuous increase in OMC and decrease to MDD value with increase in % of MD.
- It is observed that when % of MD increased up to 15%, UCS value increased from 1.125 to 2.158 kg/cm^2 which further drops to 1.191 kg/cm^2 when % of MD increased up to 20%.
- The optimum value of marble dust comes out to be 15% by weight of dry soil.
- The maximum unconfined compressive strength of sample is 2.496 kg/cm^2 for parent soil + 15%MD + 5%SBA addition.
- Use of marble dust and SBA as a stabilizer for improving the geotechnical properties of silty soil is an economical and effective solution especially for the region which has a large number of sugar and rice mills.
- Marble dust, sugarcane bagasse ash (SBA), and rice husk ash (RHA) can be used in bulk quantity for stabilization of silty soil which will solve the problem of their disposal and will reduce the environmental pollution.

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Strength Improvement of Silt Loam Using Egg Shell Powder and Quarry Dust

Vaangmayaa Singh and V. K. Arora

Abstract Proper sub-soil investigation at the proposed site and proper foundation design on the basis of settlement and shear strength criteria is essential for long-life serviceability of a structure. Stabilization of weak and soft soil deposits with solid domestic and industrial wastes is a beneficial alternative of stabilizing the soil using traditional expensive agents like cement, lime, etc., which also gives a suitable solution for disposal of waste materials and environmental pollution. Silt has low bearing capacity and hence requires improvement for bearing the structural load. Chicken Egg Shell Powder is rich in CaO and Quarry Dust is rich in SiO_2. In this study, the suitability of Egg Shell Powder and Quarry Dust as stabilizing materials for silt loam is analyzed through laboratory experiments. Soil was mixed with Egg Shell Powder and Quarry Dust in varying % of dry wt. of soil. Unconfined Compressive Strength tests (UCS) were conducted on soil samples mixed with optimum percentages of Egg Shell Powder and Quarry Dust and a significant increase in strength with increase in percentage of additives was observed. Hence from these results, it's concluded that Egg Shell Powder and Quarry Dust can be effectively used as eco-friendly and economic stabilizing agents for strength improvement of silt.

Keyword Strength improvement · Silty loam · Egg shell powder · Quarry dust · UCS

1 Introduction

When a deposit of weak soil is encountered, it is evident to find a probable solution out of available alternatives. The options may include finding a new site of proper soil, excavation to deep foundation level, removal and subsequent replacement of poor soil with a more suitable soil, redesigning the structure for the poor soil conditions or improving the properties of soil, also known as soil stabilization. Soil stabilization

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_7

to obtain the desired properties of soil would be the most probable and economic solution in situations of non availability of suitable alternative sites.

Over the last few years, environmental degradation issues have prompted human to research on utilizing industrial and domestic wastes as alternatives to construction materials accordingly to their useful properties. Both researchers and engineers have paid significant attention to utilizing wastes for stabilizing soil and improving index and engineering properties of soils. This may help in reducing both problems of environmental degradation and economy of the project.

Domestic and industrial wastes such as fly ash, blast furnace slag, wood ash, iron fillings, plastic wastes and fibers have shown suitable potential to stabilize the soil and are occasionally used to improve index and engineering properties of weak soils.

Silts are low plasticity fines having low strength and compressibility characteristics and hence require improvements before construction.

One of the most common methods of improvement of fine soils is to stabilizing it with additives that improve the properties of soil by physical and chemical processes. However it is to be noted that behavior of fine-grained soils should be well studied before deciding the method of improvement. Soil stabilization is generally processed to achieve the following:

- Soil strength and bearing capacity increment and improvement of engineering properties.
- Structure subsidence prevention.
- Reduction in plasticity index.
- Safety factor increment against slope and earth dam sliding.
- Reduction of adhesion in highly adhesive soils.
- Adhesion increment in low adhesive soils like sands.

In this study, Egg Shell Powder (ESP) and Quarry Dust (QD) were added to study the influence on the properties of silt loam. An improvement in the strength characteristics of soil with addition of ESP and QD will help in finding an application of waste materials to improve the properties of silt loam and hence can be used as an eco-friendly and economic stabilizing agent making them better than traditional costly soil stabilizing agents like lime, cement etc.

2 Materials Used

2.1 Soil

The soil was collected locally from Kurukshetra, Haryana. Soil sample was taken from a depth of 4ft. from ground surface. The sample was thoroughly oven dried and stored in sacks at room temperature for further laboratory investigations. The general index and engineering properties of the parent soil were analyzed in the laboratory.

Soil was classified as low plasticity silt (ML) as per IS 1498-1970. It is light brown in color. The properties of soil obtained are tabulated as in Table 1.

Table 1 Properties of soil

S. no.	Properties of soil	Test results
1.	% Sand	25
	% Silt	67
	% Clay	8
2.	Specific gravity	2.56
3.	Liquid limit (%)	25.48
4.	Plastic limit (%)	18.83
5.	Plasticity index	6.64
6.	Maximum dry density (g/cc)	2.007
7.	Optimum moisture content (%)	12.43
8.	Unconfined compressive strength (kg/cm^2)	0.8

Table 2 Properties of ESP

Constituents	Percentage (%)
CaO	95–99
Al_2O_3, SiO_2, Cl, Cr_2O_3, MnO, and Cu_2O	1–5

2.2 Egg Shell Powder

Egg shells are major domestic waste products from food industry. By review of literature it is seen that egg shells are rich in CaO and share same chemical composition as lime. Hence they can be used as an economic replacement of lime.

Egg shells were collected from the restaurants, local food joints and poultry farms. Egg shells were thoroughly washed with clean water and dried in sunshade for 48 h. Egg shells were then grinned in the laboratory grinder to obtain uniform and fine egg shell powder and then sieved through 425μ IS sieve for further laboratory investigations. The specific gravity of egg shell powder was found to be 1.34. The properties of egg shell powder as observed from literature review are tabulated as in Table 2.

2.3 Quarry Dust

Quarry Dust is an industrial waste product from stone crusher and is rich in SiO_2. From review of literature it is observed that quarry dust can be used as an economic replacement to cement and possess high strength and cementing property.

Quarry Dust was collected from the stone crusher industry in Karnal region of Haryana. Material was then dried in oven and pulverized in laboratory to obtain fine quarry dust. It was then sieved through 425μ IS sieve for further laboratory investigations. The specific gravity of quarry dust was found to be 2.91.

3 Methodology

Laboratory tests were performed to determine index properties of parent soil as per IS 1498. Following tests were performed to investigate the properties of parent soil and soil mixed with various proportions of additives by dry weight of soil in laboratory. All tests were performed by standard procedures as per IS 2720 Part III–VIII.

(a) Standard Proctor Compaction test
Compaction characteristics, i.e., Maximum dry density and Optimum moisture content were observed from resulting compaction curves.
(b) Unconfined Compressive Strength test (UCS)
Samples were prepared adding various proportions of additives and mixed with corresponding optimum amount of water. Soil Samples were then kept in airtight conditions for 24 h for moisture equilibrium. Soil samples were compacted into 76 mm long and 38 mm diameter mould to obtain maximum dry density. UCS was observed for both uncared and cured samples after 14 days.

4 Results and Discussions

4.1 Standard Proctor Compaction Results

Compaction characteristics, i.e., Maximum dry density and Optimum moisture content were observed for soil mixed with 2, 4, 6, 8, and 10% of egg shell powder by dry weight of soil.

Maximum dry density (MDD) was observed to drop significantly initially at 2% egg shell powder and then it varied non-uniformly. Overall MDD was observed to have a decreasing trend with increase in % egg shell powder. The decrease in Maximum dry density may be due to relatively low specific gravity of egg shell powder.

Optimum moisture content (OMC) was observed to slightly increase with increase in % egg shell powder. The increase in OMC may be due to water absorption characteristics of egg shell powder as it requires more water for pozzolanic reactions.

Maximum dry density and optimum moisture content variation with % egg shell powder is tabulated as in Table 3 and is shown in Figs. 1 and 2.

From UCS test results an optimum percentage of egg shell powder was selected 6% as relative increase in UCS value was found maximum at 6%. Further compaction study was conducted for soil mixed with optimum egg shell powder content and varying 2, 4, 6, 8, and 10% of quarry dust by dry weight of soil.

Maximum dry density of soil—optimum egg shell powder—quarry dust mix was observed to increase with increase in % quarry dust. Increase in MDD may be due to relatively higher specific gravity of quarry dust as compared to parent soil.

Table 3 Variation of compaction properties with % ESP

Soil mix	MDD (g/cc)	OMC (%)
Soil	2.007	12.43
Soil + 2% ESP	1.942	14.32
Soil + 4% ESP	1.955	11.89
Soil + 6% ESP	1.976	12.02
Soil + 8% ESP	1.941	13.67
Soil + 10% ESP	1.928	15.12

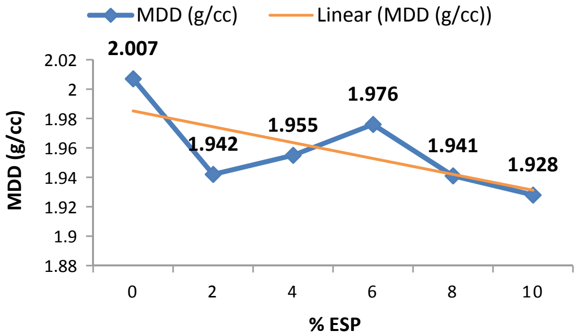

Fig. 1 Variation of maximum dry density with % ESP

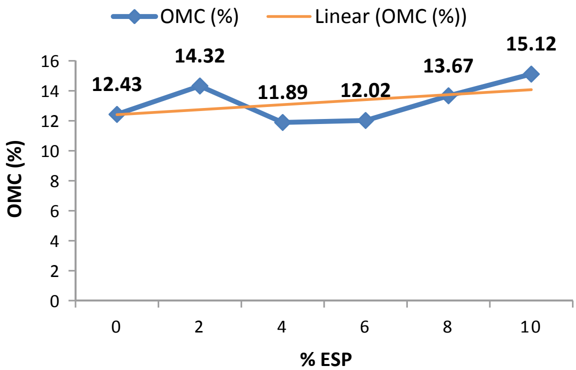

Fig. 2 Variation of optimum moisture content with % ESP

Optimum moisture content of soil—optimum egg shell powder—quarry dust mix was observed to decrease with increase in % quarry dust. Reduction in OMC value may be due to granular nature of quarry dust and replacement of soil by quarry dust. This may also be due to quarry dust nature of less attraction for water molecules.

Maximum dry density and optimum moisture content variation with % egg shell powder is tabulated as in Table 4 and is shown in Figs. 3 and 4.

Table 4 Variation of compaction properties with optimum % ESP and varying % QD

Soil mix	MDD (g/cc)	OMC (%)
Soil	2.007	12.43
Soil + 6% ESP + 0% QD	1.976	12.02
Soil + 6% ESP + 2% QD	2.031	11.54
Soil + 6% ESP + 4% QD	2.020	11.77
Soil + 6% ESP + 6% QD	2.166	10.15
Soil + 6% ESP + 8% QD	2.251	9.85
Soil + 6% ESP + 10% QD	2.278	8.34

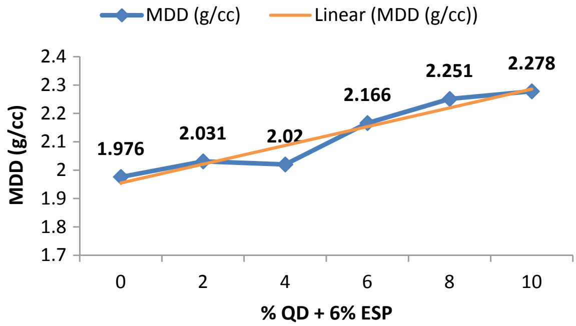

Fig. 3 Variation of maximum dry density with %QD + optimum % ESP

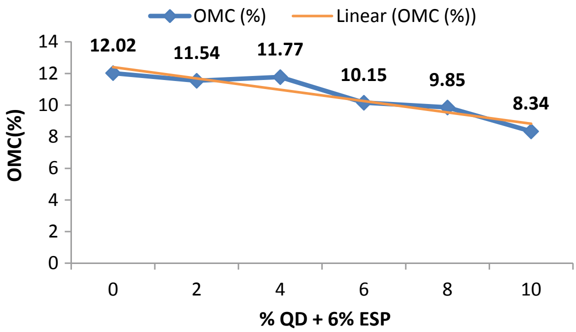

Fig. 4 Variation of optimum moisture content with %QD + optimum % ESP

4.2 Unconfined Compressive Strength Results

UCS was observed for soil mixed with 2, 4, 6, and 8% egg shell powder. Tests were conducted on samples of 76 mm length and 38 mm diameter, prepared by mixing soil-egg shell powder with corresponding optimum amount of water and kept for 24 h for moisture equilibrium.

Curing effect was also studied by observing UCS value of soil mix sample after 14 days curing.

Table 5 Variation of UCS with % ESP

Soil mix	UCS (kg/cm^2) [No curing]	UCS (kg/cm^2) [14 days curing]
Soil	0.8	0.8
Soil + 2% ESP	0.92	1.68
Soil + 4% ESP	1.00	2.80
Soil + 6% ESP	1.28	3.68
Soil + 8% ESP	1.52	4.08

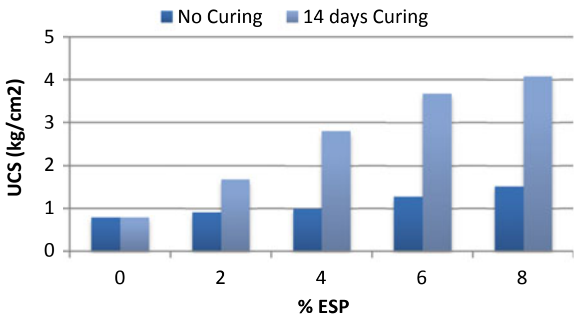

Fig. 5 Variation of UCS with % ESP

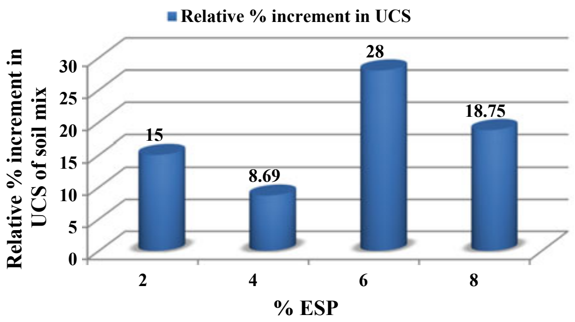

Fig. 6 Relative percentage increment in UCS of soil mix with % ESP

A significant increase in UCS of soil mix with increase in % egg shell powder was observed. This may be due to filling of voids of soil by products of pozzolanic reactions between soil and egg shell powder. Variation of UCS for both uncured and cured samples with % ESP is tabulated as in Table 5 and is shown in Fig. 5. From the relative percentage increment in UCS value with egg shell powder as shown in Fig. 6, an optimum percentage of egg shell powder was selected to be 6% for further investigations. This variation may be due to relative arrangement of soil and egg shell powder particles.

UCS value further improved significantly on addition of varying 2, 4, 6, 8, and 10% quarry dust with optimum percentage of egg shell powder in the parent soil. Variation of UCS for both uncured and cured samples with % QD and optimum % ESP is tabulated in Table 6 and is shown in Fig. 7.

Table 6 Variation of UCS with optimum % ESP and varying % QD

Soil mix	UCS (kg/cm^2) [No curing]	UCS (kg/cm^2) [14 days curing]
Soil	0.8	0.8
Soil + 6% ESP + 0% QD	1.28	3.68
Soil + 6% ESP + 2% QD	2.38	4.77
Soil + 6% ESP + 4% QD	2.45	4.84
Soil + 6% ESP + 6% QD	2.76	5.15
Soil + 6% ESP + 8% QD	3.02	5.41
Soil + 6% ESP + 10% QD	3.58	5.97

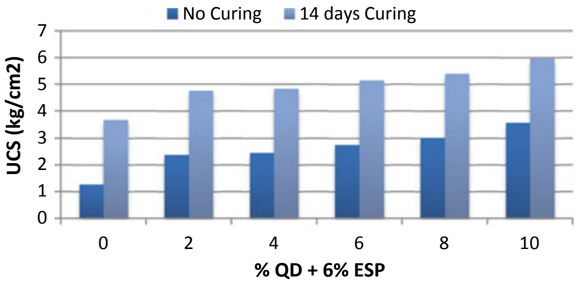

Fig. 7 Variation of UCS with optimum % ESP and varying % QD

The improvement in UCS value may be due to replacement of silt content of soil by egg shell powder and quarry dust which increase the strength of soil and also make it non-plastic. Chemical composition of Egg shell powder and Quarry dust mainly attribute in increasing the strength of soil.

Richness of CaO in Egg shell powder, same as in lime and SiO_2 in Quarry dust same as in cement may be the reason for significant increment of strength characteristics of silt. This result may be probably due to the cementitious product of egg shell powder-quarry dust, i.e., calcium silicates and aluminates which binds soil particles together and produce a more compact matrix structure and thus greatly improving the strength of silt.

UCS value of uncured samples was observed to increase by two to three times whereas of cured samples was observed to increase by three to four times, showing that curing has positive effect on strength of soil which may be due to completion of various pozzolanic reactions between soil-egg shell powder-quarry dust and hence further improvement in strength of soil.

5 Conclusions

Following conclusions were drawn on the basis of results observed in this study:

- Initially a significant decrease in Maximum dry density value and a slight increase in optimum moisture content were observed with increase in egg shell powder.
- An increase in Maximum dry density and decrease in optimum moisture content was observed with increase in % quarry dust with optimum egg shell powder content. So compressibility of silt loam was observed to increase indicating improvement of parent soil.
- UCS value of soil-egg shell powder mix increased significantly with increase in % egg shell powder due to same chemical composition as lime.
- The optimum percentage of egg shell powder was observed to be 6%.
- UCS value of soil mixed with optimum egg shell powder content and varying quarry dust increased by a significant amount with increase in quarry dust due to its high shear strength and cementing property.
- Curing also reflected a positive effect on the strength characteristics of soil sample. UCS value of uncured sample was observed to increase by two to three times whereas of cured samples was observed to increase by three to four times.

From the results obtained by laboratory investigations, we can come to a conclusion that silt loam along with combination of Egg Shell Powder and Quarry Dust obtained high strength and compressibility characteristics which enabled ESP and QD to be used efficiently for improvement of silt. Since Egg shell powder and Quarry dust are major waste products, utilization of these products also help in tackling high stocks of waste and waste disposal making them environmentally friendly. Also, use of egg shell powder and quarry dust replacing lime and cement help the construction project economically.

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Enhancement of Shearing Strength of Poorly Graded Sand by Using Surface Modified Waste Rubber Tyre Fibres

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Abstract Used automobile tyres are a form of wastes, which cause disposal and environmental problems. The main objective of the study is to evaluate the angle of shearing resistance (ϕ) of the poorly graded sand (SP) reinforced with the untreated tyre fibres (UTTFs) and cement coated tyre fibres (CCTFs). In the paper, a surface modification of tyre fibres by cement coating is proposed to increase the specific gravity in order to obtain uniform mixing, and improve a strong bond between the tyre fibres and sand particles. Direct shear tests were performed on the mixtures of UTTFs–sand and CCTFs–sand with proportion of fibres equal to 0, 2.5, 5, 7.5, 10, and 12.5% by weight of dry sand. Three vertical effective stresses of 50, 100, and 150 kPa were assigned and all the tests were performed at a strain rate of 0.25 mm/min. Optimum fibre content is observed at 10%. The ϕ values at 10% for CCTFs and UTTFs reinforced sand are approximately 12% and 8% more than that of 0% fibre content (i.e., only sand) respectively.

Keywords Shear strength · Poorly graded sand · Rubber fibere · Cement treatment · Internal friction angle

1 Introduction

Domestic growth has resulted in use of vehicles on the roads and thereby use of tyres throughout the globe. Van Beukering and Jansen (2001) have stated that approximately 800 million tyres are discarded around the globe annually. This figure is estimated to increase by 2% every year. Sienkiewicz et al. (2012) reported that the annual global production of tyres is about 1.4 billion unit, which corresponds to an estimated 17 million tonnes of used tyres each year. It is noted that India contributes approximately one million tonnes of waste tyres annually.

The disposal of waste tyres can cause environmental problems as they take considerable time to decompose completely (i.e., they are weatherproof and non-

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_8

biodegradable materials). Tyre fibres have less density compared to the density of soil; hence they occupy large volume if disposed of into the landfills which might become the source of pollution. Many researchers have investigated the effect of physical, chemical, and mechanical behaviour of soil medium(cohesive and cohesionless soils) with the inclusion of waste tyre fibres (Yetimoglu and Salbas 2003; Cetin et al. 2006; Suat et al. 2007; Tang et al. 2007; Phanikumar and Ravideep 2016; Sharma and Kumar 2017). Use of waste rubber tyre fibres in soil medium to improve the strength of soil media has recently increased the attention in the field of geotechnical engineering (Shukla 2017). The concept of soil reinforcement with natural fibres has originated in the ancient time. The modern form of soil reinforcement was first developed by Vidal (1969). He demonstrated that the introduction of reinforcement elements in a soil mass increases the shear resistance of the medium. A surface modification method was proposed by He et al. (2016) to introduce strong polarity groups to rubber surface and to generate a strong chemical bond between the rubber and the cement matrix. Onuaguluchi (2015) reported the reduction in the mechanical strength of concrete composite due to addition of poorly crumb rubber. Availability of natural sand to the required standards is diminishing day by day in use of making concrete and is severely affecting the construction industry (Gupta et al. 2016). Gupta et al. (2016) reported the use of rubber tyre crumbs in fraction as a replacement of fine aggregate.

The main objective of this study described here is to investigate the feasibility of using cement coated tyre fibres (CCTFs) over uncoated tyre fibres (UCTFs) to enhance the shear strength of cohesionless soil. The factors influencing the shear strength of sand are investigated in the experimental investigation. The factors considered are vertical effective stress, horizontal shear stress, type of the tyre fibre (coated or uncoated), sand and tyre fibre matrix unit weight and tyre fibre content. The surface modification method applied on waste tyre rubber fibres has significantly increased the shear strength of poorly graded sand over untreated tyre fibres. The results of the tests are presented, compared, and discussed to determine the applicability of use of waste tyre fibre in the field of geotechnical engineering.

2 Materials

A relatively, uniformly distributed, round-shaped marine sand was used in the study. Sand was collected from the banks of Dumus beach, Surat, India. Specific gravity of sand is 2.75. The minimum and maximum dry unit weights of sand are 15 kN/m^3 and 17 kN/m^3, respectively. The sand used has following properties: effective particle size (D_{10}) 0.15 mm, mean particle size (D_{50}) 0.3 mm, coefficient of uniformity (C_u) 2.16, and coefficient of curvature (C_c) 0.82 (D_{30} ~ 0.2, D_{60} ~ 0.325). The sand is classified as the poorly graded sand (SP) according to the Indian standard classification system, IS 1498 (1970).

The waste tyre rubber fibres (WTRFs) were collected from "National Procured Retreaders", National Highway-8, Surat, Gujarat, India. Rubber fibres obtained were

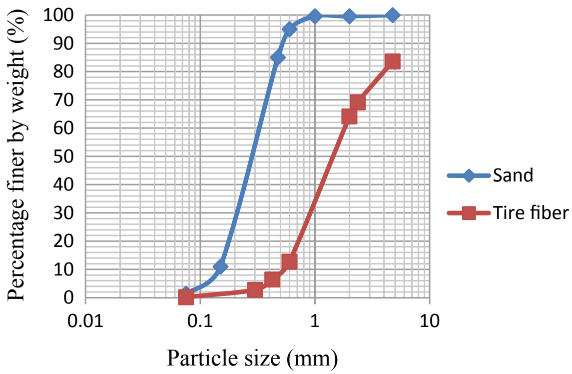

Fig. 1 Particle-size distribution of sand and rubber particles

free from steel strands and threads (i.e. steel, 0% & thread, 0%). The fibres obtained were sieved through IS sieve sizes 4.75, 2.36, 2.0, 0.6, 0.425, 0.3, and 0.075 mm. The size distribution of the fibres as per IS 1498 (1970) is found to be the same as of poorly graded sand in nature. The fibres used in this study are those, having 19 mm length and 4.5 mm width (aspect ratio *L*/*B* equals to 4.22). It is noted that the larger size rubber fibres i.e. 4.75 mm and above will have a boundary effect in the direct shear test. It is difficult to separate the smaller size tyre fibres by sieving. The experimental programme includes the reuse of sand–tyre mixture and hence the fibres of length 4.75 mm and above were used in the study. The fibres can be separated easily by sieving. The longest dimension of the fibre is recorded as its length. Specific gravity of tyre fibre is 1.15. The particle-size distributions of sand and tyre fibres are shown in Fig. 1.

The Ordinary Portland cement (OPC), Grade 53 was used in the present study. Standard consistency limit of the OPC cement is 30% of water to the dry unit weight of the cement. It has initial and final setting times of 30 min and 600 min, respectively (IS 12269 1987). Specific gravity of OPC is 3.22.

The material calculations for test specimens were done based on the minimum and maximum of dry unit weights of sand–fibre mixtures (sand + 0% fibre, sand + 2.5% fibre, sand + 5% fibre, sand + 7.5% fibre, sand + 10% fibre, sand + 12.5% fibre) at the relative density of 70% (for avoiding large vertical deformations and to provide strong surface bond between tyre fibres and sand particles), which are considered as a dense mixtures (Fig. 2).

Ideally, the shear strength of soil–tyre fibre mixtures should be evaluated using the triaxial shear tests. However, testing the mixture of soil and tyre fibres in triaxial shear is difficult, because of the size of the tyre fibres and the sharp uneven texture requires a triaxial apparatus used for testing must also be fairly large. The membrane used must be tough enough to resist puncture and the stiffness of the membrane would not influence the measured strength. To avoid these problems, the direct shear box machine was chosen to evaluate the shear strength properties of soil–tyre fibre mixtures. The errors in shear strength incurred by using direct shear test rather than triaxial shear test were acceptable for this practical study.

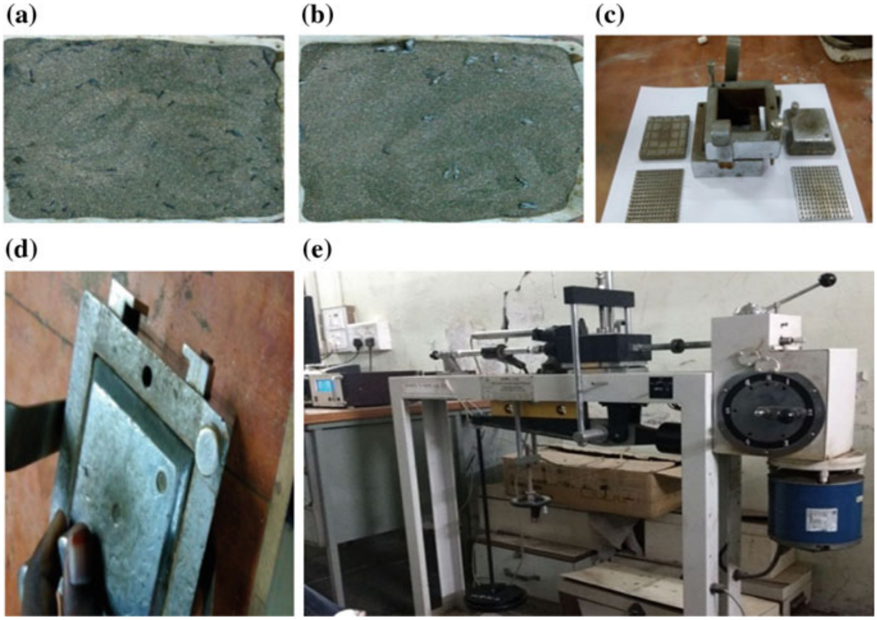

Fig. 2 Shear test specimen preparation and testing. **a** Uncoated tyre fibres + sand, **b** cement coated tyre fibres + sand, **c** elements of shear box, **d** assembly of shear box with sample, **e** direct box shear test apparatus

A total of 33 (few tests were repeated due to manual errors while performing) direct box shear tests were performed to study the shear characteristics of sand with the inclusion of untreated and cement coated rubber fibres. The fibre contents were taken in the study are 0, 2.5, 5, 7.5, 10, and 12.5% by dry weight of sand. All samples were prepared with the mixtures of dry sand and rubber fibres at the room temperature. The minimum and maximum unit weights of sand can be readily controlled and were kept relatively the same in all tests, in dry condition. Three vertical effective stresses 50, 100, and 150 kPa were chosen to shear the samples at a strain rate of 0.25 mm/min. Standard direct shear test device with strain controlled unit was used to apply the horizontal load to shear the specimen in a rectangular box of size is 60 mm × 60 mm × 25 mm. Tests were performed in a consolidated drained (CD) condition, which represents the development of pore water pressure as zero; it implies that the stresses measured are effective stresses.

Preparation of cement coated tyre fibres (CCTFs): The CCTFs were prepared with three different fibre/cement proportions (1:1, 1:1.5, and 1:2) with 30% of the water to the dry weight of the cement. The tyre fibres content was kept constant with changing cement content to improve the specific gravity of the fibres by modifying the fibres surface called the cement coated tyre fibres. Cement and fibres were mixed thoroughly in dry condition then water is added to the fibre/cement mixture and mixed thoroughly to achieve uniform surface adhesion of cement paste to the fibres.

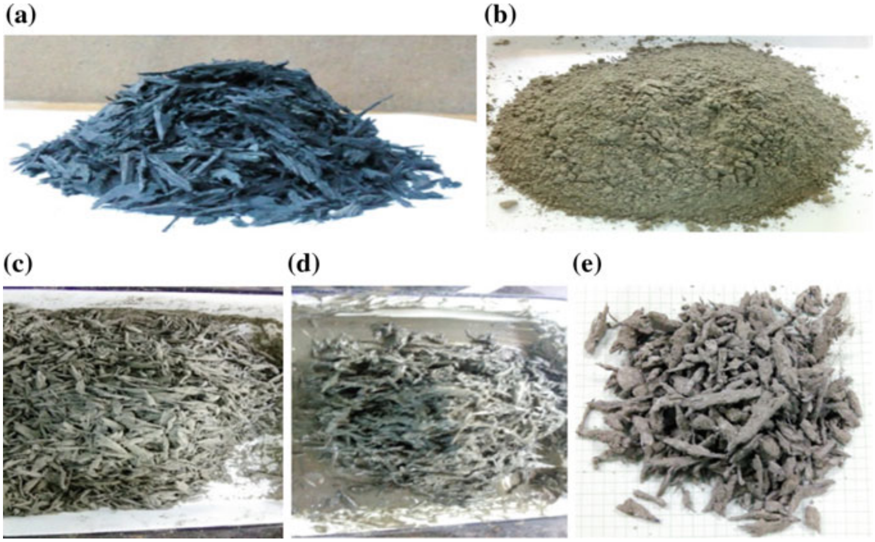

Fig. 3 Stages involved in the preparation of cement coated tyre fibres. **a** Tyre fibres, **b** Ordinary Portland Cement (OPC_53), **c** dry mixtures of tyre fibres and cement, **d** wet mixture of tyre fibres and cement, **e** cement coated tyre fibres

The wet CCTFs were kept for one day for proper bonding between tyre fibre surface and cement. After drying of wet cement coated tyre fibres were subjected to curing in water for a period of 3 days before being used in the study. The specific gravity (G_s) of uncoated fibres increased from 1.15 to 1.23, from 1.15 to 1.39, and from 1.15 to 1.5 for cement coated fibres at 1:1, 1:1.5, and 1:2 (fibres/cement) proportions, respectively. In the present study, 1:2 (fibres/cement) proportions were selected for surface modification of tyre fibres, which increase 30.43% of specific gravity of rubber fibre. The starting proportion of 1:1 was assumed as a trail proportion and then continued up to 1:3, finally 1:2 proportion has given better surface coating to the fibres. Further increase in cement proportion (beyond 1:2) in fibre/cement ratio caused the formation of cement fibre lumps, which leads to an improper coating to the fibre surface. Proper care has been taken during preparation and curing of CCTFs fibres (Fig. 3).

3 Results and Discussion

Effects of UCTFs and CCTFs on minimum and maximum dry unit weights of sand: Figure 4 show the relationship between dry unit weight and tyre fibre content. The dry unit weights of UTTFs and CCTFs decrease with the inclusion of tyre fibres. The minimum and maximum dry unit weights were determined by

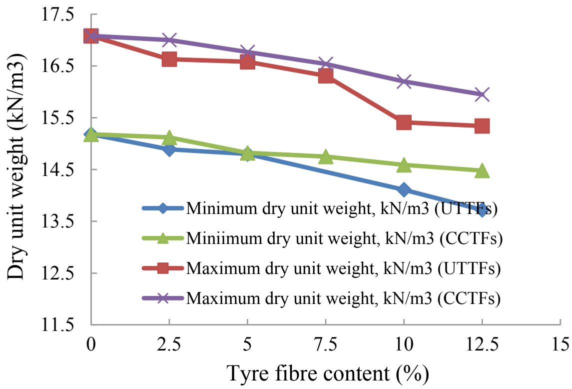

Fig. 4 Variation of minimum and maximum dry unit weights of sand with tyre fibre content

performing relative density test according to IS 2720-Part 14 (1983). The CCTFs had slightly higher unit weights compared to UTTFs, because the specific gravity of CCTFs (i.e., *G* ~ 1.5) was more than UTTFs (i.e., *G* ~ 1.15). Increase in tyre fibre content from 0 to 12.5% by dry weight of sand reduced the minimum and maximum dry unit weights for the two types of tyre fibres. The minimum dry unit weights are 15.18, 14.89, 14.8, 14.75, 14.11, 13.72 kN/m^3 and maximum dry unit weights are 17.08, 16.63, 16.58, 16.31, 15.41, 15.34 kN/m^3 at tyre fibre contents of 0, 2.5, 5, 7.5, 10, 12.5% for untreated tyre fibres (UTTFs), respectively. Similarly for cement coated tyre fibres (CCTFs) are 15.18, 15.12, 14.82, 14.75, 14.59, 14.48 kN/m^3 and 17.08, 17.0, 16.77, 16.54, 16.2, 15.95 kN/m^3, respectively. The relationship between the dry unit weight and tyre fibre content is linear with a decreasing trend.

Effects of UCTFs and CCTFs on shear stress: The results of box shear test were presented in this section. For each type of fibres (UTTFs and CCTFs), tyre fibre content (0–12.5%), and sand matrix unit weight, direct shear tests were performed using three normal stresses of 50, 100, and 150 kPa. The orientation of the tyre fibres in the sample is more or less horizontal. Figures 5 and 6 illustrate the variation of shear stress with normal stresses for tyre fibres of UTTFs and CCTFs, respectively. At an applied normal stress on specimens, the shear resistance of the sand–tyre fibre mixtures found to be greater than that of the sand alone at the same sand matrix unit. The shear resistance of the mixtures increased with increase in vertical effective normal stresses. The stress distribution depends on the uniformity of sample matrix. Assumption involved in this test is sand–tyre fibre mixtures are homogeneous, i.e., the relationship between stress and strain is linear. Figure 5 represents the variation of shear with the application of effective normal stress. The slope of the line (shear stress vs normal stress) increases with increase in UTTFs and then decreased after reaching optimum point. The average slope of the three points of effective stress (i.e. 50, 100, 150 kPa) and shear stress is taken for the measurement of angle of shearing resistance.

Effects of UCTFs and CCTFs on tyre fibre content: The shear resistance of the mixtures increases with increasing tyre fibre content up to optimum fibre content and

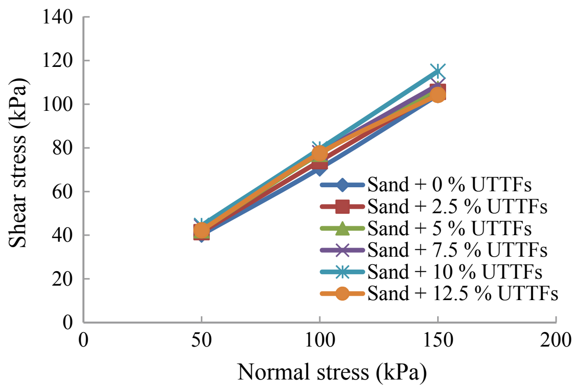

Fig. 5 Variation of shear stress with normal stress for UTTFs

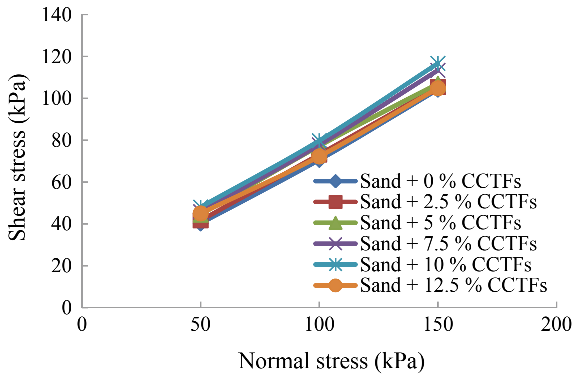

Fig. 6 Variation of shear stress with normal stress for CCTFs

then reduces. Figures 7 and 8 illustrate the variation of shear stress with tyre fibre content at normal stresses of 50, 100, and 150 kPa. For 50 kPa of normal stress, the shear stresses are 40.29, 41.41, 42.25, 43.92, 44.48, and 42.25 kPa at a fibre content of 0, 2.5, 5, 7.5, 10, and 12.5%, respectively. Similarly, for 100 and 150 kPa of normal stresses, the shear stresses are 70.62, 73.94, 77.27, 77.83, 79.53, 77.54 and 104.23, 105.68, 107.01, 108.82, 115.08, 104.27 kPa, respectively for UTTFs. For CCTFs shear stresses are 40.29, 41.69, 44.47, 45.86, 48.08, and 45.03 kPa for normal stress of 50 kPa, 70.62, 73.14, 77.27, 77.81, 79.78, and 72.27 kPa for normal stress of 100 kPa, and 104.23, 106.76, 107.01, 113.41, 116.73, and 104.82 kPa for normal stress of 150 kPa at fibre content of 0, 2.5, 5, 7.5, 10, and 12.5%, respectively. The CCTFs have the maximum shear strength over UTTFs, because of uniform mixing and strong bond between CCTFs and sand matrix. After reaching optimum content of fibres in the mixtures, the maximum load taken by the fibres and the shear resistance contribution of sand reduced due to this the shear strength reduced after optimum fibre content.

Effects of UCTFs and CCTFs on angle of shearing resistance: Figure 9 shows the variation of angle of shearing resistance with tyre fibre content for UTTFs and

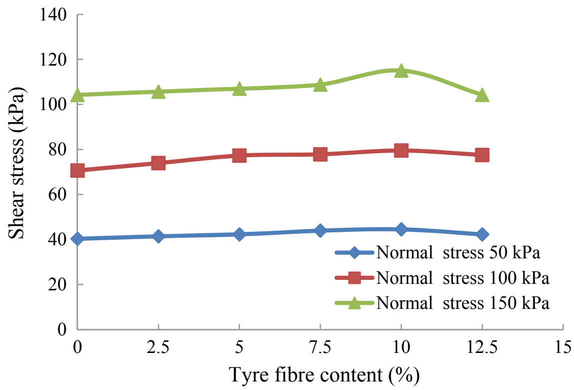

Fig. 7 Variation of shear stress with tyre fibre content for UTTFs

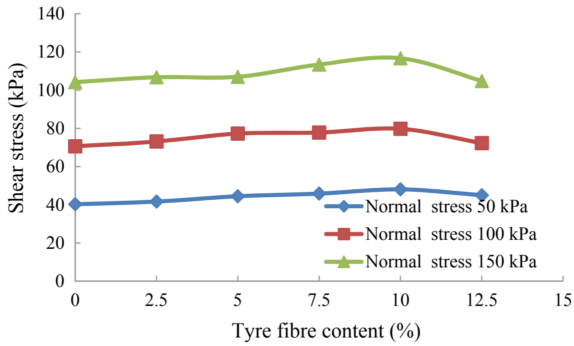

Fig. 8 Variation of shear stress with tyre fibre content for CCTFs

CCTFs, respectively. The angle of shearing resistance (ϕ) increases with the inclusion of tyre fibres. The CCTFs have higher shearing resistance than UTTFs, because the CCTFs can form uniform mixtures with sand and have strong surface bond between CCTFs–sand mixtures. The CCTFs had rough surface due to cement coating hence, CCTFs offered more shearing resistance compared to UTTFs. The angle of shearing resistance of the UTTFs are 32.59°, 33.12°, 33.32°, 33.38°, 35.22°, 31.8° and for the CCTFs are 32.59°, 33.19°, 33.26°, 34.03°, 36.46°, 33.06° at 0%, 2.5%, 5%, 7.5%, 10%, and 12.5%, respectively. Optimum fibre content is observed at 10%. The ϕ values at 10% for CCTFs and UTTFs reinforced sand are approximately 12% and 8% more than that of 0% fibre content (i.e. only sand) respectively.

4 Conclusions

The surface of the tyre fibre is modified with cement coating and the effects of the modification on the shear strength of the poorly graded sand have been investigated. The results of direct shear tests on sand–UTTFs and sand–CCTFs mixtures are

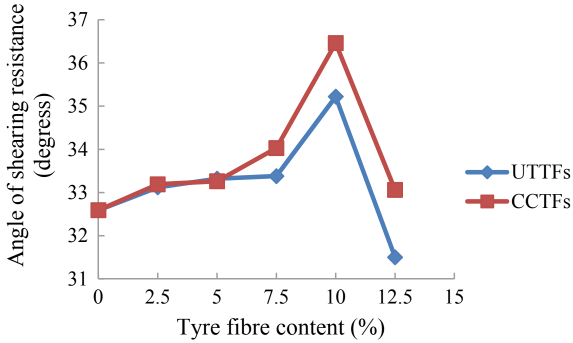

Fig. 9 Variation of angle of shearing resistance with tyre fibre content for UTTFs and CCTFs

presented, where the content of tyre fibres varies from 0 to 12.5% by weight of dry sand. From the present study, the following conclusions are made:

1. The specific gravity of the modified tyre fibre (i.e. cement coated tyre fibres) is higher by 30.43% compared to the specific gravity of untreated tyre fibres. This results in a uniform mixing of tyre fibres with sand.
2. Inclusion of tyre fibres (UTTFs or CCTFs) reduces the dry unit weight of the sand–tyre fibre mixture.
3. The shear strength of sand–tyre fibre mixture increases comparably at the optimum fibre content. The shear strength of sand–CCTFs mixture is slightly higher than that of the sand–UTTFs mixture, due to uniform mixing and strong bond between the CCTFs and sand particles.
4. The angle of shearing resistance of sand increases by 12% with the inclusion of optimum tyre fibres, i.e., 10%. Further inclusion of tyre fibres reduces the shear strength of sand.
5. The type of tyre fibres (i.e., UTTFs and CCTFs), tyre fibre content, and the normal stresses are the influencing factors governing the shear strength of the mixture.
6. The waste tyre fibres can be used as soil reinforcement in the field of geotechnical engineering. However, the long-term effects of the use of such fibres need to be addressed.

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Effects of Granulated Ground Blast Furnace Slag and Fly Ash on Stabilization of Soil

Arshad Tyagi and D. K. Soni

Abstract My research work is oriented towards the extended studies on stabilization of soil using industrial waste Granulated Ground Blast Furnace Slag (GGBFS) to achieve positive results for index properties, compaction characteristics and strength characteristics by investigating so many soil samples with varying proportions of GGBFS and Fly Ash by weight of soil. Main objective of this research paper is to elaborate and take previous studies to another level and to establish a conclusion that GGBFS and Fly Ash are best byproduct stabilizer material for increasing the strength and stability of soil by investigating samples of soil. In this dissertation, effect of GGBFS and Fly Ash on various engineering properties, i.e. plastic limit, liquid limit, specific gravity, optimum moisture content, maximum dry density, unconfined compressive strength and California bearing ratio value have been investigated. During the course of investigation, GGBFS and Fly Ash were used in proportions of 0%, 5%, 10%, 15%, 20%, 25%, 30% and 0%, 3%, 6%, 9%, 12%, 15%, 18% respectively by weight of soil sample for various experiments. Finally, on the bases of experimental results it is concluded that the utilization of industrial wastes, i.e. GGBFS and Fly Ash are much effective in terms of cost, time, stability, strength and also environment friendly for the construction purpose.

Keywords GGBS · Fly ash · Soil stabilization · Compaction · Strength

1 Introduction

There are mainly three types of soils found in India namely alluvial soil, black cotton soil and red soil. Some of these soils show major volume changes due to change in the moisture content. This causes major damage to property and structure constructed on it. These soils contain minerals such as montmorillonite that are capable of absorbing water. When they absorb water their volume increases and when water evaporates the soil shrinks and volume decreases. This alternate wetting and drying of soil

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_9

results in micro and macro cracks and a remarkable settlement of soil mass. Some of these soils show a remarkable settlement due to expulsion of air and water as a result of compaction and consolidation respectively. In order to face these challenges mechanical compaction, dewatering and earth reinforcement have been found to improve the strength of the soils, other methods like stabilization using admixtures are more advantageous. The different admixtures available are lime, cement, fly ash, blast furnace slag, etc.

In developing country like India due to the extensive development in embankment and road infrastructure, soil stabilization has become the major issue in construction activity. Stabilization is an inevitable for the purpose of highway and runway construction, stabilization denotes improvement in both shear strength and durability which are related to long-term performance of soil. The emphasis is definitely placed upon the effective utilization of wastes byproducts like Granulated Ground Blast.

Furnace Slag (GGBFS) and Fly Ash, with a view to decrease the construction cost and increase the soil suitability. In the present investigation the evaluation of the shear strength, compaction, UCS and CBR values of the stabilized soil using ground granulated blast furnace slag (GGBFS) and Fly Ash has been done. This new technique of soil stabilization can be effectively used to meet the present challenges of society, to reduce the quantities of waste, producing useful material from non-useful waste material. Around 120 million tonnes of fly ash get accumulated every year at the thermal power stations in India. Internationally Blast Furnace Slag and Fly Ash are considered as best byproducts that can be used for many applications. Blast Furnace Slag Mission was initiated in 1994 to promote its gainful bulk utilization in the construction of roads and embankments.

2 Literature Reviews

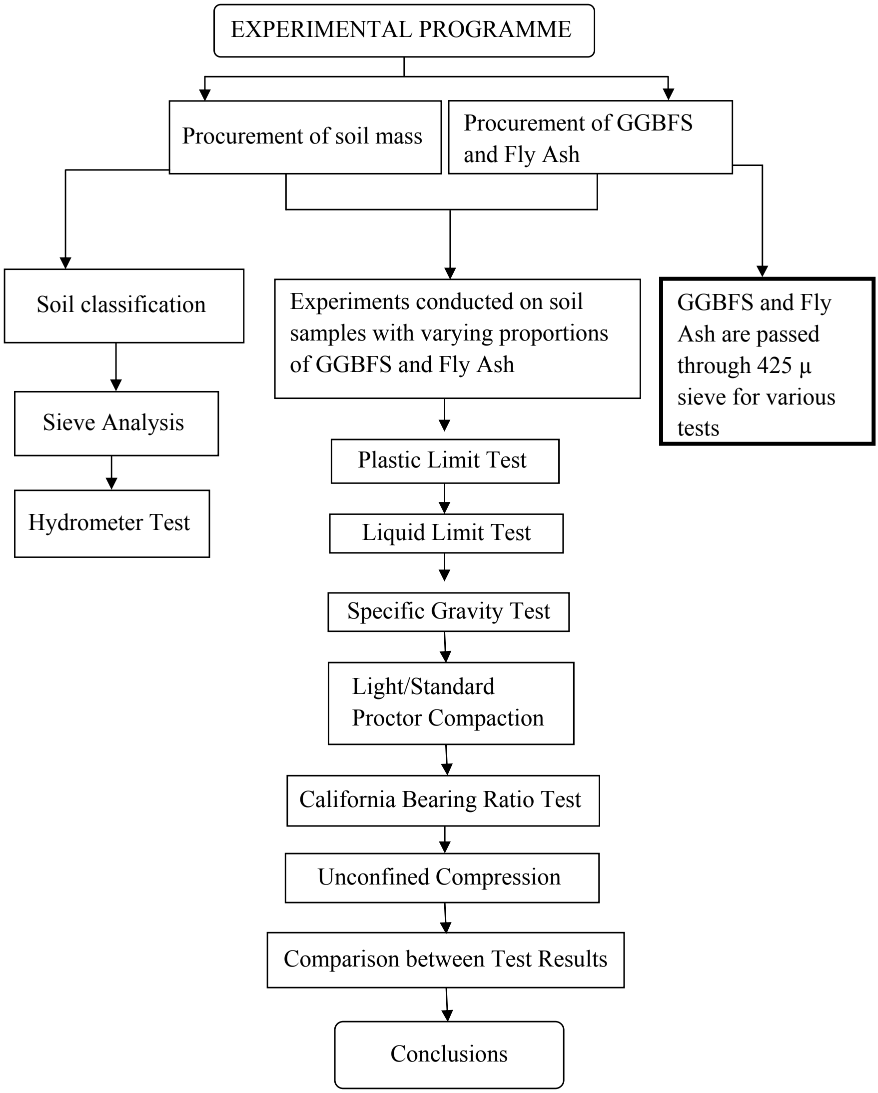
Ashish Kumar Pathak et al. (2014) studied the soil stabilization using GGBFS. The GGBFS was procured from blast furnace of cement plant, which is the byproduct of iron (ACC Plant, Sindri). The effect of different proportions of GGBFS (0–25%) on different engineering properties (OMC, MDD, Plastic Limit, Liquid Limit, Unconfined Compressive strength and CBR value) was investigated. The addition of GGBFS resulted in a dramatic improvement in soil properties.

Osman Sivrikaya et al. (2014) studied on the effects of GGBFS on the index and compaction properties of clayey soils. The GGBFS was procured from the Iskenderum Iron Steel Plant as an industrial waste. The effect of GGBFS was studied on low plasticity kolsuz clay and high plasticity bentonite clay in various proportions (5, 10, 20, 30 and 50%). Based on experimental results, it is clear that GGBFS has a positive effect on the stabilization of both clayey soils. It was also concluded that the improvement in bentonite clay is greater than that in kolsuz clay.

3 Experimental Programme

Collection of Blast Furnace Slag and Fly Ash from Rana Group of Steel Industries Muzaffarnagar (UP) and utilize them to modify the major properties of soils which are not favourable for infrastructure development commonly occurring in Haryana.

To study the geotechnical properties and carry out various tests, the soil mass was procured from the campus of NIT Kurukshetra, Haryana.



4 Test Results and Discussion

4.1 Properties of GGBFS and Fly Ash

Granulated Ground Blast Furnace Slag (GGBFS) and Fly Ash were procured from Rana Group of Steel Industries Muzaffarnagar (UP). The main components of the blast furnace slag and fly ash are CaO, SiO_2, Al_2O_3 and MgO. The physical and chemical properties of GGBFS and Fly Ash that I have brought from the producer are shown in Tables 1, 2 and 3.

Table 1 Physical properties of GGBFS in percentage

Properties	Values
Specific gravity	2.88
Bulk density (kg/m^3)	1210
Surface area (m^2/kg)	425
Insoluble residue (%)	0.16
Loss on ignition (%)	0.20
Moisture content (%)	0.13

Table 2 Chemical properties of GGBFS in percentage

Composition	Percentage (%)
CaO	35.80
SiO_2	32.85
Al_2O_3	14.40
MgO	9.00
MnO	0.08
Fe_2O_3	0.80
Sulphide sulphur	2.25
Sulphite sulphur	0.25
Total chlorides	0.02

Table 3 Chemical properties of fly ash in percentage

Composition	Percentage (%)
SiO_2	51.83
Al_2O_3	20.83
CaO	11.21
Fe_2O_3	4.81
MgO	3.67
K_2O	1.56
SO_3	1.39
Na_2O	0.61

Table 4 Plastic limit of soil sample

GGBFS (%)	Fly ash (%)	Experiment 1	Experiment 2
0	0	21.83	21.68
5	3	20.13	20.10
10	6	17.61	17.53
15	9	15.76	15.57
20	12	13.71	13.42
25	15	12.61	12.31
30	18	11.13	11.18

4.2 Plastic Limit Test

The plastic limit is defining limit of soil until which soil remains in plastic state. The plastic limit is defined as the moisture content where the thread breaks apart at diameter of 3 mm. PL computes the average of the water contents obtained from the three plastic limit tests. The plastic limit (PL) is the average of the three water contents. This test was performed as per IS 2720 (Part 5) 1985 (Table 4).

4.3 Liquid Limit Test

Liquid limit is defined as the moisture content at which soil begins to behave as a liquid material and begin to flow. The liquid limit is determined in the laboratory as the moisture content at which the two sides of the groove cut in soil come simultaneously and touch a distance of half inch after 25 blows. We can plot these results as number of blows versus moisture content and interpolate the moisture content at 25 blows from the graph. This test was performed as per IS 2720 (Part 5) 1985 (Table 5).

Table 5 Liquid limit of soil sample

GGBFS (%)	Fly ash (%)	Experiment 1	Experiment 2
0	0	26.58	26.71
5	3	24.10	23.98
10	6	22.48	22.33
15	9	20.81	20.51
20	12	19.61	19.46
25	15	18.23	17.93
30	18	16.95	16.32

Table 6 Specific gravity of soil sample

GGBFS (%)	Fly ash (%)	Experiment 1	Experiment 2
0	0	2.62	2.60
5	3	2.63	2.61
10	6	2.64	2.63
15	9	2.66	2.65
20	12	2.67	2.66
25	15	2.65	2.64
30	18	2.64	2.63

4.4 Specific Gravity Test

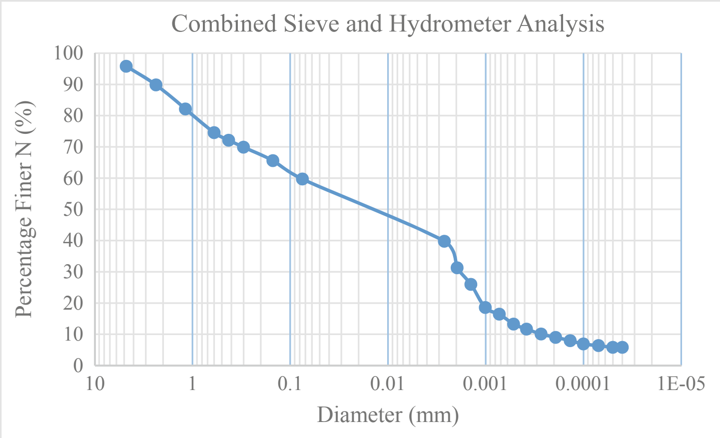
Specific gravity is defined as the relative amount of the weight in air of a given volume of a material at a specified temperature to the weight in air of the same volume of distilled water at a specified temperature. The pycnometer is used for determination of the specific gravity of the soil particles for both fine-grained- and coarse-grained soils. This test was performed as per IS 2720 (Part 3) 1980 (Table 6).

4.5 Sieve Analysis

This test is performed to determine the proportion of different grain sizes contained in the soil mass of NIT Campus Kurukshetra, Haryana. Sieve analysis is performed to determine the distribution of the finer and coarser sized particles. Grain size analysis provides the grain size distribution and it is required in classifying the soil. This test was performed as per IS 2720 (Part 4) 1985 (Tables 7 and 8).

Table 7 Particle size distribution

IS Sieve (mm)	Wt. of soil retained (gm)	Percentage wt. retained (%)	Cumulative percentage wt. retained (%)	Percentage passing (N%)
4.75	12.60	4.20	4.20	95.80
2.36	17.88	5.96	10.16	89.84
1.18	23.13	7.71	17.87	82.13
0.600	22.74	7.58	25.45	74.55
0.425	7.38	2.45	27.90	72.10
0.300	6.60	2.20	30.10	69.90
0.150	12.96	4.32	34.42	65.58
0.075	17.67	5.89	40.31	59.69
Pan	179.07	59.69	100	0.00



4.6 *Light/Standard Proctor Test*

Light/Standard Proctor compaction test is a laboratory method of tests to define the Optimum Moisture Content (OMC) at which a given soil will get specifically its Maximum Dry Density (MDD). A graph is drawn between water content and dry density to obtain the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC). This test was performed as per IS 2720 (Part 7) 1980 (Table 9).

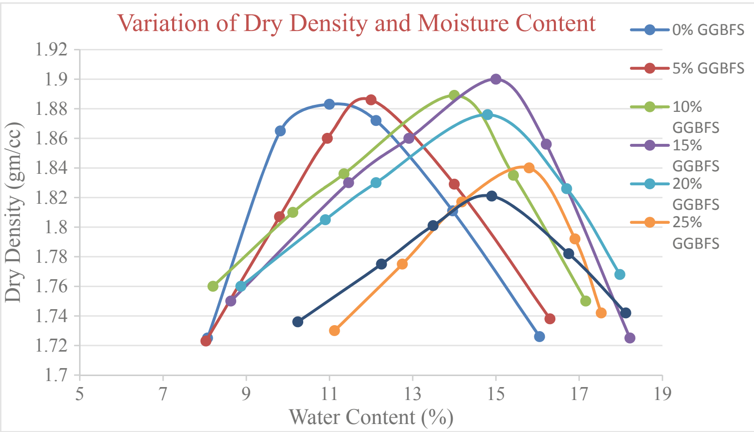
Table 8 Index properties of soil

Test	Parameters		Symbol	Description
Sieve analysis	Sand		S	36.11
	Silt & clay		M & C	59.69
Atterberg's limits	Liquid limit		W_L	26.58
	Plastic limit		W_P	21.83
	Plasticity index	$I_P = W_L - W_P$	I_P	4.75
		A–line equation	$I_P = 0.73(W_L - 20)$	4.80
Classification of soil				ML

Table 9 Effect of GGBFS on OMC and MDD

GGBFS (%)	Fly ash (%)	Optimum moisture content (%)	Maximum dry density g/cc
0	0	11	1.883
5	3	12	1.888
10	6	14	1.900
15	9	15	1.912
20	12	14.75	1.882
25	15	15.65	1.846
30	18	14.85	1.829

4.7 Moisture Content Versus Dry Density Curves



4.8 California Bearing Ratio Test

The CBR is a penetration test for evaluation of mechanical strength of road sub grades and base coarses. It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/mint to that required for the corresponding penetration of a standard material. This test was performed as per IS 2720 (Part 16) 1987 (Tables 10 and 11).

Table 10 Effect of GGBFS on CBR value for un-soaked soil

GGBFS (%)	Fly ash (%)	CBR in % at 2.5 mm penetration	CBR in % at 5 mm penetration
0	0	6.93	5.73
5	3	7.62	6.10
10	6	7.90	6.38
15	9	8.18	6.56
20	12	8.60	6.75
25	15	8.87	6.93
30	18	9.43	7.49

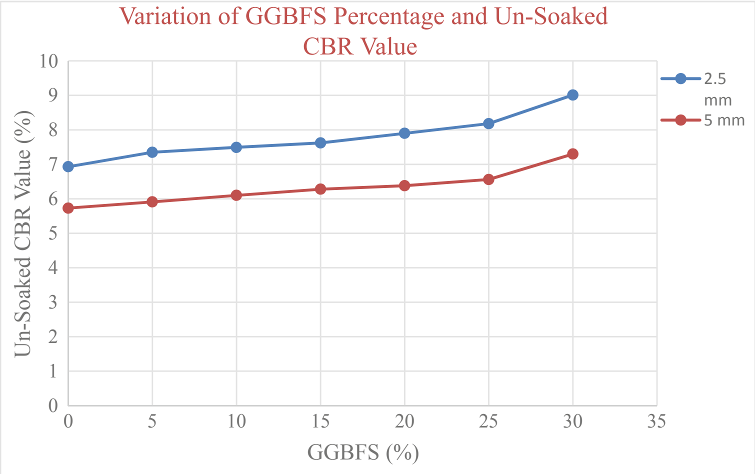
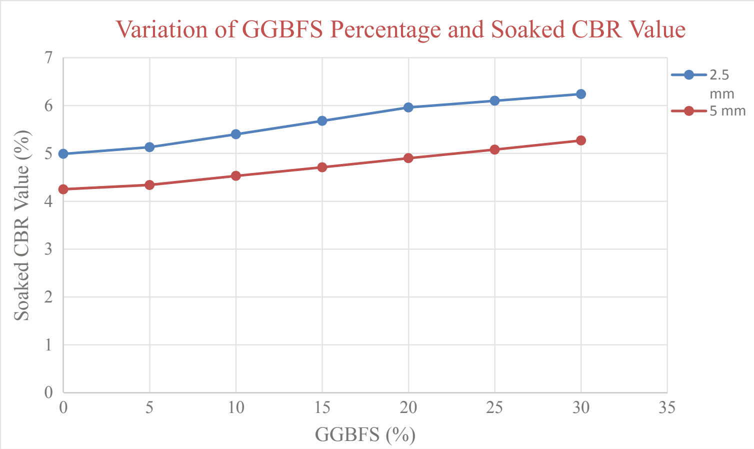


Table 11 Effect of GGBFS on CBR value for soaked Soil

GGBFS (%)	Fly ash (%)	CBR in % at 2.5 mm penetration	CBR in % at 5 mm penetration
0	0	4.99	4.25
5	3	5.40	4.53
10	6	5.68	4.90
15	9	6.10	5.08
20	12	6.51	5.27
25	15	6.80	5.73
30	18	7.35	6.19

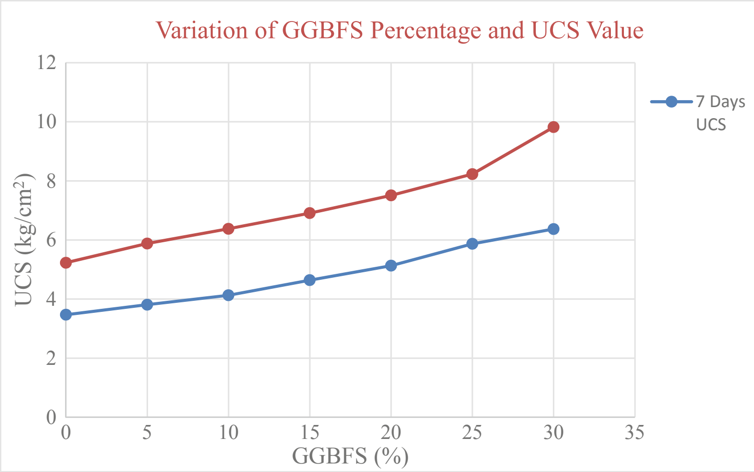


4.9 Unconfined Compression Test

The unconfined compression test is by far the most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The unconfined compressive strength is the load per unit area at which an unconfined cylindrical specimen of soil will fail in a simple compression test. This test was performed as per IS 2720 (Part 10) 1991 (Table 12).

Table 12 Effect of GGBFS on compressive strength of soil

GGBFS (%)	Fly ash (%)	7 days unconfined compressive strength (kg/cm^2)	14 days unconfined compressive strength (kg/cm^2)
0	0	3.47	5.23
5	3	3.95	5.97
10	6	4.63	6.76
15	9	5.39	7.59
20	12	6.13	8.36
25	15	6.79	9.30
30	18	7.29	10.43



5 Conclusions

The study has been conducted to assess the potential of GGBFS and Fly Ash for the stabilization of the soil and detailed comparison has been presented based on various properties of soil. By analysis of results the following conclusions may be drawn:

(1) The primary benefits of using these additives for soil stabilization are

  (a) Cost Saving: because slag and fly ash is typically cheaper than cement and lime, and
  (b) Availability: because slag and fly ash sources are easily available across the country from nearby steel plants.

(2) Waste management of the industrial wastes can be done economically.
(3) Use of slag and fly ash as an admixture for improving engineering properties of the soils is an economical solution to use locally available poor soil.
(4) It is observed that with increase in percentage of slag and fly ash, more stability of soil is achieved as compared to untreated soil.
(5) With the increase in GGBFS and Fly Ash percentage, Optimum Moisture Content (OMC) goes on increasing while Maximum Dry Density (MDD) first goes on increasing and then decreasing, hence, the maximum compaction of soil is achieved at 15% OMC, 15% GGBFS, and 9% Fly Ash.
(6) With the increase in GGBFS and Fly Ash percentage, Specific Gravity (G) first goes on increasing and then decreasing, hence, the maximum value of specific gravity is achieved at 20% GGBFS and 12% Fly Ash.
(7) With the increase in GGBFS and Fly Ash percentage, percentage finer goes on decreasing, which strengthens the soil.

(8) With the increase in GGBFS and Fly Ash percentage, Liquid Limit and Plastic Limit decreases, which makes the soil less plastic and hence Plasticity Index reduces.
(9) CBR value for soaked and un-soaked condition increases with increase in the percentage of GGBFS and Fly Ash which shows that the densification of soil takes place and the soil is more suitable for pavement construction.

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Soil Stabilisation Using Plastic Waste

Kamal Singh and Anupam Mittal

Abstract Stabilisation of a fine-grained soil using plastic waste is experimentally investigation in this study. Samples are prepared by mixing with four different plastic waste contents (0, 0.5, 1, and 1.5% of weight of dry soil). Variations in compaction characteristics and Unconfined compressive strength are investigated as per Indian standard experimental procedures. Percentage decrease/increase in the stated parameters is computed with respect to their untreated value. Study shows that plastic waste additive increases maximum dry density, optimum moisture content, and unconfined compressive strength to some extent. The plastic waste cut into strips form of size 5 mm × 3 mm

Keywords Soil stabilisation · Silt · Plastic waste · PET · Compaction · UCS

1 Introduction

Plastic bottles made of Polyethylene Terephthalate (PET) are un-decomposable and destructible if it is melted it releases a compound gas which is very harmful to health and environment. Increased use of plastic bottles in day-to-day consumer application has the result in bottled water is fastest growing beverage industry in the world. From consumer market research company Euromonitor, The Guardian reported that 20,000 plastic bottles are brought every second around the world. About 480 billion bottles were purchased globally in 2016 but less than half get recycled. Arpitha et al. (2017) studied the effects of plastic waste on soil with respect to the variations of California Bearing Ratio test (CBR). Results showed that CBR values of soil increases with increasing plastic waste content up to a specified percentage of plastic waste. In this study, fine-grained soil sample is tested with different plastic waste contents and the variations in Unconfined Compressive Strength and compaction characteristics of the sample are investigated. The percentage increase of these parameters with different

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_10

plastic waste contents is computed with respect to the untreated values. Comparison of plastic waste admixture with some common admixtures like RHA, lime, cement, lime-fly ash, plastic begs, etc., can be pursued as a future scope of this study. Effect of variation of curing period (1, 3, 7, 14, 28 days) can also be investigated from lateral standpoint. Based on previous study more than 2% of plastic waste will reduce the strength of soil hence four samples with plastic waste contents (0, 0.5, 1, 1.5% of weight of dry soil) are tested.

2 Methodology

2.1 Materials

2.1.1 Soil

Soil was collected locally from NIT Kurukshetra. Sample was obtained from 3 m depth below the ground surface was tested for their geotechnical properties and strength characteristics. The various tests conducted to obtained geotechnical parameters are specific gravity test, sieve analysis of soil, liquid limit, plastic limit, Standard Proctor test, UCS test. Physical Properties of soil as shown in Table 1.

2.1.2 Plastic Waste

In this project plastic waste in the form of plastic strips is collected from Yamunanagar, Haryana. Aspect ratio of plastic strip is 1. Physical properties of PET as shown in Table 2.

Table 1 Properties of soil

S. no.	Properties of soil	Test result
1	IS classification (10% clay, 65% silt, 25% sand)	ML
2	Specific gravity	2.556
3	Liquid limit (%)	24.58
4	Plastic limit (%)	16.456
5	Plasticity index	8.124
6	Maximum dry density (g/cm^3)	1.779
7	Optimum moisture content (%)	12.60

Table 2 Properties of plastic waste

S. no.	Behaviour parameters	Values
1	Chemical formula	$(C_{10}H_8O_4)_n$
2	Molar mass	Variable
3	Density	1.38 g/cm^3
4	Melting point	>250 °C
5	Boiling point	>350 °C
6	Solubility in water	Insoluble

2.2 Methodology

2.2.1 Standard Proctor Test

It is a test in which mechanical energy is provided to reduce voids and increase density. In this test dry density of soil calculated for different proportion of water content and then a curve is plotted between water content and dry density which gives MDD and OMC. Standard Proctor test is conducted on four different samples with different replacement percentage of plastic waste from 0 to 1.5% as per IS 2720 (part 7): 1980

2.2.2 Unconfined Compressive Strength Test

To determine the unconfined compressive strength of fine-grained soil, remoulded compacted specimen is prepared in a cylinder (38 mm diameter, 76 mm length) by adding required water (OMC). Then wrap it tight in a polythene cover and place it in a desiccator containing little water and place the desiccator in a constant temperature room after 7 days curing unconfined compressive strength test is carried out and reading was noted as per IS 2720 (part 10): 1973

3 Results and Discussions

3.1 Standard Proctor Test Results

Standard Proctor test is performed as per the guidelines of IS-2720 (part 7): 1980. The compaction curves of untreated soil and plastic waste mixed soils are plotted in Fig. 1. The increase in the MDD can be attributed to the replacement of soil particles by the comparatively larger plastic waste particles. Increase/Decrease in MDD values with the percentage of plastic waste are shown in Fig. 2.

Fig. 1 Compaction curve

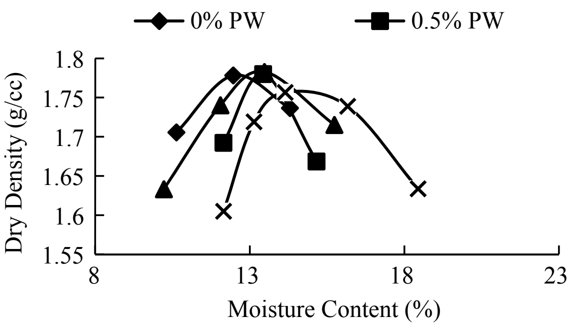
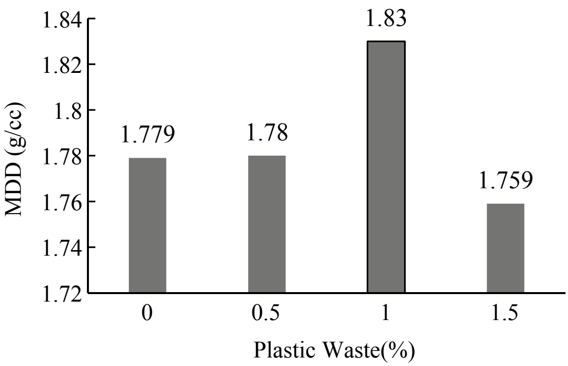


Fig. 2 Plastic waste versus MDD



3.2 *Unconfined Compressive Strength Test Results*

The curves obtained from unconfined compression test performed as per IS-2720: part 10: IS-2720: part 10: 1991 on treated samples (mixed with 0.5, 1, and 1.5% plastic waste) are compared with that of untreated sample in Fig. 3. Increase/decrease in UCS values of treated soils with the percentage of plastic waste as shown in Fig. 4. It can be seen that the untreated soil is having a low value of UCS, whereas after addition of plastic waste content from 0.5 to 1%, a substantial increase in unconfined compressive strength (nearly 2–13%) is observed. It is to be noted that the plastic waste treated samples are cured for 7 days maintaining water content equal to the optimum water content. With the addition of plastic to the sample of soil there is an increase in the cohesion of soil which leads to increase in the unconfined compressive strength of the soil. But further increase in the plastic content leads to decrease in the cohesion and thereby decrease in the strength.

Fig. 3 Result of unconfined compression strength test (stress vs. strain curve)

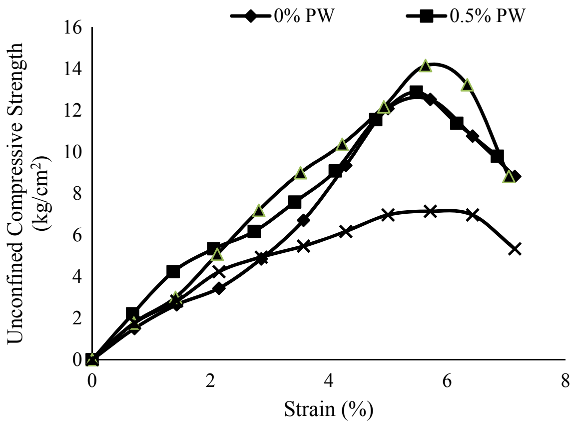
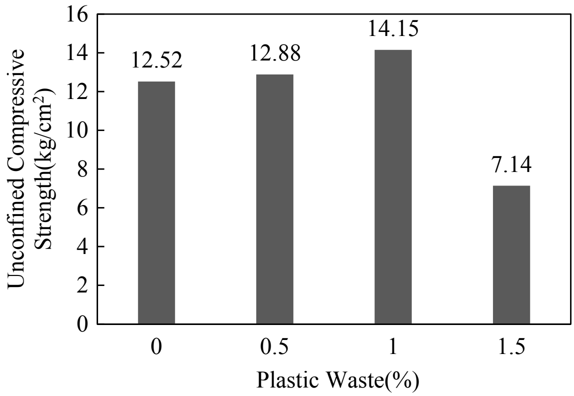


Fig. 4 Graph for optimum proportion of strips (strength vs. plastic waste)



4 Conclusions

This study is focused on the review of performance of plastic waste as a soil stabilisation material. The study suggest following conclusions.

1. Study reveals that the parameter that drastically improves with addition of plastic waste is Unconfined Compressive Strength (UCS) of soil. Addition of 0.5–1% plastic waste increases the UCS by 3–13% compared to that of untreated soil.
2. Addition of plastic waste content shows marginal effect on Maximum Dry Density. Study shows that MDD of treated soils (with plastic waste content 0.5–1%) increases by roughly 0.06–0.23% with respect to that of untreated soil.
3. Addition of plastic waste content (0.5–1.5%) increases the OMC by 3–13% with respect to untreated soil .

4. We can conclude from the results obtained after performing the test with plastic bottles strips that 1% of the total weight of the soil is the optimum proportion to be added to the soil for reinforcement but it decreases further percentage of plastic bottles strips is added.

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Effect of Fly Ash on Permeability of Soil

Sourav Debnath and Anupam Mittal

Abstract Permeability of soil is one of the most significant property. It controls the hydraulic stability of soil mass. It is dependent on various index properties like particle size of soil, percentage of impurities, void ratio, etc. However, permeability of soil is difficult to find out and it consumes time, especially in the case of fine grained soils. In this paper, change in permeability of soil due to mixing of additive (Fly ash) is investigated. Experiments were conducted in the National Institute of Technology, Kurukshetra soil laboratory. Various samples were collected for laboratory investigations to determine various soil parameters such as specific gravity, grain size distribution (particle mean size), and coefficient of permeability. Collected soil for the experiment is locally available sand. Additives are added in collected soil samples at different replacement ratios. Permeability of sample is checked and it is observed that permeability of sand firstly decreases up to a certain limit, then it increases.

Keywords Permeability · Flyash · Specific gravity · Particle mean size

1 Introduction

The behavior of any structure depends upon the property of soil on which the structure is constructed. To assure safe and good condition of the structure for a longer time, it should be constructed on a soil which has good properties. When we design a structure, condition of soil beneath the structure should be known to reduce general construction problems. Without proper knowledge of soil, it is very risky to design a structure. Soil properties depend upon grain size distribution, specific gravity, soil classification, permeability, etc. It is the property of soil by which fluid is allowed

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes
in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_11

to pass through its void space (Liu and Evett 1984). So, permeability of soil is very crucial for any construction (e.g., under seepage, retaining wall, road construction, etc.) as it can influence the stability of the structure. Permeability of soil depends on various factors like void ratio, grain size distribution, entrapped air, and texture of soil. Impurities can also affect the permeability of parent soil. Fly ash is the waste generated by thermal power plants. The disposal of fly ash is a major problem for environmental and civil engineers. The usage of fly ash may be a feasible alternative as a backfill material because it mainly consists of silt-sized particles having high permeability (Prashanth et al. 2001). So, the utilization of fly ash is very much important in soil improvement and the relation between permeability and other engineering properties like grain size, specific gravity, and percentage of flyash content are to be determined. The main objective of this study is to determine the permeability of sand–flyash mixture for different replacement ratio.

2 Methodology

Prashanth et al. (2001) studied that flyash having silt size particle has high permeability as compared to clay. Locally available sand was collected from campus of National Institute of Technology Kurukshetra, Kurukshetra, Haryana, India and flyash was collected from Panipath thermal power plant, Panipath, Haryana, India. To check the effect of fly ash on permeability of sand various amount of flyash was added at different replacement ratios. Total 10 samples were prepared for testing. Each soil sample has undergone different laboratory test.

(I) Specific Gravity test was done according to IS: 2720 (part 3)-1980a, b.
(II) Grain size analysis was done according to IS: 2720 (part 4)-1985.
(III) Falling head permeability test was done according to IS: 2720 (part 17)-1986.
(IV) Relative density test was conducted according to IS: 2720 (part 14)-1983.

(I) Specific Gravity Test: The objective of this test is to find out the specific gravity of the sample.

Specific gravity is the ratio between weights of soil in air to weight of equal amount of water at 27 degrees Celsius. By this specific gravity, we can also find the density of soil. Pycnometer is used to find out the specific gravity. This test is conducted according to IS: 2720 (part 3)-1980a, b guideline.

(II) Grain Size Analysis: This test is done to find out the grain size of samples. 200 grams sample was taken, then it was placed on the properly arranged IS sieve according to IS: 2720 (part 4)-1985 guideline and it was shaken properly for a specific time. After that, the retaining material from each sieve was collected and weighed. The percentage of fineness of each sieve material was calculated. Depending on the experimental result, grain size distribution curve was drawn and required grain size is achieved.

(III) Falling Head Permeability Test: Falling head permeability test was conducted according to IS: 2720 (part 17)-1986. The falling head permeability test

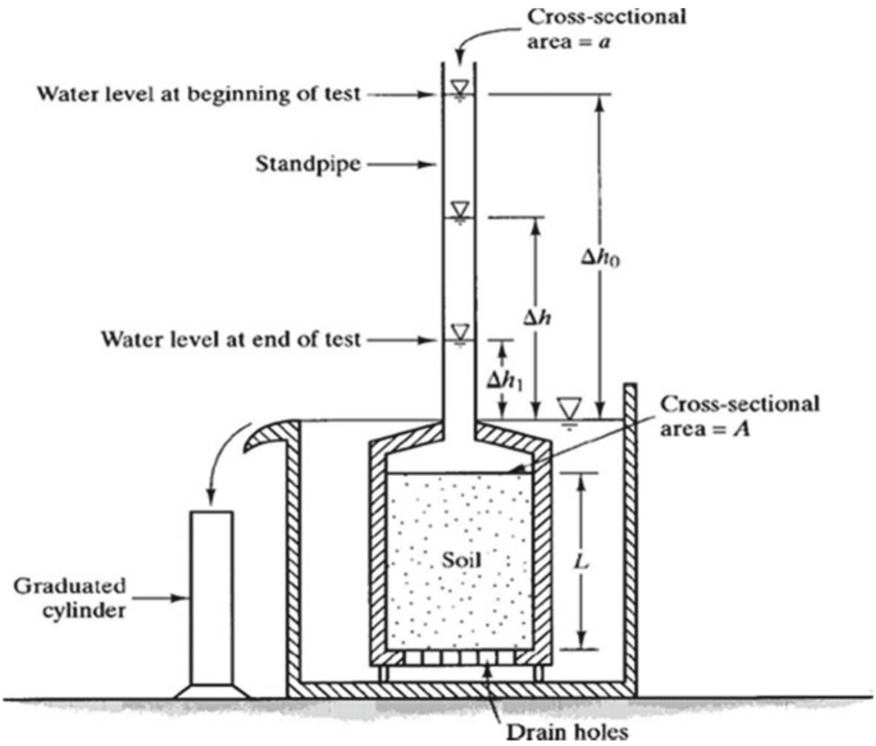

Fig. 1 Falling head permeability test apparatus

(Fig. 1) permits the water flowing through a small soil sample attached to a graduated standpipe providing measurement of the water head along with the volume of water passing through the sample. We can find the permeability of sample by following equation:

$$k = \frac{al \ln\left(\frac{h_1}{h_2}\right)}{At} \quad (1)$$

where

k Coefficient of permeability in cm/s
a Area of falling head tube in cm^2
A Area of specimen in cm^2
l Length of the specimen in cm
h_1 Initial head in cm
h_2 Final head after time t
t Time interval between two head reading in s

Table 1 Properties of sand

S. no.	Property	Value
1	Effective size (D_{10})	0.190 mm
2	D_{60}	0.450 mm
3	D_{30}	0.3 mm
4	Coefficient of uniformity (C_u)	2.368
5	Coefficient of curvature (C_c)	1.05
6	IS classification	SP
7	Specific gravity	2.65
8	Minimum dry density	1.40 g/cm^3
9	Maximum dry density	1.613 g/cm^3
10	Minimum void ratio (e_{min})	0.643
11	Maximum void ratio (e_{max})	0.887
12	Void ratio (e)	0.683
13	Relative density	87.6%

Table 2 Property of flyash

S. no.	Property	Value
1	Specific gravity	2.1
2	C_u	2.73
3	C_c	0.9056
4	Color	Gray

(IV) Relative Density Test: Relative density is parameter by which we can determine the degree of denseness or looseness of cohesion less soil. Relative density or density index is the ratio of the difference between the void ratios of a cohesionless soil in its loosest condition and the existing natural condition to the difference between its void ratio in the loosest and densest condition. This test is conducted by according to IS: 2720 (part 14)-1983. We can find the relative density by the following equation:

$$\text{Relative Density} = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (2)$$

where

e_{max} Void ratio in loosest state
e_{min} Void ratio in densest state
e Void ratio in natural state

Experimental result regarding properties of sand is shown in Table 1. Properties of flyash are shown in Table 2.

Table 3 Property of mixture

Percentage of flyash	Percentage of sand	Specific gravity	D_{50} (mm)	Permeability (cm/s)
0	100	2.65	0.42	0.00033
10	90	2.60	0.26	0.000325
20	80	2.54	0.25	0.0003114
30	70	2.49	0.22	0.0002676
40	60	2.43	0.20	0.0002294
50	50	2.38	0.20	0.0001986
60	40	2.32	0.16	0.0001248
70	30	2.27	0.12	0.00002356
80	20	2.21	0.088	0.0001782
90	10	2.16	0.085	0.0001936

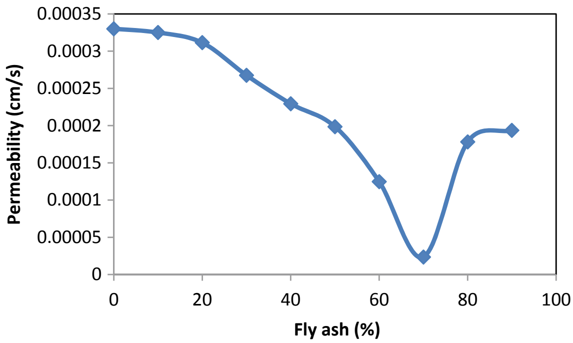

Fig. 2 Permeability versus percentage of fly ash

3 Results and Discussion

Percentage of flyash replacements, specific gravity, particle mean Size (D_{50}), average permeability of different samples are shown in Table 3. A relationship between percentage of flyash and permeability of sample is shown in Fig. 2. It indicates that if the percentage of fly ash increases, the permeability of sample decreases up to a certain limit, after that permeability of sample started increasing with increase in the percentage of fly ash. It is found that pure sand has maximum permeability and when mixture has the proportion of 70% flyash and 30% sand, it has minimum permeability. In accordance to it, we have derived Fig. 3, which shows that increase in percentage of flyash in sand decreases the particle mean size (D_{50}) of the mixture due to increase of fineness of mixture. So, obtained maximum particle mean size for pure sand is 0.42 mm.

Figure 4 represents the relationship between specific gravity and flyash percentage. This figure suggests that if we increase the percentage of flyash in sand then specific gravity of mixture reduces.

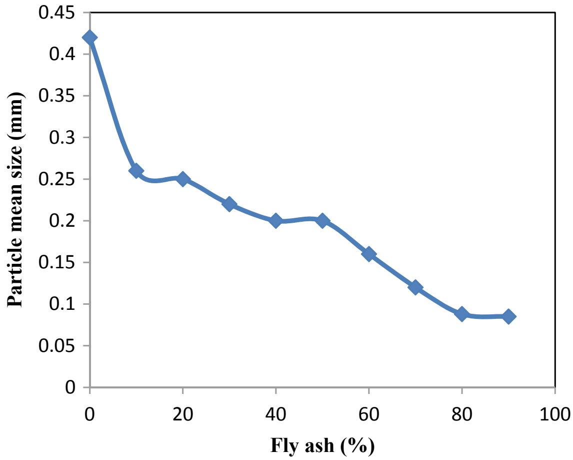

Fig. 3 Particle mean size (D_{50}) versus fly ash (%)

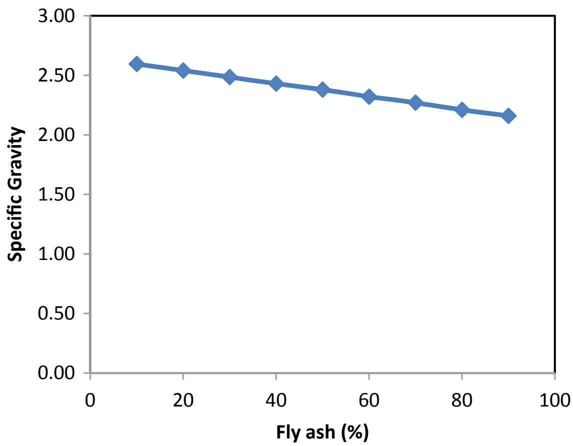

Fig. 4 Specific gravity versus flyash (%)

Figure. 5 depicts the relationship between permeability and time for different percentage of fly ash quantity. It shows that the permeability of soil decrease with increase in time.

4 Conclusions

Study of permeability of the soil is an important element of hydraulic and structural studies. For construction of road, using material with low permeability will prevent water flow from one side to another which will lead the structure with longer durability. Results of this study show that with increase in flyash content in sand, permeability of the mixture decreases as flyash has lower specific gravity than sand. On

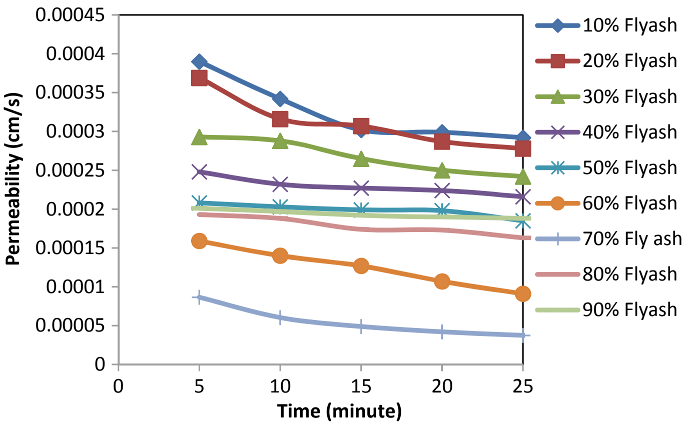

Fig. 5 Permeability versus time

the other hand, particle mean size also decreases with increase in fly ash percentage because flyash has finer particle than sand. Experiment also shows that permeability of soil decreases with time. Finally, minimum permeability, i.e., 2.356×10^{-5} cm/s is achieved at 70% flyash content and 30% sand content. From environmental perspective also using of fly ash in construction to get lower permeable material at low cost is beneficial. So, mixture of 70% fly ash content and 30% sand content with minimum permeability, i.e., 2.356×10^{-5} cm/s is cost effective which can be used as raw material for construction.

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Influence of Waste Marble Powder and Metakaolin on Strength Properties of Concrete: A Short Review

Shubham Sahni, Sudhir Arora and Ranjodh Singh

Abstract Current article reviews the results of various research studies which were carried out in the recent past to investigate the compressive strength of concrete containing Waste Marble Powder (MP) and metakaolin (MK) as a replacement of fine aggregates and cement. A number of research studies were reviewed to check the potential of MP and MK as partial replacement of fine aggregates and Portland cement respectively. Various researchers replaced the fine aggregates in the range of 0–50% with MP reported the increase in compressive strength, however beyond 20% replacement the strength properties went on decreasing. Consequently most of the research studies reported that Portland cement was replaced with the MK in the range of 0–20%. The strength enhancement reported from 7 to 15% replacement levels of MK with Portland cement beyond that replacement level of MK their existed adverse effect on strength properties of concrete. The potential of these two by-products (MK and MP) has not been fully explored yet and still a number of properties can be investigated and improved by replacing them with fine aggregates and cement in different percentages and types.

Keywords Marble powder · Metakaolin · Portland cement · Fine aggregates · Compressive strength

1 Introduction

Concrete is the most widely and key structural material in the world for infrastructure development. It is economical, versatile, robustness, etc., and can be molded to a variety of shapes and finishes. Concrete used nowadays made with Portland cement is probably the most widely used man made material in the world. One of the major threat to environment is emission of CO_2 during the manufacturing of cement. Due to high in demand of concrete, architects and engineers are doing research in replacing cement with different waste material as they are sustainable. Around 90% of

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_12

the world's production of marble comes from India and approx 85% of India's production is received from Rajasthan. India, larger producer of Marble and its widely used in flooring of homes and nearly 330 marbles mines are there only in Rajasthan, India. Fact is that, we get only 30% of the marble used in our purpose, rest of the marble dust/slurry is waste. When marble powder is dumped in open land, its productivity decrease, and reduces the porosity and affect ground water recharge. With the increased demand of fine aggregates in concrete production, several countries have developed difficulties in meeting the demands of fine aggregates. Marble waste when dumped on open land affects adversely the productivity of land as it reduces the porosity and affects ground water recharge. The marble is widely used in buildings due to its beauty, strength, and resistance to fire. The advancement of concrete technology can reduce the consumption of natural resources and energy sources which in turn further lessen the burden of pollutants on the environment. Presently, large amount of marble dust are generated in natural stone processing plants with an important impact on the environment and humans. Waste Marble dust (WMD) can be used to improve the mechanical and physical properties of the conventional concrete. The possibility of utilizing WMD as an alternative very fine aggregate in the production of concrete will also induce a relief on waste disposal issues. In India MK can be produced in large quantities, as it is a processed product of kaolin mineral which has wide spread proven reserves available in the country. Metakaolin is a thermally activated alumina silicate material obtained by calcining kaolin clay within the temperature range 650–800 °C, which is a relatively new material in the concrete industry, is effective in increasing strength, reducing sulfate attack and improving air-void network. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C–S–H), resulting in an increased strength and reduced porosity and therefore improved durability. Metakaolin is refined calcined kaolin clay under carefully controlled conditions to create an amorphous aluminosilicate which is reactive in concrete. Metakaolin is refined calcined kaolin clay under carefully controlled conditions to create an amorphous aluminosilicate which is reactive in concrete.

2 Concrete Properties Reported by Various Authors

2.1 Compressive Strength

Reddy et al. (2015) replaces marble dust with sand up to 100% and concluded that sand can be replaced with marble dust up to 50% without affecting its compressive strength and found that 7 day strength after 50% replacement would be 23.91 MPa for M-25 grade and after increasing the replacement the strength decreases while some other author also done the replacement ranging 45% and found that their replacement give the highest compressive strength value.

Rai et al. (2011) and Kumar (2016) replaces fine aggregates by marble dust and found that till 15% replacement the result are incredibly good and with 20% replacement the compressive strength decreases as compared to 15% replacement. Additionally Sharma and Kumar (2015) noted that on replacing cement and sand by marble powder individually up to 10% increases the compressive strength but above 10% content of marble powder decreases the compressive strength.

Nikhila and Kumar (2016) observed that 15% replacement of cement with metakaolin give best result for compressive strength moreover some other author concluded that replacement of cement with metakaolin ranging from 7.5 to 10% give the result of higher compressive strength and the effect of acids like HCL is negligible when there is addition of metakaolin in the concrete mix.

2.2 Flexural Strength

Rai et al. (2011) replaces fine aggregates by marble waste and states that flexural strength of beam will also increase up to 15% replacement and further replacement decreases the strength and Kumar and Kishor (2015) stated that 10 and 15% replacement of fine aggregates by marble powder, flexural strength improve over 0% of replacement of marble powder further flexural strength decreases. While Sharma et al. (2015) noted that the flexure strength for the concrete mix containing 10% of replacement of cement and sand with marble powder individually got increased by the value of 9.2% and 9.3% respectively.

Chavhan and Bhole (2014) concluded that compressive strength increases with the increase of marble powder and found that 45% replacement of sand with marble powder has highest split tensile strength than other mix while some author state that 7.5% replacement of cement with metakaolin increases the flexural strength.

2.3 Split Tensile Strength

Rai et al. (2011) replaces fine aggregates by marble dust and states that, split tensile strength of beam will also increase up to 15% replacement and further replacement there is decreases in its strength and Kumar et al. (2015) stated that 10 and 15% replacement of fine aggregates by marble powder, split tensile strength improve over 0% of marble powder further strength decreases while other author split tensile strength for the concrete mix containing 10% of marble powder dust in cement and sand got increased by the value nearly by 10%.

Chavhan and Bhole (2014) concluded that compressive strength increases with the increase of marble powder and found that 45% replacement of sand with marble powder has highest split tensile strength than other mix while some state that replacement range from 7.5 to 15% increases the split tensile strength of the concrete.

3 Discussion

By considering the above investigation that replacing cement with metakaolin up to 10% increases the compressive strength and split tensile strength of concrete mixes while replacement of fine aggregates with marble dust up to 30% give same result as that of normal mix.

4 Conclusions

With the increase in population and increase in standard of people, waste and by product are increasing day by day and they are affecting the environment moreover with highest production of marble and its waste in India and the properties of marble dust are similar with aggregates similarly there is resemblance in properties of metakaolin and cement. Test result show that these waste can increase the strength of concrete up to certain percentage. The combined use of metakaolin and marble dust exhibit excellent performance due to the similarities in the properties of cement and aggregates respectively. Furthermore the study provides the strong recommendation to use the metakaolin and marble dust instead of cement and aggregates respectively. In this paper, some basic study of using MK and marble powder is investigated therefore further investigation of slump, consistency and durability is to be considered.

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Review Paper on Partial Replacement of Cement and Aggregates with Various industrial Waste Material and Its Effect on Concrete Properties

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Abstract This study is conducted to evaluate the performance of various type of industrial waste by-products that can be used as an admixture in concrete as a replacement of cement or aggregate as the demand of cement is increasing in the market. Increased demand leads to increased production of cement at large scale which leads to environmental issues and reduction in the number of natural resources on one hand and increase in the cost on the other hand. To deal with these, alternate materials were tested experimentally for use in preparing concrete. Properties of a number of materials such as steel fibre, asphalt, slag, asbestos, lead, dry sludge, wet sludge, fly ash, bagasse ash, red mud, plastic, glass, etc., were studied to find an alternative for replacement of cement. A detailed study of compressive strength, flexural strength and slump value were made by various researchers for 7 days and 28 days respectively. This work compiles the study of a number of waste materials which makes it easy to compare the properties of these waste materials and find out which waste material is more suitable as an alternative for better performance and for environmental suitability as well.

Keywords Partial replacement · Cement · Aggregates · Industrial waste · Compressive strength · Flexure strength · Slump

1 Introduction

Concrete is a mixture of cement, coarse aggregates, fine aggregates and water. In the green stage, it can be moulded into any desired shape. The relative quantity of ingredients used in the mix, controls the property of concrete at various stages, i.e., in wet as well as at hardened stage. Two or three decades ago, due to easy availability of ingredients of concrete, construction of buildings was used to be carried out with

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_13

OPC without considering the quality and the future of concrete structures. But, in the modern era, since last two decades, investigation has been made by engineers and scientists considering the structural stability of concrete structures which requires quality concrete with improved concrete strength, durability and other characteristics. Due to the requirement of these properties, the search for supplementary cementitious material which can be used as a replacement of cement in the concrete mix was carried out. This could be any material which has the lowest possible environmental impact and is universally sustainable.

A number of waste materials can be used as a replacement (generally partial) of cement or aggregate from the concrete mix. The present study is focused on some of the waste materials which includes plastic, dry and wet sludge, red mud, blast furnace slag, sawdust and its ash, silica fume and glass. The work done by various research scholars on replacement of cement or aggregate by waste material has been shown in Table 1.

1.1 Components of Concrete that can be Replaced by Waste Material

Concrete mix comprises of cement, water, coarse and fine aggregates, and various studies have been conducted on replacement of these constituents. The present study mainly focuses on replacement of cement and fine aggregates by waste materials and the effects of these replacements on the properties of the concrete mix. The replacement of cement and fine aggregates by waste materials has been shown in Table 2.

In present study, mainly replacement of cement and fine aggregates has been carried out by the researchers and not much study has been done regarding replacement of water and coarse aggregate in the concrete mix.

1.2 Effect of Replacement of Cement by Waste Material on Various Properties of Concrete

Table 3 shows the effect on various properties of concrete when cement is partially replaced by various industrial waste material and based on the observations it can be found out that which of the following materials is best suitable as a replacement of cement. It has been observed from Table 3 that dry and wet sludge and red mud can be used as a replacement of cement because with the addition of these materials the strength of the cement concrete increases from 20 to 30% replacement by 15.61% in case of red mud and then decreases.

Table 1 Different types of waste materials used

S. no.	References	Plastic	Dry &wet sludge	Fly ash	Red mud	Blast furnace slag	Saw dust & its ash	Silica fume
1.	Ghannam (2016)	–	✓	–	–	–	–	–
2.	Soni (2015)	–	–	✓	–	–	–	–
3.	Kale et al.	–	–	✓	–	–	–	–
4.	Ghutke et al.	–	–	–	–	–	–	✓
5.	Ashok et al. (2010)	–	–	–	✓	–	–	–
6.	Rathod et al.	–	–	–	✓	–	–	–
7.	Dubey et al. (2012)	–	–	–	–	✓	–	–
8.	Kumar et al. (2015)	–	–	–	–	✓	–	–
9.	Pandey et al. (2016)	–	–	–	–	✓	–	–
10.	Gopinath et al. 2015)	–	–	–	–	–	✓	–
11.	Ganirom (2014)	–	–	–	–	–	✓	–
12.	Raheem (2014)	–	–	–	–	–	✓	–
13.	Cheng et al. (2013)	–	–	–	–	–	✓	–
14.	Roy et al. (2012)	–	–	–	–	–	–	✓
15.	Vivek et al. (2015)	–	–	–	–	–	–	✓
16.	Jibrael et al. (2016)	✓	–	–	–	–	–	–
17.	Patil et al. (2014)	✓	–	–	–	–	–	–
18.	Subramani et al. (2015)	✓	–	–	–	–	–	–
19.	Rabie (2016)	–	✓	–	–	–	–	–
20.	Bhargava et al. (2016)	–	✓	–	–	–	–	–

Table 2 Various components of concrete mix replaced

S. no.	References	Cement	Water	Coarse aggregate	Fine aggregate x
1.	Ghannam (2016)	✓	–	–	–
2.	Soni (2015)	✓	–	–	–
3.	Kale et al.	✓	–	–	–
4.	Ghutke et al.	✓	–	–	–
5.	Ashok et al. (2010)	✓	–	–	–
6.	Rathod et al.	✓	–	–	–
7.	Dubey et al. (2012)	✓	–	–	–
8.	Kumar et al. (2015)	–	–	–	✓
9.	Pandey et al. (2016)	✓	–	–	–
10.	Gopinath et al. (2015)	✓	–	–	✓
11.	Ganirom (2014)	–	–	–	✓
12.	Raheem (2014)	✓	–	–	–
13.	Cheng et al. (2013)	–	–	–	✓
14.	Roy et al. (2012)	✓	–	–	–
15.	Vivek et al. (2015)	✓	–	–	–
16.	Jibrael et al. (2016)	–	–	–	✓
17.	Patil et al. (2014)	–	–	✓	–
18.	Subramani et al. (2015)	–	–	✓	–
19.	Rabie (2016)	✓	–	–	–
20.	Bhargava et al. (2016)	–	✓	✓	–

In case of dry and wet sludge, the compressive strength increases by 5.81% for 10% replacement. Use of these waste material limits the use of cement in the construction operation.

1.3 Effect of Replacement of Fine Aggregates by Waste Material on Various Properties of Concrete

Table 4 shows the effect on various properties of concrete when the aggregate is partially replaced by various industrial waste material and based on the observations it has been found that which of the following materials is best suitable as a replacement of aggregate. The case of fine aggregate is quite different to that of cement, not a large number of waste materials have been studied for replacement of fine aggregate as compared to that of cement.

Table 3 Effect of replacement of cement by waste material

S. no.	References	Waste materials	Compressive strength	Flexural strength	Workability (slump value)	Durability
1.	Ghannam (2016), Rabie (2016)	Dry & Wet Sludge	↑ for 0–10%	–	↓	↑
2.	Soni (2015), Kale et al.	Fly ash	↓	–	↑	–
3.	Ashok et al. (2010), Rathod et al.	Red mud	↑for 0–15%, then↓	↑for 15–30%, then ↓	↑	–
4.	Dubey et al. (2012), Pandey et al. (2016)	Blast furnace slag	↓	↓	↑	↑
5.	Gopinath et al. (2015), Raheem (2014)	Saw dust	↓	–	↑	–
6.	Ghutke et al., Roy et al. (2012), Vivek et al. (2015)	Silica fume	↑ up to 10% then ↓	–	May ↑ or ↓	–

Table 4 Effect of replacement of fine aggregates by waste materials

S. no.	References	Waste materials	Compressive strength	Workability (Slump value)
1.	Jibrael et al. (2016), Patil et al. (2014), Subramani et al. (2015)	Plastic	↓	↓
2.	Bhargava et al. (2016)	Dry & wet sludge	↓	↓, up to 30%
3.	Kumar et al. (2015)	Blast furnace slag	↑up to 75%	Constant
4.	Ganirom (2014), Cheng et al. (2013)	Saw dust	↓	–

It has been observed from Table 4 that the compressive strength of the concrete increased by 16.02% for 75% replacement of FA by blast furnace slag. Blast furnace slag is the most suitable replacement because with an increase in the compressive strength it does not affect the workability of the concrete mix.

2 Conclusions

- Red mud is the best waste material that can replace cement from cement concrete as it not only leads to an increase of 15.61% in the compressive strength but also increases the durability of the mixture.
- The second material that can be used as a replacement for cement is dry and wet sludge because replacement of 10% leads to an increase of 5.81% in the strength. But further replacements show a decrease in the compressive strength.
- For replacement of fine aggregates only Blast furnace slag is suitable, because 75% replacement of fine aggregate shows an increase in the strength of cement concrete by 16.02%.

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Size Effect of Fiber on Mechanical Properties of Mud Earth Blocks

Sangketa Sangma, Lumlangki Pohti and Deb Dulal Tripura

Abstract Mud earth blocks are green constructional materials with zero carbon footprints, low embodied energy, economical, etc., but having low compressive as well as least tensile strength and subjected to high shrinkage. This paper presents an experimental study on the behavior of mud earth blocks reinforced with natural fiber. The test blocks were prepared by adding 5% coir fiber by weight of dry soil as reinforcing material with varying sizes ranging from 2 to 8 cm. The effect on properties like shrinkage, compressive and tensile strength, cracking time, and failure pattern due to the presence of fiber were studied in comparison to unreinforced mud earth blocks. The test results showed that the mechanical properties of the blocks are highly affected by the fiber length. Compressive and tensile strength of the blocks with fiber length 4 cm gave the maximum results about 1.45 times and 4 times than that of unreinforced blocks, respectively. Thus, 4 cm length size fiber reinforced mud earth construction is recommended to achieve better structural performances.

Keywords Mud earth block · Natural fiber · Coir · Size effect · Reinforced

1 Introduction

Mud earth structure is one of the oldest traditional construction techniques used from thousands of years under all climates condition with significant historical and cultural value (Greer et al. 1995). Mud earth structures are found almost in various parts of the world. Figure 1 shows the mud structure present in Tripura. According to Millogo et al. (2016), new researches have focused on earth as construction materials throughout the world. Soil is one of the important materials for the construction of mud earth structure.

As compared to conventional building materials, mud earth structure possesses low compressive strength as well as low tensile strength (Blondet and Garcia 2004; Oliveira et al. 2012; Bhattacharya et al. 2013). This can be minimized by using

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_14

Fig. 1 Mud structure at Tripura

different types of stabilizer and reinforcing materials with soil (Tripura and Singh 2014). The presence of fiber in case of mud structure influences the behavior in various conditions, which affects its strength and bonding also (Miccoli et al. 2014).

The aim of the present study is to determine the suitable fiber length in terms of imparting strength and bonding to mud earth blocks. A series of experimental tests have been conducted to evaluate appropriate fiber length as bonding materials to give appropriate strength.

2 Methodology

For the production of mud earth blocks, the soil was collected from NIT Agartala campus from the depth of 0.5 m (approximate), dried and passed through 4.75 mm sieve (Fig. 2). The basic soil properties were determined according to IS 2720 Part 4, 5, 7 (Indian Standard 1995). The tensile strength of coconut fiber (Fig. 3) was determined according to ASTM C1557-14 (ASTM 2014). Table 1 shows the basic properties of soil and fiber used.

For the present study, 150 × 150 × 150 mm size of unstabilized and fiber reinforced mud earth blocks were prepared (Fig. 4). The coconut fibers used were of length 2, 4, 6, and 8 cm with 5% content by weight of dry soil. The samples were

Fig. 2 Locally available soil

Fig. 3 Coconut fiber

air dried for 28 days after casting, and then tested to determine the effect of fiber sizes on mechanical characteristics by compressive strength test and splitting tensile strength test according to IS 4332 Part 5 (Indian Standard 2006) and IS 5816 (Indian Standard 1999), respectively, using Universal Testing Machine (UTM) of capacity 400 kN at a loading rate of 2.5 kN/min.

Table 1 Basic properties of soil and fiber

Property		Details
Sp. gravity of soil		2.64
Grain size distribution	Sand	60.50%
	Silt	25.25%
	Clay	14.25%
Atterberg limit	Liquid limit (LL)	42%
	Plastic limit (PL)	27.75%
	Plasticity index (PI)	14.25%
Optimum moisture content (OMC)	19%	
Dry density of soil	1826 kg/m^3	
Bulk density of soil	2040 kg/m^3	
Tensile strength of coconut fiber (thickness of 0.3 mm)	94.02 MPa	

Fig. 4 Fiber reinforced mud earth blocks

3 Results and Discussion

The effect on strength and bonding due to the addition of different sizes of fiber were studied. Figures 5 and 6 gives the detailed results for the compressive strength and splitting tensile strength. From the figures, it was observed that on increasing fiber sizes, the average compressive strength and average splitting tensile strength

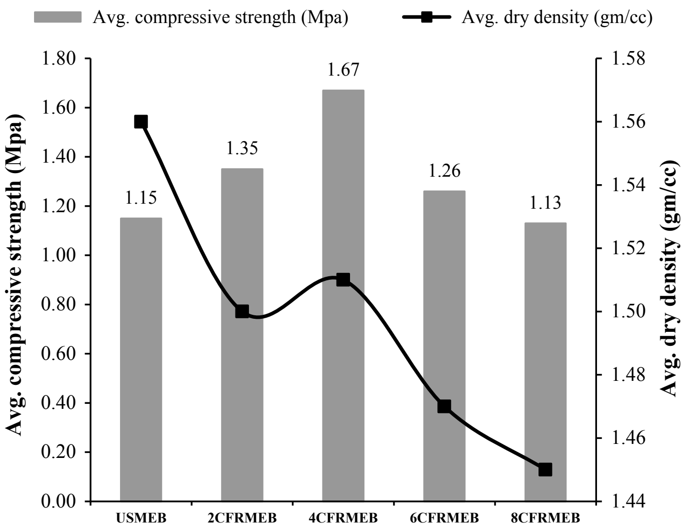

Fig. 5 Compressive strength versus dry density

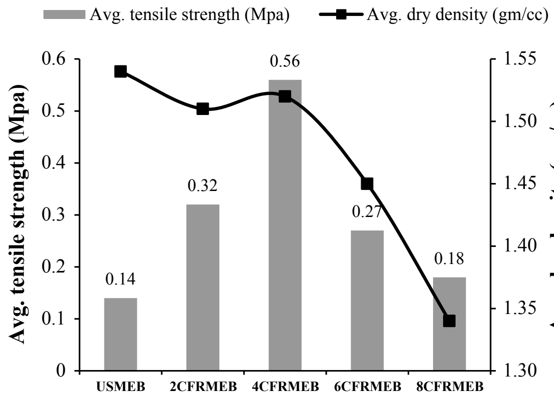

Fig. 6 Splitting tensile strength versus dry density

increases up to 4 cm and thereafter, it decreases. The average compressive strength and splitting tensile strength for 4CFRMEB was 1.45 times and 4 times than that of the URMEB, respectively. It was observed from the experimental test for both compressive strength and splitting tensile strength, 4 cm fiber length blocks gain the maximum strength. However, on increasing further than that both compressive strength and splitting tensile strength decreases. The reason is due to the fact that coconut fibers are very light in weight and makes up significant volume while preparing the blocks. This as an outcome which affects the bonding of the soil particles and their packing. From the testing results, it was also observed that 4CFRCMB withstand maximum strength and showed strong bonding (Fig. 7) which increases the cracking time, density and also reduces shrinkage.

Fig. 7 Cracking during testing

4 Conclusions

The compressive strength and splitting tensile strength were conducted in order to understand the mechanical behavior of mud earth blocks due to the presence of different sizes of fiber. From the tests, it was observed that 4CFRMEB obtained the maximum strength compare to USMEB. On the other hand, 4CFRMEB showed good bonding between soil and fibers as well as it increases the cracking time also. The dry density and moisture content shows the consistency for each blocks. Thus, from the present study, it was observed that fiber length play a vital role on the mechanical properties of the blocks, out of which, 4 cm fiber size gave the best results for compressive and tensile strength.

Notation

USMEB	Unstabilized mud earth block.
2CFRMEB	2 cm coconut fiber reinforced mud earth blocks.
4CFRMEB	4 cm coconut fiber reinforced mud earth blocks.
6CFRMEB	6 cm coconut fiber reinforced mud earth blocks.
8CFRMEB	8 cm coconut fiber reinforced mud earth blocks.

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Investigation on the Potential Use of EAF Dust and RSA for Sustainable Concrete Production

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Abstract In the construction field, cement is one of the most commonly used materials for concrete production, wherein 5–7% of globally anthropogenic CO_2 emissions are contributed in this process. Agricultural and industrial fields produce various types of Supplementary Cementitious Materials (SCMs) as wastes, which otherwise can be used as a replacement in cement for concrete production. In the present context, rice straw, which is a by-product of the rice plant, is subjected to open burning which causes numerous health and environmental problems. Moreover, Electric Arc Furnace (EAF) dust produced from steelmaking processes contains heavy metals, which is being dumped in landfill. Considering the severe impact of the above-highlighted issues, it has thus become the need of the time to identify the feasibility of waste integration in concrete production. The objective of the current study is to utilize the mixture of rice straw ash and electric arc furnace dust in cement at fixed 10% partial replacement criteria for feasibility analysis. The test results obtained shows that there is a marginal difference between the compressive strength of concrete casted with and without replacement. However, the concrete casted with 10% replacement of cement is still preferable for casting.

Keywords Sustainable · Concrete production · Rice straw ash · Electric arc furnace dust · Cement replacement

1 Introduction

Portland cement is the material which is being extensively used for construction proposes. It is a material that binds the other materials like sand and aggregates that are used in the production of concrete. Cement contains Lime (65%), Silica (22%), Aluminium oxide (6%), Iron oxide (3%), Magnesium oxide (1–3%) and Gypsum

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_15

(1–4%). The Indian Cement industry has achieved second position with 7% of cement production in the world after China (56%) (US Geological Survey 2018). The problem related to cement is that 1 ton of cement manufacturing process releases about 1 ton of CO_2, which leads to the generation of 7% of all CO_2 emissions worldwide (Gibbs et al. 2001). Hence, there is a necessity to use supplementary cementitious materials whose properties are similar to cement, as a partial replacement of cement for concrete production (Mujedu et al. 2014). To meet that requirement, the rice straw ash and electric arc furnace slag that is collected by air pollution control device is used as a partial replacement in cement. Approximately, one ton of the rice paddy produces 290 kg of rice straw that is a large amount in terms of waste (Zafar 2015). It has been found that rice straw produces 15% ash after burn. It means for each 1000 kg of rice straw burnt, 150 kg ash is created. About 74% silica content is observed in rice straw ash, which indicates that rice straw ash can be used as a partial replacement of cement in concrete manufacturing ash (Lim et al. 2012; El-Sayed and El-samni 2006). Burning of rice straw is an old fashion in Punjab, which results in the emission of CO_2 and severe health problems. The particulate matter level become several times high against the permissible limits in Punjab during paddy harvesting season. The Electric Arc Furnace (EAF) that is used for steelmaking process from reused scrap iron produces between 15 and 25 kg of dust per ton of steel. The particle size of EAF dust ranges from 0.2 to 500 μm (Guézennec et al. 2005).

The problems related to dust is that when the dust is subjected to dump in landfills, it causes the leaching of metals present in dust in the rainy season (Manso and Gonzalez 2004). Another problem is related to the size of dust which is very small, and due to its small size, it gets easily mixed with ambient air and causes some serious effect on kidney, central nervous system, and may also cause lung cancer (Hutchinson and Meema 1987). When EAF dust will be mixed with cement having particle size 0.1–250 μm, due to the smaller particle size of dust, it will easily fill the voids present in the cement and thus results in increase in strength of concrete. Thus, it indicates that rice straw ash (Munshi et al. 2013) and electric arc furnace dust (Magalhães et al. 2017; Alizadeh et al. 2003) can be used as a partial replacement in cement.

Another aspect of this study is the wastage of water during the curing of concrete. During this process, a large share of water gets wasted in order to overcome the heat of hydration that evolves during the reaction of cement and water. Due to the increase in the population and industrialization, there is a need to meet the water demand (UN-Water WWAP 2006). We cannot produce water but can reduce the quantity of water that gets wasted. Thus, there is to a need to find a way to minimize the usage of water in construction sites.

This paper includes the replacement of cement with rice straw ash and EAF dust to check the feasibility of concrete manufacturing for sustainability enhancement. A few studies have been reported on the use of RSA and EAF dust alone as a partial replacement to cement in the production of concrete, but no such work has been reported on the combined use of Rice Straw Ash and Electric Arc Furnace dust in concrete. Therefore, this study tends to focus on the combined use of Rice Straw

Ash and Electric Arc Furnace dust as replacement material to identify its impact on required concrete properties such as compression strength and water absorption.

2 Literature Review

Large number of studies have been reported on the various supplementary cementitious materials (Papadakis et al. 1992) like rice husk ash, rice straw ash, sewage sludge ash, (Al-Khaja 1997) and fly ash (Marsh et al. 1985) have undergone wide researches. After the cultivation of rice plant, rice straw is produced that is generally subjected to burning. Burning of rice straw increases the major pollutants in the atmosphere that creates various environmental and health problems to the people living around (Urmila 2017). The first ash replacement in concrete was done with agricultural waste rice husk (Mehta 1983). A study conducted on locally available rice straw ash was burned in uncontrolled condition and found that 10% replacement by weight was the optimum dose that improves the properties of mortar (Munshi et al. 2013). Some studies have performed the use of rice husk ash and it has been found that besides reducing the environmental polluting problems, the RHA can bring several improvements for the concrete properties. The maximum concentration of silica is found in rice husk (Tashima et al. 2004). The studies show that 1 kg of rice plant produces 1–1.5 kg of rice straw (Binod et al. 2010). A few studies have been conducted on the incorporation of electric arc furnace dust and found that there is an increase in final setting time of cement due to the addition of EAF dust. Addition of 7–15% of EAFD is described to improve the concrete properties and beyond this range, the integration of dust in concrete does not provide sound results (Sikalidis and Mitrakas 2006). The optimum increment in compressive strength and decrement in water absorption was observed due to the maximum 10% replacement of cement with dust (Balderas et al. 2001). An average of 15–25 kg of dust is made per ton of steel and has the particle size between 0.2 to 200 μm (Guézennec et al. 2005).

As per the available studies on RSA and EAF dust, it has been observed that both materials show the increase in compressive strength and decrease in water absorption at 10% replacement of cement by weight. A few studies have been reported on the use of RSA and EAF dust alone as a partial replacement to cement in the production of concrete but no such work has been reported on the combined use of Rice Straw Ash and Electric Arc Furnace dust in concrete. Therefore, the objective of current study tends to focuses on the feasibility of combined 10% replacement of Rice Straw Ash (5%) and Electric Arc Furnace dust (5%) with cement to identify its impact on required concrete properties.

3 Experimental Methodology

3.1 Preparation of Rice Straw Ash

Rice straw is an agriculture waste that is generated after the cultivation of rice plant. Rice straw was picked up from fields in jute bags. Rice straw was cut into small pieces with the help of chaff cutter, and then burned in the muffle furnace at controlled temperature of 550 °C for 2 h. After burning rice straw, the ash was collected and was subjected to a manual roller so as to provide the powdered form to ash. After converting ash into powdered form, it was stored in bags. Ash was dried in hot air oven at 105 °C for 2 h to remove the moisture present in the ash. By sieving process, the size of 300 μm was separated out from ash for its final use. The SiO_2 content was found to be 74% in rice straw ash (Lim et al. 2012). The specific gravity of RSA was 2.0. A total of 5% of cement was replaced with rice straw ash.

3.2 Procurement of Electric Arc Furnace Dust

EAF dust was collected from the Arora Steels and Rolling mills, Ludhiana in bags. Dust was originally in the powdered form, so it was subjected to temperature of 105 °C for 2 h in hot air oven to remove the moisture content present in it. By sieving, the particle size of 300 μm was separated from the whole bag. The specific gravity of EAF dust was 3.97.5% of which the total cement was replaced with dust. The dust contains SiO_2 (3.89%), Fe_2O_3 (35.92%), CaO (13.32), MgO (2.52%) and ZnO (31.34%) as major ingredients (Magalhães et al. 2017).

3.3 Preparation of Concrete Blocks

3.3.1 Cement

Ordinary Portland cement (OPC) of 43 grades conforming to IS: 8112-1989 was used. It acts as a binding agent for other constituents when mixed with water. For proper mixing of ingredients, the required amount of water is added to the cement to form slurry. The physical properties of cement are shown in Table 1.

3.3.2 Water

It is one of the most important ingredients of the concrete mix. In this experimental work, locally available cleaned water was used.

3.3.3 Coarse and Fine Aggregates

Natural coarse aggregates were used for the current study. Aggregates were washed with water to remove the dust, and then moisture was removed from the aggregates to provide surface dry conditions. The coarse and fine aggregates were tested as per (IS: 383-1970). The physical properties of coarse and fine aggregates are given in Table 2.

3.3.4 Casting of Cubes

Cement was partially replaced by the combined mixture of RSA (5%) and EAF (5%) dust at a fixed percentage of 10% by weight. The proper mixing of cement, EAF dust, RSA, coarse and fine aggregates and water was done. The mixing of all these components results in the formation of concrete paste, which was poured in the moulds. These moulds are of size 150 × 150 × 150 mm. Proper compaction was done with the vibrating machine so as to remove the air bubble from the paste in mould. On the very next day, the cubes were demoulded from the moulds and immersed in water. The testing was done after curing of 7, 14 and 28 days.

Table 1 Physical properties of cement

Tests	Test values obtained
Standard consistency	33%
Specific gravity	3.14
Initial setting time	125 min
Final setting time	215 min

Table 2 Physical properties of coarse and fine aggregates

Characteristics	Test values of coarse aggregates	Test values of coarse aggregates
Colour	Grey	–
Shape	Angular	–
Specific gravity	2.60	2.56
Water absorption	1.0%	1.0%
Fineness modulus	6.2	2.2
Grading zone	–	II

Table 3 Initial and final setting time of OPC, RSA, EAFD

Mix symbol	Initial setting time	Final setting time
OPC (100%)	2 h 5 min	3 h 35 min
RSA 5%	2 h 15 min	4 h
EAFD 5%	15 h 50 min	19 h 57 min
OPC (90%) + RSA (5%) + EAFD (5%)	25 h 30 min	32 h 12 min

4 Experimental Results and Discussions

4.1 *Initial and Final Setting Time*

As per the standard procedure, the initial and final setting time assessment of OPC, EAF dust (5%) and RSA (5%) is given in Table 3.

As per the above results, the delay in the setting times is observed due to the addition of EAF dust (5%) in cement. The main reason is due to presence of zinc oxide, which is a major constituent of EAF dust. The presence of Zn^{2+} results in the delay in premature hydration of C_3S, which leads to postponing in setting times Chen et al. (2007).

4.2 *Compressive Strength*

The test was conducted according to IS: 516-1959. The specimens were taken out from curing tank at the end of 7, 14 and 28 days respectively as per the experimental design for testing them further for compressive strength. The load was applied on cubes without any shock at a constant rate of 140 Kg/cm^2 per min with universal compression testing machine, until the breakdown of specimen takes place. The result represents that at 28 days of curing, the difference between compressive strength of cubes casted with and without replacement gets reduced as compared to 7 and 14 days of curing. The results are given below in Fig. 1.

Table 4 shows the related studies conducted by other authors with the integration of rice straw ash and electric arc furnace dust separately.

The reason of increase in the compressive strength of cubes casted with the incorporation of EAF dust and RSA might be due to the presence of silica in RSA as already mentioned; RSA contains 74% of silica (Lim et al. 2012) which imparts the hardness to the concrete. Other reason might be due to the fineness of two SCMs which increases the density of concrete ultimately resulting in the increase of the compressive strength of cubes.

Fig. 1 Compressive strength of specimens

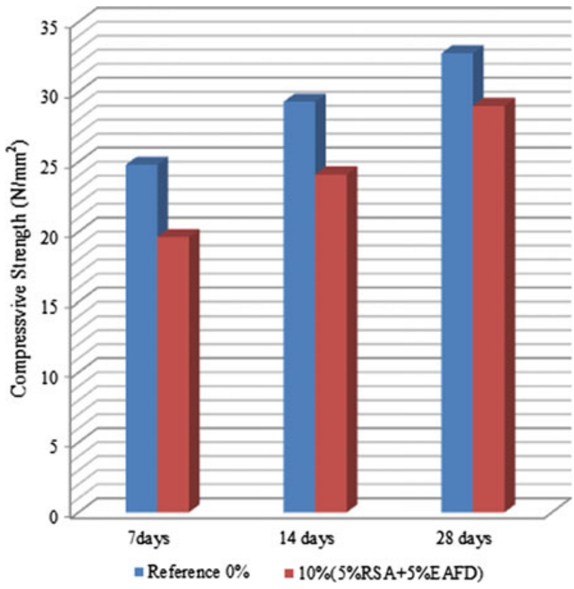

Table 4 Comparison of compressive strength from literature

Author(s)	Material used to replace cement	Compressive strength after 7 days of curing (N/mm^2)	Compressive strength after 28 days of curing (N/mm^2)
Munshi et al. (2013)	RSA at 5%	12	29
Magalhães et al. (2017)	EAF dust at 5%	42	55
Current study	RSA (5%) + EAF dust (5%)	19	29

4.3 Water Absorption Test

The amount of water absorbed by the cubes was determined by water absorption test. The cubes were tested after 7, 14 and 28 days. The cubes were tested according to IS: 1124-1974. According to the results, cubes casted with replacement absorb more water than cubes without replacement. At 28 days of curing, the cubes casted with replacement absorbs 20% more water than reference cubes. The results of water absorption test are given below in Fig. 2.

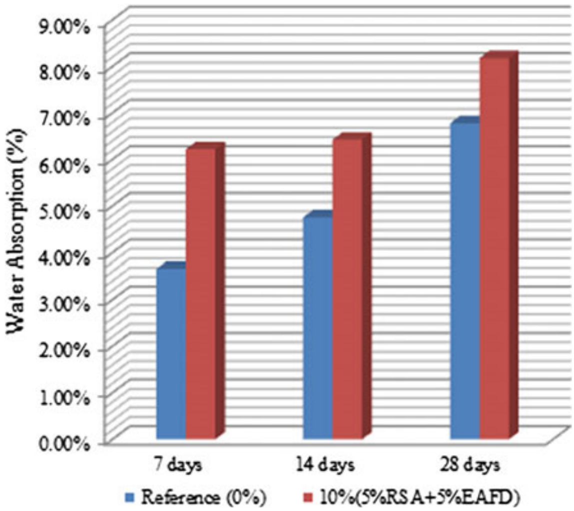

Fig. 2 Water absorption of specimens

5 Conclusions

The conclusions based on the current experimental study indicated the following important points:

1. At 28 days, the results represent that cubes casted with 10% replacement shows 12% less compressive strength than reference cubes. However, the concrete casted with 10% replacement of cement is still preferable for casting.
2. The initial setting time and the final setting time are increased with the addition of RSA and EAF dust (5%). As EAF dust and RSA concrete take longer time to set thus live loading should be avoided on the concrete members for at least 2–3 days, so as to remove any chance of cracking in the concrete.
3. It has also been observed that 20% more water is getting absorbed by the cubes casted with replacement at 28 days as compared to reference cubes.
4. Due to high temperature, the concrete with the replacement of EAF dust (5%) and RSA (5%) takes less time to set. So, it can be concluded that this type of concrete can be preferred in tropical areas where usually high temperature is observed.

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A Study on Strength Behavior of Alkali-Contaminated Soils Treated with Fly Ash

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Abstract Alkali-contaminated soils have being considered for research in the recent past to counter the industrial failures encountered due to accidental spillages and leakages. It was observed by the researchers that alkali contamination can change the engineering behavior of the soils to a large extent. The change in soil behavior may alter with the concentration of the alkali, type of soil, and duration of alkali interaction. In the present work, the effect of 2 N and 4 N NaOH on the Unconfined compressive strength (UCS) of BC soil and kaolinite clay was studied for 7, 14, and 28 days. From the results, it was evident that the reduction in UCS values were 46 and 43% for BC soil and 44 and 36% for kaolinite clay with a contamination of 2 N and 4 N NaOH, respectively, after a curing period of 28 days. In order to address this reduction in strength, treatment with 10, 15, and 20% of fly ash was opted for both the soils. In the case of BC soil, 15% fly ash was found to be optimum for 2 N contamination while for 4 N contamination, it was linearly increasing up to 20%. For kaolinite clay, 20% of fly ash addition gave an optimum strength for 2 N contamination and for 4 N contamination, it was observed at 15% fly ash content. The increase in strength can be attributed to the initiation of pozzolanic reaction by alkali and subsequent strength improvement with time due to the formation of pozzolanic compounds.

Keywords Alkali contamination · UCS · Fly ash

1 Introduction

The intrinsic nature and heterogeneity of the geological processes involved in soil formation are responsible for the wide variability in the geotechnical properties of the soils. But the natural soil–water system can be polluted by land disposal of industrial, mining, agricultural waste, and accidental spillage of chemicals during

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_16

industrial operations. When the ever increasing array of chemical agents produced by industrial activity enters the soil system, it can alter the basic mineralogy of soils and hence alter it's properties. Comprehending the soil–water–pollution system is vital in the geoenvironmental engineering as it may lead to changes in the soil properties. Soils are susceptible to contamination with a variety of chemicals due to inappropriate dumping or disposal of waste. Geotechnical failures such as heaving of ground soil beneath the industrial structures and tilting of storage tanks were attributed to changes in soil properties (Lukas and Gnaedonger 1972; Sridharan and Sivapullaiah 1987; Assa'ad 1998; Sivapullaih et al. 2004). One of the major pollutant that has proven to have a considerable effect is the alkali contamination of the soil (Rao and Rao 1994; Rao and Reddy 1997). High-strength alkali is a significant pollutant that can have substantial impact on behavior of the soils. The high concentration of alkali solution used to extract alumina from bauxite in the digester can leak into the foundation soils in aluminum extraction plants, resulting in the heave of the foundation footings and consequent distortion of floor and roof beams. Throughout alkalization, clayey minerals dissolve with their discharge of aluminum ion, and eventually leading to the formation of depolymerized silicic acids. The clayey minerals interaction with acid and alkali leads to irreversible reactions. The rate of process will be proportional to the magnitude of the surface at each point of time. The soils in semiarid regions experience periodic swelling and shrinkage during the alternating wet and dry seasons. Such cyclic swell–shrink movements of the ground cause considerable damage to the structures found on them (Lew 2010). On the whole, the process will not depend on the rate of chemical reaction, but the rate at which reacting ions diffuse through the layer and the product being formed (Sokolovich 1995). Fly ashes in dry and fully saturated situations does not exhibit any UCS due to the absence of cohesion for dry fly ash and loss of apparent cohesion upon total saturation (DiGioia and Nuzzo 1972; Gray and Lin 1972). However, unconfined compressive strength values for fine ashes can be attributed to the difference in capillary tensions between coarser and fine ashes (Leonards and Bailey 1982; Manjit and Mridul 1999; Antiohos and Tsimas 2004) and also, most of the shear strengths is due to the internal friction (Singh and Panda 1996). Therefore, experimental studies have been conducted in the laboratory to investigate the effect of alkali contamination on black cotton soil (BC) soil and kaolinite clay for 28 days. Also, the feasibility of using fly ash as an additive for enhancing the unconfined compressive strength of BC soil and kaolinite clay was studied. A varying percentage of fly ash was added to the alkali-contaminated soil to identify the optimum dosage of fly ash to be added to attain effective improvement of strength.

2 Materials and Methodology

2.1 Soils Used

The locally available BC soil was collected by open excavation at a depth of 1 m from natural ground level at the National Institute of Technology, Warangal, India.

Table 1 Physical properties of soils used

Property	BC soil	Kaolintie clay
Specific gravity	2.655	2.55
Grain size analysis (%)		
Gravel Sand Silt + Clay	3 17 80	00 03 97
Plasticity index (%)	28	19
IS soil classification	CH	CH
Free swell index (%)	150	110
Compaction properties	20	21
Optimum moisture content (%)		
Maximum dry density (g/cm^3)	1.64	1.66

Oven-dried soil passing through no. 40 (425μ) sieve was used for performing the tests. Whereas, commercially available kaolinitic sedimentary clay was purchased from Heilen Biopharm Pvt. Ltd. The physical properties of the soil are shown in Table 1.

2.2 Fly Ash Used

Fly ash considered in the present study was classified as class F and is collected from the National Thermal Power Corporation, Ramagundam, Telangana. The chemical composition of fly ash is presented in Table 2.

Experimental Procedure:

Depending on the arrangement, the entire experimental work was divided into two phases. In Phase I, soils were inundated with 2 N NaOH and 4 N NaOH and is kept

Table 2 Chemical composition of fly ash

Constituent	Percentage
Total silica (SiO_2)	62.89
Alumina (Al_2O_3)	24.72
Ferric (Fe_2O_3)	6.54
Total calcium (CaO)	1.77
Magnesium (MgO)	1.08
Sulphuric anhydride	0.68
Water + soluble salts	0.036
pH	10
Loss of ignition	2.21

for a curing period of 28 days. UCS of alkali-contaminated soils was determined at OMC in accordance with IS 2720 Part X-1985. In the second phase, a varying percentage of fly ash (10, 15, and 20) was added to alkali-contaminated soil and is kept for a curing period of 28 days. UCS of fly ash-treated contaminated soils were determined at OMC in accordance with IS 2720 Part X-1985.

3 Results & Discussion

3.1 *The Effect of 2 N and 4 N NaOH on the UCS of BC Soil and Kaolinite Clay*

The unconfined compressive strength (UCS) test results of the BC Soil and kaolinite clay inundated with 2 N and 4 N NaOH for a curing period up to 28 days are presented in Fig. 1.

From the results, it was evident that there is a continuous reduction in UCS values with the increase in curing period. And, it was observed that a decreasing pattern for 2 N NaOH and 4 N NaOH was more or less similar. This decrease in UCS can be attributed to dissolution of clayey minerals in the alkaline environment (Sivapullaiah and Manju 2005; Reddy and Sivapullaiah 2011). The % decrease in UCS after a curing period of 28 days is presented in Table 3.

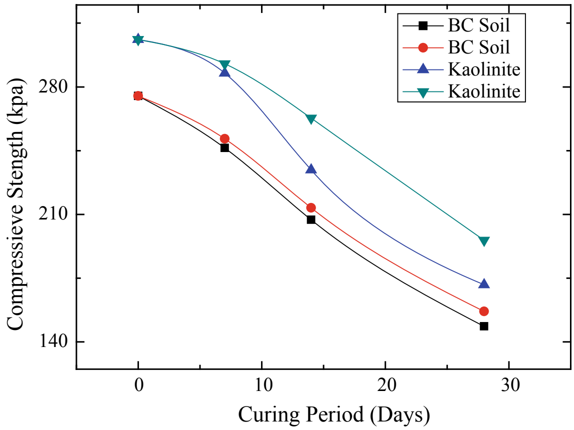

Fig. 1 UCS of alkali-contaminated soils

Table 3 % of decrease in UCS of alkali-contaminated soils

Soil type	BC soil		Kaolinite clay	
Concentration of NaOH	2 N	4 N	2 N	4 N
% of decrease in UCS	46	43	44	36

3.2 The Effect of Fly Ash on the Alkali-Contaminated BC Soil and Kaolinite Clay

The unconfined compressive strength (UCS) test results of fly ash-treated BC soil and kaolinite clay inundated with 2 N and 4 N NaOH days are presented in Fig. 2.

It can be noted that UCS of alkali-contaminated soils increased to multiple times on treating with fly ash. The rate of increase was found to be greater for soils inundated with higher concentration of NaOH. The optimum amount of fly ash at which the highest value of UCS reported was found to be at 15% for BC soil inundated with 4 N NaOH and for kaolinite clay inundated with 2 N NaOH. For the other two cases, the optimum fly ash could not be arrived as the UCS showed a linear increasing trend up to 20%. The increase in UCS may be attributed to the initiation of pozzolanic reaction by alkali and subsequent strength improvement with time due to the formation of different types of cementitious crystalline compounds such as reinhardbraunsite, katotite on alkaline treatment of fly ash. The multiple increase in UCS of fly ash-treated alkali-contaminated soils after a curing period of 28 days is presented in Table 4.

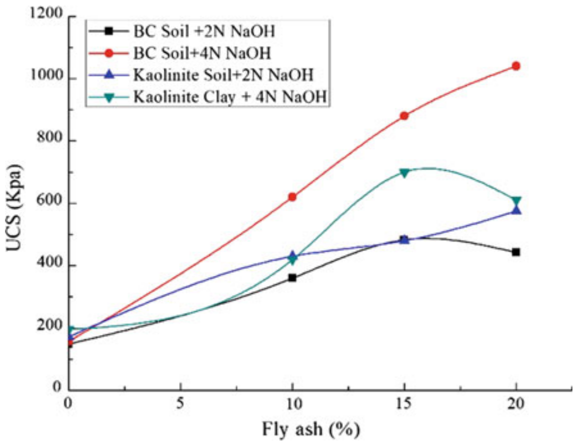

Fig. 2 UCS of fly ash-treated alkali-contaminated soils

Table 4 UCS of fly ash-treated alkali-contaminated soils

Soil type	BC soil		Kaolinite clay	
Concentration	2 N	4 N	2 N	4 N
% fly ash for optimum UCS attained	15	20	20	15
The rate of increase in UCS	3.22	7.40	2.29	3.01

4 Conclusions

The main conclusions drawn are:

1. Alkali inundation has lead to decrease in unconfined compressive strength (UCS) of BC soil and kaolinite clay. It was also found that concentration of alkali has a profound effect on the decrement of UCS.
2. It was observed that the fly ash treatment of alkali-contaminated BC soil and kaolinite clay has lead to increase in their UCS. The increment was found to be greater in BC soil than kaolinite clay. Highest increment of 7.40 times was found for BC soil. Whereas, the increase in concentration to 4 N NaOH has marginal effect on kaolinite clay.
3. The optimum amount of fly ash at which the highest value of UCS reported varied with a change in the concentration of soils.
4. It can be concluded that alkali worked as an activator for pozzolanic reaction and fly ash having cementitious properties eventually lead to the formation of pozzolanic compounds.

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Performance of Pond Ash and Rice Husk Ash in Clay: A Comparative Study

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Abstract Use of admixtures for improvement of the engineering behavior of soils is one of the popular techniques in ground improvement. Different wastes ashes like fly ash, pond ash, etc., are available as an option for the improvement of the soil properties. In this paper, a series of the unconfined compressive strength tests were conducted on the kaolin clay mixed with rice husk ash and pond ash, and comparison of performance improvement is done. The content of rice husk ash and pond ash was varied as 10–50%. The results have shown that both rice husk and pond ash have the potential to improve the load-carrying capacity of the clay. But the impact of the rice husk ash on the load-carrying capacity of the clay is more significant than the pond ash. Optimum rice husk content is found to be 10%, while for pond ash, optimum moisture content is found around 40%.

Keywords Pond ash · Rice husk ash · Kaolin clay · Load carrying capacity · Optimum content

1 Introduction

The need for infrastructure development has increased the construction of the different structures like high-rise buildings, high-speed railways, etc. Many times, the construction of these structures takes place over weak soil. In such condition, some ground improvement techniques are required to improve the performance of soil.

Nowadays, different options are available for the improvement of the quality of soil. The use of different admixtures is one of the popular techniques among the engineers. Different waste ashes like fly ash, pond ash, rice husk ash, etc., are becoming the most used admixtures (Priyadarshee et al. 2015). These materials are pozzolanic in nature. It means that they show cementitious behavior in the presence

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_17

of some materials like lime and cement. Other than this pozzolanic behavior, the use of such material is economic and environmental-friendly method.

Pond ash, fly ash, etc., are the industrial wastes generated from the coal power plant. These power plants generate a huge amount of the pond ash every year. The production of such huge amount of the pond ash creates a hazardous effect on the environment (Havanagi et al. 2011; Martin et al. 1990; Misra et al. 2005). Similar to the pond ash, rice husk ash is also a waste product generated from the agriculture work. Rice husk ash is obtained from burning of the rice husk, which is by-product of rice plant (Mehta 1986; Sharma et al. 2008). The utilization of these waste products in different applications is a useful technique to manage such waste. In the geotechnical construction, such waste can be utilized in bulk (Pandian 2004).

Many researchers have shown that pond ash and rice husk ash can be utilized in different geotechnical structures like embankment, roads, retaining wall, etc. Pond ash and rice husk ash both can improve the load-carrying capacity of soil. The researchers have performed different tests like laboratory test, model tests on the soil mixed with pond ash or rice husk ash. Chand and subbarao (2007), Sarkar et al. (2012), Bera and Ghosh (2007), Kumar and Gupta (2016), Roy and Chattopadhyay (2008), etc., have shown that pond ash can be effectively used for geotechnical purposes. They have shown that pond ash improves geotechnical properties like strength, compaction, etc., of weak soil. Babu et al. (2008), Balan (1995), Paya et al. (2001), Jayasree et al. (2015), Malik and Priyadarshee (2017), Priyadarshee et al. (2015), Bera and Ghosh (2016) etc., have shown that rice husk ash can be used effectively in different geotechnical purposes.

The suitability of the material for the construction depends upon the performance, and also depends upon the availability. The availability of the material near to the construction is important for the economical point. Nearly, the available material reduces the transportation cost. Sometimes, more than one material may be available as a option. In such condition through comparison of the performance, a suitable material can be selected for construction. In this paper, a comparative study on the performance of pond ash and rice husk ash is done.

2 Experimental Details

2.1 Materials Used

In this study, kaolin clay was used. Kaolin clay is one of the non-swelling soils. Basic tests were conducted on the soil to determine the physical and index properties of the soil. Specific gravity of the clay was performed as per ASTM D 854 and found to be 1.98. To obtain the particle-size distribution curve, wet sieve analysis and hydrometer test were conducted as per ASTM D 4221. The particle distribution of the soil used in this study is presented in Fig. 1. As per USCS classification system

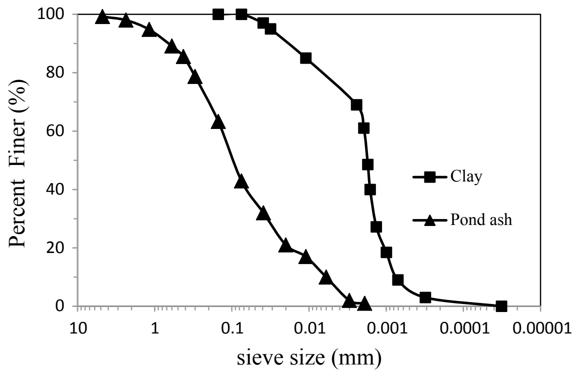

Fig. 1 Particle-size distribution curve of pond ash and clay

Table 1 Properties of kaolin clay

Properties	Values
Optimum moisture content (%)	16.6
Maximum dry density (kN/m^3)	17.4
Liquid limit (%)	38.1
Plastic limit (%)	20.1
Plasticity index (%)	18
Specific gravity	2.71

Table 2 Properties of pond ash

Properties	Values
Optimum moisture content (%)	26
Maximum dry density (kN/m^3)	12.3
Liquid limit (%)	NP
Plastic limit (%)	NP
Plasticity Index (%)	NP
Silt & clay (%)	42
Sand (%)	58
Specific gravity	2.10

(ASTM D 2487), the soil was classified as CL. Other properties of the clay are presented in Table 1.

Pond ash used in this study was obtained from the Ropar Thermal Plant. Specific gravity of pond ash was found to be 2.4. Particle-size distribution of the pond ash is presented in Fig. 1. Properties of the pond ash used in this study are presented in Table 2. Rice husk ash used in this study was also obtained from the locally available market. Specific gravity of the rice husk ash was found to be 1.9. The properties of the rice husk ash are presented inTable 3.

Table 3 Properties of rice husk ash

Properties	Values
Optimum moisture content (%)	61
Maximum dry density (kN/m^3)	9
Liquid limit (%)	NP
Plastic limit (%)	NP
Plasticity index (%)	NP
Specific gravity	1.98

2.2 Experimental Program

To compare the performance of the clay mixed with the pond ash and the rice husk ash, a series of unconfined compressive strength test was performed as per ASTM. Detail of the series of the test is presented in Table 4. The first series of test 'A' was performed on the clay alone. In this series, no additives were mixed in the clay. 'B' series of tests were performed on the clay mixed with the pond ash. In this series of test, content of pond ash was varied as 10, 20, 30, 40, and 50%. 'C' series of test was conducted on the clay mixed with the rice husk ash. In this series of test, the content of the rice husk (RC) was varied as 5, 10, 15, and 20%. Content of the additives was varied until optimum content was obtained. Content of the additives is defined as the ratio of the weight of the admixtures to the total weight of the mix, i.e., the weight of the clay and admixture.

Strength is most important factor for clay. So, it is taken as a parameter to decide the suitability of the admixture. For this purpose, unconfined compressive strength test was performed as per ASTM D 2166. Test samples were prepared at the optimum moisture content and maximum dry density obtained from the standard Proctor test. For the preparation of the soil sample without addition of mixture, first dry soil sample was weighed according to the density requirement. Then, water is added to the soil sample in accordance to the optimum moisture content, and then mixing of the soil and water was done manually by hand. Then, the mix was placed in the mold in layers and compacted. For the preparation of the soil sample with admixture, mixing of clay and admixtures was done first. Admixtures were taken as replacement of clay. Admixtures were taken as the part of the solid. The density of the mix was

Table 4 Details of the test series

Series of test	Details of mix	Pond ash content (%)	Rice husk ash (%)
A	Clay alone	–	–
B	Clay + pond ash	10, 20, 30, 40, 50	–
C	Clay + rice husk ash	–	5, 10, 15, 20

taken as a constant as obtained from the standard Proctor test. After the preparation of mix, the desired amount of the mix was taken. Then, the mix was placed in mold in layers and compacted.

3 Results and Discussion

Results obtained from the standard Proctor tests and unconfined compressive strength tests performed on the clay mixed with pond ash and rice husk ash is presented and discussed here. Figures 1 and 2 show the variation of the optimum moisture content with different content of rice husk ash and pond ash. It can be observed that with increment in the admixtures, optimum moisture content is increasing. Increment in the optimum moisture content due to the inclusion of pond ash can be observed from Fig. 2 and due to that, the rice husk ash can be observed in Fig. 3. Since optimum moisture content of pond ash alone is more than the clay (Tables 1 and 2). This shows that the compaction process of pond ash required more water. Similarly in the case of rice husk ash, optimum moisture content is increasing because rice husk ash Increase in the OMC due to increase in the RHA content is attribute to the increase in the surface area of RHA. RHA has a property to adsorb water due to which more water is required to achieve MDD. It can be further observed that increment in optimum moisture content is more in the case of rice husk ash, because RHA has more specific surface area.

Variation of the maximum dry density with different content of admixtures is presented in Figs. 4 and 5. It can be observed that maximum dry density is decreasing with the addition of pond ash and rice husk as both. Decrement in the maximum dry density is more in the case of rice husk ash. The reason for such a behavior is the inclusion of the lightweight particle in heavy weight particles. Pond ash and rice husk ash both are lighter than the clay. Due to this reason, maximum dry density is decreasing with inclusion of both admixtures. Since rice husk ash is lighter than the pond ash (Tables 2 and 3), decrease in the maximum dry density is more in the case of rice husk ash. These observations show that to construct lightweight structures or

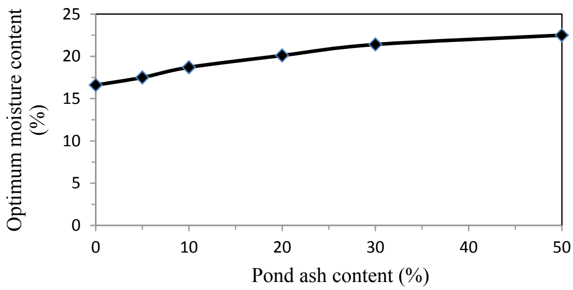

Fig. 2 Variation of optimum moisture content of clay with pond ash content

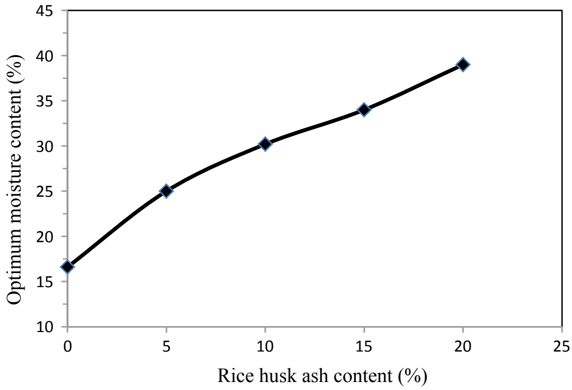

Fig. 3 Variation of optimum moisture content with different rice husk ash content

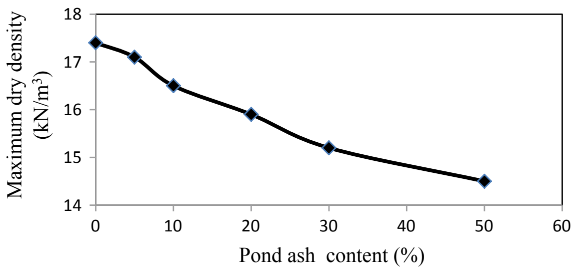

Fig. 4 Variation of maximum dry density of clay with different pond ash content

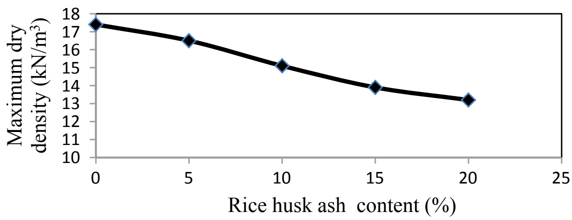

Fig. 5 Variation of maximum dry density of clay with different rice husk ash content

at the places where lightweight fill is required, rice husk ash and pond ash can be used as a replacement of the soil.

Variation of unconfined compressive strength of clay with variation of the different contents of pond ash and rice husk ash is presented in Figs. 6 and 7. It can be observed from the Fig. 6 that unconfined compressive strength of clay increases with increase in the content of pond ash. Around 2.4 times increment in the unconfined compressive strength is observed at the pond ash content of 40% with reference to clay alone. Further increment in pond ash content after 30% content does not contribute significantly. This shows that the optimum content of the pond ash is around 40% for strength improvement. In the case of rice husk ash as shown in Fig. 7, unconfined compressive strength increases with increase in the content of rice husk ash up to 10% content of rice husk ash. But further increment in the content of the rice husk ash

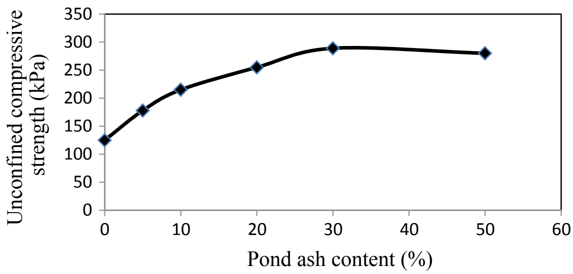

Fig. 6 Variation of unconfined compressive strength of clay with different pond ash content

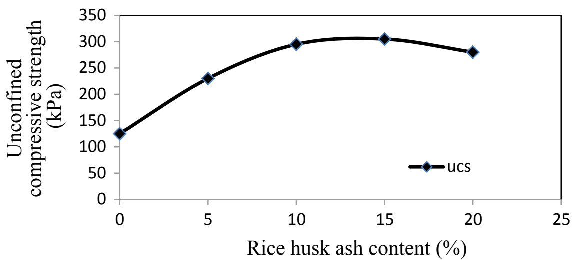

Fig. 7 Variation of unconfined compressive strength of clay with different rice husk ash content

does not contribute in the increment in the unconfined compressive strength of mix. This shows that the optimum content of rice husk ash for the strength improvement is around 10%. In the case of clay alone, the strength is mainly contributed due to the cohesion of soil. But when particles of the rice husk ash and pond ash is included in the clay, then friction component of the mix also mobilize. Due to these reasons, the strength of the clay increases with inclusion of the pond ash and rice husk ash. It can be further noted from Figs. 6 and 7 in the case of rice husk ash can improve strength significantly at lesser content than the pond ash. Both materials can be used for construction purpose. Selection of the material depends upon the availability of the material. If both materials are available in bulk, then pond ash is preferable. It is because bulk utilization of waste material will be possible and it will be helpful to save natural clay.

4 Conclusions

From the laboratory study, comparison of the performance of the rice husk ash and pond ash is done. For compaction behavior standard, Proctor tests were conducted and for strength behavior, unconfined compressive strength test was conducted. The following major conclusions can be drawn.

- Due to inclusion of the pond ash and rice husk ash, the optimum moisture content of clay increases. This increment in the optimum moisture content is more in the case of rice husk ash.

- Maximum dry density of the clay decreases with increase in the content of the pond ash and rice husk ash. This decrease in the maximum dry density is more in the case of the rice husk ash.
- Pond ash and rice husk ash both have the potential to improve the load-carrying capacity of the clay significantly.
- The optimum content of the pond ash is found around 40%, while optimum content of the rice husk ash to improve the strength is found around 10%.

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Reviewing Some Properties of Self-Compacting Concrete Containing Recycled Materials

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Abstract The manuscript presents an assessment of the available data on the properties of Self-Compacting Concrete (SCC) containing recycled materials in its fresh and hardened states. A large number of studies has been conducted which showed that SCC is a sensitive product in its fresh state, wherein different recycled products have been used to access its fresh properties like flowability, passing ability and stability. It is assessed that a huge data is available regarding the investigations conducted to study the characteristics of hardened SCC using various recycled materials. The workability and suitability of SCC for various structural applications viz., bridge decks and piers, highway and airfield pavements, offshore structures, rapid mass transport systems, dams, tunnel linings, high-rise structures, precast and prestressed elements has also been accessed. The literature reveals that the use of different recycled materials in SCC would be a sustainable solution for developing a versatile construction material along with the environmental benefits.

Keywords Self-Compacting concrete · Recycled material · Stability · Workability · Environmental suitability

1 Introduction

The rapid growth of high-performance concrete structures resulted in the development of innovative construction materials like Self-Compacting Concrete, which offers the best solutions viz., high workability, passing ability through confined and densely reinforced spaces, economical and noise-free construction for the development of concrete industry and opened up new areas for the use of this product all over the world. Economically and technically, the Self-Compacting Concrete offers very attractive benefits over Normally Vibrated Concrete (NVC),

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_18

which can be further extended when combined with fibres, particularly steel fibres. Today, SCC is widely accepted material for the construction of bridge deck overlays, reinforced concrete bridges, prestressed bridge elements and railroad structures.

2 Self-Compacting Concrete (SCC)

In the past one decade, a significant number of researches related with various aspects of concrete technology and practice have been dedicated specifically to SCC and the available literature on SCC is further growing rapidly. The following section briefly discusses the characteristics of SCC in fresh and hardened state investigated in the recent past.

2.1 Properties of Fresh SCC

The SCC is much more preferred over NVC due to its fresh state properties, i.e. flowing characteristics and it is therefore more important to verify its fresh state properties. Alteration in the water-to-cement ratio and the amount of admixtures is the main properties in obtaining workable and stable SCC mixtures. Feys et al. (2008) and Khayat et al. (2010) studied the effect of water-to-cement ratio, superplasticizer (SP) and viscosity modifying agent (VMA) dosage levels on the workability and rheology of Self-Compacting Concrete. The optimum parameters for self-compatibility were determined through the tests of workability such as L-Box, V-funnel and slump flow. The constant dosage of superplasticizer was more effective in increasing the mix workability when applied at constant at lower water/cement ratios. The decrease in w/c ratio increases the extent of possible workability improvements of SCC. The optimal dosage of superplasticizer depends on the concrete mix proportions, which can be determined through experimental trials only. A range of 0.84–1.07 by volume is the suggested optimum water-to-cement ratio for producing SCC. The blocking may happen if the ratio is above and segregation of the mixture may happen for ratios outside this range. The use and type of VMA have affected the fresh properties of SCC significantly. The addition of VMA resulted in major enhancement in passing ability with the increase in slump flow without any negative impact on surface settlement, rheological properties and mechanical properties (Khayat et al. 2010).

Hwang et al. (2006) investigated about 70 SCC mixtures made with water-to-cementitious material ratios (w/cm) of 0.35 and 0.42 to evaluate the acceptability of various test methods for workability assessment and to propose stipulations for better structural performance of SCC. It was suggested to evaluate workability parameters of SCC to supervise the quality and design for place ability in constrained sections, encountered in various structures, through use of a combination of the slump flow and the L- box, J-Ring or V-funnel tests.

Sonebi et al. (2007) investigated the consequence of the water-to-cement ratio, superplasticizers (HRWRA) and the content of coarse aggregates, on filling ability and passing ability of Self-Compacting Concrete through statistical models. The established models provide a capable method to determine the effect of main variables on fresh characteristics of SCC and the models are applicable for a wide array of mix proportions. Kovler and Roussel (2011) reviewed the data related to workability, i.e. loss of slump, setting time and rheological characteristics of SCC, i.e. thixotropy, bleeding, segregation and problems related to formwork filling and pressure.

A number of investigations have been made to study the impact of different filler material viz., fly ash, limestone powder, metakaolin, chalk powder, etc. on the workability and stability of fresh SCC. The use of some other waste materials like spent foundry sand, ground-granulated blast-furnace slag (GGBFS), crump rubber, were also studied to investigate the SCC in its fresh state. It has been found that different filler materials, as well as waste materials investigated, could be efficiently used to develop SCC mixes with minute modification in dosage of superplasticizer. A summary of the some recent studies conducted in this regard is presented in Table 1.

For the successful placement of SCC, a concrete mixture with tailor-made workability properties was required to ensure a good balance between deformability and stability and ensure a homogeneous distribution of the concrete constituents. To ensure adequate structural performance and durability, such a homogeneous distribution is of utmost importance. There was a huge challenge for researchers and technologists to deal with intricate task of manipulating several variables to enhance concrete performance and at the same time reduce the cost while using SCC. Initially, Okamura and Ozawa (1995) has proposed an effortless mix design method in which the fine and coarse aggregate amount was kept constant and the water/powder ratio and dosage of superplasticizer were adjusted to achieve the self-compactability, which was later on modified by Okamura and Ouchi (1999). Su et al. (2001) used the concept of packing factor (PF) to suggest a new method for proportioning of SCC mixes. The most important deliberation of the proposed method was to fill the voids between the loosely piled aggregates by the paste of binders. The aggregate packing factor (PF) determines the amount of aggregate and affects the strength, flowability and self-compactability and other desired SCC properties. The guidelines for proportioning of SCC mix proposed by EFNARC (2005) and ACI 237R 2007 are presented in Table 2.

Lately, Kheder and Al Jadiri (2010) developed a new method for proportioning SCC mixtures based on specified strength under compression, not just emphasizing on the fulfilment of fresh properties requirements unlike the previous methods of proportioning. It also considers the effect of fineness modulus of fine sand and maximum size of coarse aggregate in proportioning SCC mixtures. This method suggested the design of SCC for compressive strength from 15 to 75 MPa. Silva et al. (2011) also studied the technical practicality of two design methods for proportioning of SCC to obtain required characteristics with minimum number of experiments.

Table 1 Summary of investigations made on properties of fresh SCC

References	Filler material used	Properties investigated	Major conclusions
Ho et al. (2002)	Quarry dust	Plastic viscosity and yield stress	SCC with high dosage of superplasticizer can be obtained
Zhu and Gibbs (2005)	Different limestone and chalk powder	Flowability and passing ability	SCC mix with limestone powder requires less dosage of superplasticizer as compared to chalk powder for the same workability
Gesoglu and Ozbay (2007)	GGBFS, fly ash (FA) and silica fume (SF)	Filling ability, passing ability, viscosity, and setting time	Slump flow time reduced with all admixtures Ternary and quaternary blends yield more satisfactory results for passing and filling ability FA and GGBFS prolonged the setting times
Guneyisi et al. (2009)	Marble powder and slag	Filling ability and viscosity	Use of marble dust increased the flow time and SP dosage, while the addition of slag decreases the flow time as well as superplasticizer demand
Guneyisi (2010)	Crump rubber waste and fly ash	Flowability, viscosity, passing ability, segregation resistance	Use of crump rubber increased the flow time and setting time addition of fly ash to rubberized mix decreases the flow time
Güneyisi et al. (2016)	Fine and coarse recycled concrete aggregates	Rheology, passing and filling ability	The self-compaction of the SCC mixes is outstandingly improved by replacing the coarse RCA and fine RCA at different levels
Singh and Singh (2018)	Recycled concrete aggregates, fly ash and Silica fumes	Shear thickening and thinning	Normal-strength SCRCAs showed shear thickening behaviour, whereas the medium- and the high-strength SCRCAs depicted shear thinning

Table 2 Proposed limits for constituents for SCC mixes

References	Cementitious material (kg/m^3)	Fine aggregate	Coarse aggregate	Water/cementitious material
EFNARC (2005)	380–600	48–50% of total aggregate by weight	750–1000 kg/m^3	0.85–1.10 by volume
ACI Committee 237R-07 (2007)	386–475	Mortar fraction 68–72% of total mixture by volume	28–32% of total mixture by volume	0.32–0.45 by weight

2.2 Properties of Hardened SCC

Initially, when SCC was adopted by the construction industry, the achievement of fresh properties was the major concern of the research and development work. It is, however, the properties of hardened concrete that are of principal interest to structural engineers and designers and contractors. A significant amount of research data has also been generated relating to properties of hardened SCC and a comprehensive review of the characteristics such as strength under compression and tension, fracture mechanism, modulus of elasticity, creep, shrinkage and other in situ and structural properties are presented in this section.

An investigation to compare the strength, elastic modulus, creep and shrinkage characteristics of SCC with NVC was conducted by Persson (2000). The study included specimens of eight different mix proportions with water-to-binder ratio (w/b) ranging from 0.24 and 0.80. The result shows that modulus of elasticity, creep and shrinkage of Self-Compacting Concrete at constant strength was similar to much extent with the corresponding properties of NVC.

Druta (2003) compared the values of strength under compression splitting tension for SCC and NVC. The coarse aggregate–cement paste bonding was also examined. All SCC mixtures exhibited higher strength compared to NVC under compression as well as split tension. The increase in strength under compression was approximately 60% while the strength under splitting tension of SCC was 30% higher than NVC. The reason for the increase observed in strengths was the enhancement in the bonding between aggregate and cement paste due to the use of mineral and chemical admixtures, which ultimately has increased the strength of concrete. The scanning electron microscope images taken from concrete samples have shown that the greater widths of the aggregate–cement paste interface micro-cracks for NVC than for SCC. Brouwers and Radix (2005) observed a higher splitting tensile strength for SCC compared to NVC of similar strength under compression.

The deformation behaviour of Self-Compacting Concrete under sustained loading was investigated by Wustholz and Reinhardt (2007). The different compressive strength grades of SCC were subject ted to sustained tensile load for up to 2.5 years. It was reported that the long-term tensile strength was found to be 69% of the short-term tensile strength and the stress-induced shrinkage tends to amplify on decreasing the compressive strength.

A widespread assessment of mechanical properties of SCC under hardened state was done by Domone (2007). The data have been analysed from more than 70 investigations and correlated to compare with the properties of NVC with similar strengths. The data so obtained depicted significant scatter, which may be due to a wide variety of materials and mixes used for SCC. It is evident that limestone powder makes a significant increase in strength, which was a common supplementary addition to SCC mixes. SCC showed similar or higher bond strength to reinforcing and prestressing steel as that for NVC. The in situ properties and the performance of the structural elements cast with SCC showed similar behaviour as that with NVC. A significant data has been obtained from this analysis which gives assurance in the general behaviour of Self-Compacting Concrete, and further investigations need to be designed to obtain confirmatory data for particular applications such as earthquake resistant structures and structures subjected to fatigue loads.

Hassan et al. (2008) studied the strength under shear and cracking behaviour of large-scale beams made with Self-Compacting Concrete and compared with NVC. The study revealed that ultimate strength under shear for NVC beams was somewhat higher than that of similar beams of SCC and the difference increases with the decrease in main steel reinforcement and increase of depth of beam.

The bond characteristics of Self-Compacting Concrete plays an important role when SCC is specifically to be used in structural elements with dense and congested reinforcement under difficult casting conditions without applying vibration. Esfahani et al. (2012); Desnerck et al. (2010) carried out extensive investigations to determine the bond strength and top-bar effect between deformed steel bars and different SCC mixes. SCC performed better than NVC depicted by less decrease in bond strength of SCC due to more stable and less inhomogeneous mix compared to NVC. The variation in bond strengths at different casting levels was also observed to be lesser in SCC than that of NVC. Due to its more consistent nature and superior filling ability, the Self-Compacting Concrete also showed a lesser top-bar effect compared to NVC. The behaviour of different structural elements of SCC under statically applied loads has been studied by several researchers and the results were compared with that of NVC. Table 3 summarized the results of such tests conducted on various structural elements made with Self-Compacting Concrete and NVC of similar strengths.

The effect of addition of different types of mineral admixtures/filler materials on the characteristics of Self-Compacting Concrete in hardened state viz., compressive strength and tensile strength, fracture processes, rupture modulus, creep and shrinkage, etc. were investigated by a number of researchers under statically applied loads. The impact of specimen size, size and type of aggregate on properties of hardened Self-Compacting Concrete has also been studied by various researchers. Thus, Table 4 presents a brief summary of the investigations carried out to study the afore-mentioned characteristics of SCC in hardened state.

The durability properties of SCC mixes viz., chloride ion penetration, freeze and thaw resistance, alkali-aggregate reaction, carbonation sulphate attack, resistance to fire, etc. have also been a subject of investigation (Persson 2003). It has, in general, been observed that the sorptivity and oxygen permeability of SCC mixes had remarkably reduced than that of NVC of the same strength. Zhu and Bartos (2003) depicted that the type of filler used is one of the main factors affecting the chloride diffusivity of SCC. The Self-Compacting Concrete mixes with no additional cementitious material were found to have significantly better chloride diffusion than the reference mixtures and other Self-Compacting Concretes, in presence of a viscosity modifying agent. Reinhardt and Stegmaier (2006) tested normal and high-performance SCC, respectively, under fire. The study revealed that the risk of spalling was greater in normal SCC as well as high-performance Self-Compacting Concrete in comparison to NVC and high performance NVC. The initial and residual mechanical properties for SCC were similar. The properties viz., internal frost resistance and salt resistance were extensively explored by Persson (2003). The results indicated a significant improve-

Table 3 Summary of tests on structural concrete elements

References	Test details	Type and strength of concrete	Results with respect to NVC
Khayat et al. (1999)	2.35 m columns, axial load	40–50 MPa SCC and NVC	SCC showed 50% higher ultimate strains in columns with comparable stiffness and load response
Sonebi et al. (2003)	4-point bending on 3.8 m span beams	60 MPa NVC and SCC beams	SCC beams showed narrower cracks and 5% greater deflection with similar cracking and ultimate loads
Peter et al. (2004)	3 m beams in 4-point bending: (a) Singly under-reinforced	72 MPa SCC, 69 MPa NVC	SCC beams achieved 12% higher peak loads and 10–15% higher deflection at first cracking
	(b) As (a) with shear stirrups		Similar crack width and spacing with 10% more curvature in Self-Compacting Concrete beams
Das et al. (2005)	4-point bending on 1.2 m span beam	28 days strength of 46 MPa and 59 MPa for SCC and NVC resp.	SCC showed narrower cracks and similar load deflection behaviour, shear strength was 9–12% higher
Naito and Hoover (2005)	10 m pretensioned T-beams	SCC 59 MPa and NVC 51 MPa	SCC showed similar strength and marginal greater deflection in beams
Kumar et al. (2009)	2.5 m T-beams under single point loading	45–55 MPa SCC and NVC	SCC beam was stiffer than NVC beam and depicted similar initiation and propagation of cracks, mode of failure and ultimate strength
Hassan et al. (2010)	Length 1050–4500 mm, depth 150–750 mm, width 400 mm, tested in three point loading	45 MPa SCC, 47 MPa NVC with 1–2% longitudinal steel reinforcement	SCC beams showed similarity in terms of widths, heights, and angles of cracks and overall failure mode

ment in the freeze and thaw resistance of SCC as compared to NVC whereas, frost scaling due to salt and internal fundamental frequency were more or less similar in SCC and in NVC.

Dinakar et al. (2008) studied the effect of adding high volume fly ash on the durability of Self-Compacting Concrete. The results indicated that the high volume fly ash SCCs depicted higher water absorption and permeable voids in comparison to normal NVCs of the similar strength under compression. The high-volume fly ash SCCs has shown a significant reduction in loss of weight and diffusion of chloride ion.

Table 4 Summary of investigations on properties of hardened SCC

References	Filler/recycled material	Property investigated	Major conclusions
Kim et al. (1998)	Class F fly ash content and aggregate-concrete ratio	Compressive and split tensile strength, elastic modulus, creep and shrinkage	Gain in compressive strength is slower As compared to NVC Splitting tensile strength is similar to NVC Creep rate is higher for SCC in early ages
Bouzoubaa and Lachemi (2001)	Class F fly ash	Compressive strength and drying shrinkage	No significant difference in compressive strength and drying shrinkage of SCC and control NVC was observed SCC can replace NVC of similar strength at the same cost
Bosiljkov (2003)	Limestone powder	Compressive strength	Better compressive strength than NVC due to improved fine particle packing of limestone filler
Bignozzi and Sandrolini (2006)	Tyre rubber waste	Compressive strength and stiffness	Compressive strength and stiffness of SCC decreases on the addition of tyre waste but the values better than the NVC with rubber tyre waste
Roziere et al. (2007)	Limestone fillers and paste volume	Fracture properties shrinkage and cracking	Increasing paste volume causes decrease in strength, elastic modulus, fracture resistance and increase in shrinkage and cracking. SCC becomes more brittle
Esping (2008)	Limestone fillers with different surface areas	Compressive strength	Compressive strength increased for mixes with limestone fillers with larger surface area because of denser packing
Gowda et al. (2009)	Quarry dust	Compressive strength and splitting tensile strength	Hardened properties remained unchanged for both SCC without and with quarry dust up to 70% replacement level
Karjinni et al. (2009)	Fly ash, metakaolin and silica fume	Compressive strength, flexural strength, tensile strength, Young's modulus, Poisson's ratio and density	Mechanical properties were better with silica fume than with fly ash and metakaolin Young's modulus increased with increase in strength Poisson's ratio was identical for all mixes

(continued)

Table 4 (continued)

References	Filler/recycled material	Property investigated	Major conclusions
Hossain and Lachemi (2010)	Volcanic ash	Compressive strength	SCC mixes for structural applications can be developed with compressive strength more than 15 MPa by replacing up to 50% of cement with volcanic ash but the compressive strength reduces drastically after 40% of replacement
Uysal and Yilmaz (2011)	Limestone, basalt and marble powder	Compressive strength, static and dynamic eastic modulli	Mixes with marble powder were having maximum compressive strengths and dynamic and static modulus of elasticity. A reduced dynamic and static elastic modulus was observed on addition of mineral admixtures
Siddique et al. (2012)	Coal fly ash and bottom ash, water-cementitious material ratio	Compressive strength	Indicated similar behaviour of strength increase on decrease of water-cementitious ratio. Recommends an optimum quantity of 25–35% and up to 20% for fly ash and bottom ash, respectively
Dehwah (2012)	Quarry dust powder (QDP), Fly ash (FA) and silica fume (SF)	Compressive strength, split tensile strength, flexural strength, UPV	The mechanical properties of SCC incorporating QDP (8–10%) shown improvement over the SCC prepared with SF plus QDP or FA alone and resulted in significant cost saving
Pereira-de-Oliveira et al. (2014)	Recycled concrete aggregates	Permeability	The water permeability was not significantly affected by recycled coarse aggregate incorporation. On increasing the percentage of recycled aggregates, the water penetration depth is reduced in SCC
Corinaldesi and Moriconi (2015)	Expanded clay aggregates, synthetic fibres	Tensile and flexural strength, post-cracking behaviour	Use of synthetic macro-fibres has improved the post-cracking behaviour and other mechanical and functional properties
Omrane et al. (2017)	Fine and coarse recycled concrete aggregates	Compressive strength, chloride ion penetration, sulphuric acid attack	The results indicate that using 50% recycled coarse and fine aggregates produced comparable compressive strength. It resulted in reduction in the chloride ions penetration depth to 50% and also showed a better resistance for sulphuric acid attack

Boel et al. (2008) concluded in a study that the gas permeability of SCC is almost five times less than the gas permeability of similar NVC.

Hwang and Khayat (2009) suggested that regardless of the water/cementitious material (w/cm) ratio, binder type or admixture combination, properly designed SCC can develop high resistance to freezing and thawing with frost durability factor greater than 80%. Guneyisi et al. (2011) have studied the permeability properties of SCCs made with different blends of Portland cement, fly ash, metakaolin and GGBFS. The type and amount of the cementitious material used significantly effects the permeability properties of SCCs. The metakaolin has been found to be the most efficient in reducing the permeability properties of Self-Compacting Concrete mixes.

The results derived from different investigations showed an overall improvement in the properties of SCC in hardened state over the NVC of similar grades. The improved homogeneity and density of concrete coming from vibration free production and better interface bond between aggregates and paste has contributed to the better performance of SCC over NVC.

3 Concluding Remarks

The review of the literature in the preceding sections presented in brief the characteristics of Self-Compacting Concrete made using recycled materials. It can be seen that numerous investigations have been carried out to assess the properties of fresh SCC as well as the properties of hardened SCC under static conditions of loading. Different types of cementitious materials have been incorporated in concrete to enhance the properties of SCC. The aim has been to review the workability and suitability of SCC concrete for use in different structures viz., in bridge decks and piers, highway and airfield pavements, offshore structures, rapid mass transport systems, dams, tunnel linings, high-rise structures, precast and prestressed elements.

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Assessing the Performance of Self-Compacting Concrete Made with Recycled Concrete Aggregates and Coal Bottom Ash Using Ultrasonic Pulse Velocity

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Abstract The construction community has now taken up the challenge for the use of 'green and recycled by-products' in construction. The utilization of coal bottom ash (CBA) in concrete is one of the feasible options to reduce the environmental problems related to its disposal. Coal bottom ash has the potential to use as a replacement of fine natural aggregates (FNA) or Portland cement (PC) and sometimes both. The current study assess the performance of self-compacting concrete (SCC) made with coarse recycled concrete aggregates (RCA) and CBA using ultrasonic pulse velocity (UPV) tests at different curing ages. Compressive strength and workability tests have also been conducted for reference. It has been noticed that with the incorporation of RCA (0, 25, 75, and 100%) and CBA (10%), the UPV values have been decreased compared to control SCC mix, however, an equivalent performance has been achieved up to 50% replacement of RCA across all curing periods. The maximum reduction up to 4 and 18% in terms of UPV and compressive strength, respectively, for SCC made with full replacement level (100%) of coarse natural aggregates (CNA) with RCA along with CBA (10%) has been noticed. However, the best and equivalent performance has been noticed for 25 and 50% replacement levels compared to control SCC mix.

Keywords Self-compacting concrete · Recycled aggregates · Coal bottom ash · UPV · Compressive strength · Workability

1 Introduction

The introduction of self-compacting concrete (SCC) in the construction industry has already brought the revolution and has resolved few of the critical issues up to some extent due to its immense advantages over normally vibrated concrete (NVC). To achieve environmental sustainability and practical applicability of SCC in the construction industry, the incorporation of construction and demolition (C&D)

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_19

wastes as recycled concrete aggregates (RCA) seems to be the most feasible solution (Ajith and Mathew 2015; Guneyisi et al. 2016; Kou and Poon 2009; Safiuddin et al. 2011). Several investigations have carried out in the past decades regarding the feasibility of replacing coarse natural aggregates (CNA) and fine natural aggregates (FNA) with waste materials and by-products (Guneyisi et al. 2016; Kou and Poon 2009; Kasemchaisiri and Tangtermsirikul 2008). From the literature studies, it has been observed that SCC made with any proportions of CNA satisfies all the fresh property requirements (Siddique et al. 2012a, b; Aswathy and Paul 2015). The fresh properties have been varied with mix proportions, however, less workability has observed for SCC made with RCA as coarse aggregate replacements. Similarly, literature has concluded that the mechanical properties of SCC has not affected significantly with the complete and partial incorporation of RCA (Pereira et al. 2014; Modani et al. 2014; Purushothaman et al. 2016). It has been observed that performance against mechanical properties of SCC has been found to be lower than NVC but comparable figures have been obtained for lower percentages of RCA in SCC. Several investigations have been carried out earlier on SCC with possible replacements of FNA with CBA with or without the use of cement additions (Siddique et al. 2012a, b; Aswathy and Paul 2015; Abidin et al. 2014). It has been confirmed that an increase in mechanical properties of SCC has been noticed up to some extent with the inclusion of 10% CBA (Siddique et al. 2012a, b). The quality of any concrete in terms of uniformity, presence, or absence of internal flaws, cracks, and segregation, level of workmanship, etc., can be assessed successfully by using UPV test. Moreover, a good correlation between compressive strength and UPV values has been obtained in NVC/SCC mixes. Also, it has been noticed that curing conditions and type of aggregates affects the UPV figures. Based on the literature, UPV test has been found to be beneficial in estimating the overall performance of SCC.

2 Objectives of the Study

Based on the literature, it has been observed that a lot of research has been carried out to evaluate the performance of NVC made with natural aggregates (NA), NVC made with CBA and NVC made with RCA with the abovementioned Nondestructive Testing (NDT) technique. Also, a chunk of literature is available on the SCC made with different combinations of NA and RCA and SCC made with CBA in which the overall performance has been judged with some other NDT techniques. To the best knowledge of the authors, a very few or no information is available on the assessment of SCC made with different replacement levels of CNA with RCA and FNA with CBA with the use of UPV tests. Therefore, the current investigation has been planned to; evaluate the performance of SCC made with RCA and CBA at different replacement levels of CNA with RCA along with fixed amount of CBA. Further, the next objective is to recommend the most appropriate combination of materials in terms of RCA for optimum/equivalent performance of SCC made with RCA and CBA vis-a-vis SCC made with NA.

3 Experimental Program

3.1 Materials Used

Portland cement (PC) of 43 grades confirming relevant Indian Standard Specifications has been used in the current investigation. The physical properties of the PC are listed in Table 1.

Coarse natural aggregates conforming to Indian Standard 2386 (1963) and 383 (1970) was used for the preparation of SCC mixes. Crushed stone coarse aggregates of maximum size 10 mm were used throughout the experimental program. Recycled concrete aggregates were obtained manually by crushing the waste concrete specimens present in the Structures Testing Laboratory of the Department of Civil Engineering of the authors' institute. The gradation of the RCA has been kept comparable to that of CNA throughout the investigation. The gradation curve of FA, PC, CBA, FNA, CNA, and RCA is presented in Fig. 1.

The specific gravity of CBA has been found to be 2.08 and fineness modulus is observed to be 1.5. The physical properties of FNA, CBA, CNA, and RCA are shown in Table 2.

Table 1 Physical properties of PC

Characteristic	Units	Result obtained	Permissible range specified (IS: 8112-1989)
Specific gravity	–	3.15	3.10–3.15
Fineness	cm^2/gm	2340	2250 (minimum)
Soundness	Mm	3	10 (maximum)
Normal consistency	%	34	30–35
Setting time	Minutes	65	30 (minimum)
		410	600 (maximum)
Compressive strength	MPa	23	23.00 (minimum)
		35.5	33.00 (minimum)
		45.1	43.00 (minimum)

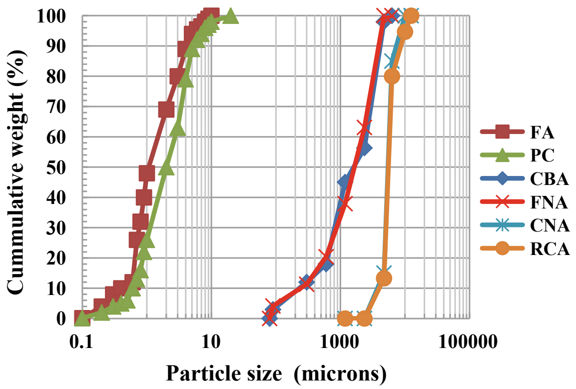

Fig. 1 Particle size distribution of FA, PC, CBA, FNA, CNA, and RCA

Table 2 Physical properties of FNA, CBA, CNA, and RCA

Properties	FNA	CBA	CNA	RCA
Fineness modulus (FM)	2.90	1.5	6.92	6.88
Specific gravity	2.75	2.08	2.64	2.44
Aggregate impact value (%)	1.25	6.8	16.35	30.43
Aggregate crushing value (%)	–	–	15.8	25.6
Water absorption (%)	1.25	6.8	0.68	5.65

3.2 *Mix Proportions*

A control SCC mix has been prepared with the use of PC, FA, and natural aggregates. In total, five numbers of SCC mixes were prepared in which the level of replacement of CBA has been kept constant (10%), which is reserved as optimum level of replacement in earlier investigations. The content of FA was kept 30% in all SCC mixes. With constant amount of CBA, the replacement level of RCA has been varied as 0, 25, 50, 75, and 100%. The details of SCC mixes are presented in Table 3. The control SCC mix has been designated as CFB-R0, whereas the rest of the mixes are designated as CFB-R0, CFB-R50, CFB-R75, and CFB-R100 containing 0%, 25%, 50%, and 100% of RCA, respectively.

3.3 *Workability Tests*

The workability tests have been performed on freshly made SCC mixes. Filling ability (V-Funnel and L-box), passing ability (L-box and J-ring), flowability (slump flow and J-ring), and stability (visual stability index) of all the SCC mixes has been examined with these tests. All the tests were conducted in accordance to EFNARC guidelines/ACI.

Table 3 Details of SCC mixes

S. no.	Notation	Mix description
1	CFB-R0 (Control)	70%PC + 30%FA + 100%CNA + 0%RCA
2	CFB-R25	70%PC + 30%FA + 10%CBA + 90%FNA + 75%CNA + 25%RCA
3	CFB-R50	70%PC + 30%FA + 10%CBA + 90%FNA + 50%CNA + 50%RCA
4	CFB-R75	70%PC + 30%FA + 10%CBA + 90%FNA + 25%CNA + 75%RCA
5	CFB-R100	70%PC + 30%FA + 10%CBA + 90%FNA + 0%CNA + 100%RCA

3.4 Compressive Strength Tests

The compressive strength tests were conducted in accordance with Indian Standard 516 (1959). The compressive strength tests were performed on all the SCC mixes at curing period of 7, 28, and 90 days of curing on the cube specimens of size 100 × 100 × 100 mm.

3.5 Ultrasonic Pulse Velocity Tests

These tests were performed according to the recommendations given in Indian Standard 13311, Part-(1)1991. In the present investigation, 'Direct Testing Method' was adopted for measuring UPV values for all the SCC mixes. The tests were conducted on specimens of size 100 × 100 × 100 mm at curing period of 7, 28, and 90 days.

4 Results and Discussions

The current investigation has been conducted to assess the performance of SCC mixes made with different replacement levels of CNA with RCA in relation to UPV behavior. Since the compressive strength of any concrete provides the general behavior of any type of concrete therefore, the compressive strength tests have been conducted for reference on all SCC mixes. The results of fresh properties and compressive strength are discussed in brief.

Table 4 Fresh properties of SCC mixes

Mix code	Slump flow		V-funnel (s)	L-box
	Diameter (mm)	T500 (s)		
CFB-R0 (Control)	725	2.8	4.8	1
CFB-R25	720	2.8	4.8	0.98
CFB-R50	700	2.95	5.8	0.98
CFB-R75	695	3.2	6.5	0.96
CFB-R100	685	3.3	7.1	0.94

4.1 Fresh Properties Tests Results

The result of various fresh properties is tabulated and presented in Table 4. It represents the variation of slump flow values with the percentage replacement levels of RCA. It has been clear from the results that the flowing ability of the SCC decreases with the addition of RCA. At lower replacement levels (25%), the percentage reduction in slump flow value was negligible however; it has been increased linearly with increase in RCA levels. Further, the slump flow values have reduced up to 6% with respect to control mix CFB-R0, when CNA are completely replaced with RCA (CFB-R100). The viscosity of the SCC mixes has been estimated with T500 test. The minimum and the maximum times for T500 tests varied 2.8–3.3 s. With complete replacement of CNA with RCA (i.e., 100%), T500 value has been increased by around 18% compared to control CFB-R0. The result obtained for V-funnel test indicates that the SCC mixes meet the flow requirements as recommended by EFNARC guidelines. However, the flow time has been greatly affected by the addition of RCA and other cement additions. The flow time has been increased by 48% (V-funnel) with complete replacement of coarse aggregate with RCA (i.e., 100%). A similar behavior has been noticed for L-box test in which it has been noticed that the incorporation of RCA affects the L-box ratio adversely.

4.2 Compressive Strength Tests Results

The compressive strength tests results of SCC mixes at curing periods of 7, 28, and 90 days are presented in Fig. 2. Each presented value is the mean value of three readings. In general, it has been observed that compressive strength has been decreased for all SCC mixes made with the incorporation of RCA (in place of CNA) across all curing periods. Among the results, it has been noticed that SCC mixes containing RCA up to 50% shows better compressive strength than that control SCC mix. For particularly 25 and 50% RCA (CFB-R25 and CFB-R50) based SCC mixes, an improvement in compressive strength up to 8% has been noticed at 7 days curing period. Further, for

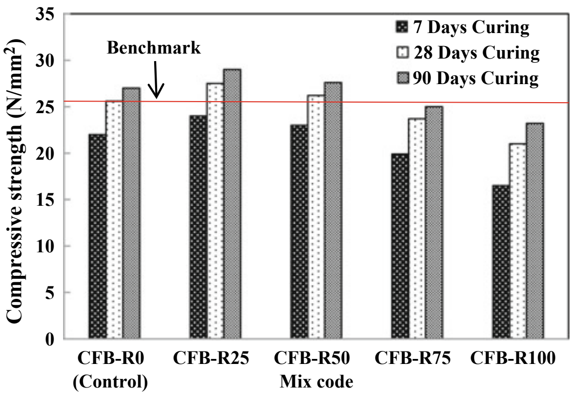

Fig. 2 Compressive strength test results for SCC mixes at different days of curing

the same curing period, the compressive strength has been reduced up to 22% with complete replacement of CNA with RCA (CFB-R100). At 28 days of curing, the compressive strength has been increased slightly up to 7% for SCC mix CFB-R25, whereas the compressive strength has been found to be comparable for SCC mix CFB-R50 in comparison to control SCC mix. For SCC mixes CFB-R75 and CFB-R100 the compressive strength has been found to be decreased sharply as reduction up to 18% has been noticed for the theses SCC mixes compared to that of control SCC mix CFB-R0 (benchmark values). The compressive strength has been increased with the effect of curing (90 days of curing), however, the overall trends remain similar to that of the patterns as observed for lower curing periods (Hamidian and Shariati 2011; Brito and Robles 2010; Sturrup et al. 1984). The presence of higher percentage of attached mortar and the exceptionally weak microstructure of RCA might become the probable reason for the higher reductions in the compressive strength (Hamidian and Shariati 2011; Katz 2003).

4.3 Ultrasonic Pulse Velocity Tests Results

Direct testing method was adopted for measuring UPV values for all the SCC mixes. The test provides information of the mechanical parameters and structural graders (compositions and densities) of the concrete investigated. The UPV tests results of SCC mixes are presented in Fig. 3. The obtained values were ranged from 3710 to 3854 m/s. All the specimens were cured for the period of 7, 28 and 90 days. The results indicate that UPV values decreased with increasing RCA content at all ages. The minimum values of UPV were seen in SCC mixes containing 100% replacement of RCA with CNA. Since UPV values depend directly on the density of aggregates and interfacial transition zone (ITZ) characteristics of the concrete, hence presence of weak ITZ and higher porosity leads to decrease in these values. The obtained UPV values are in agreement with previous researches and clearly proved that they are

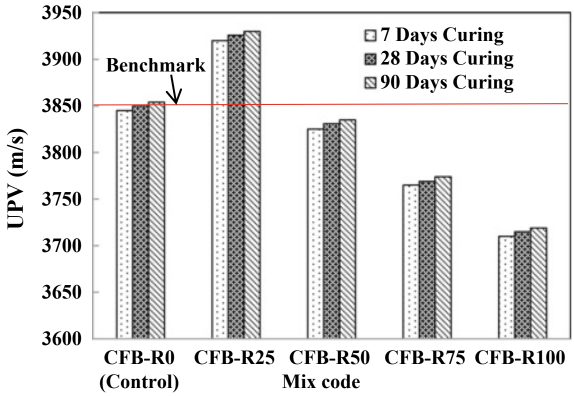

Fig. 3 UPV test results for different SCC mixes

highly influenced by the presence of cracks (joints) or cavities. IS 13311(Part-1): 1992 classified the concretes as excellent, good, medium, and doubtful for UPV values of 4500 m/s and above, 3500–4500 m/s, 3000–3500 m/s, and below 3000 m/s, respectively. In general, the UPV test results resemble with the results of compressive strength tests. As reported in the literature, a unique correlation exists between UPV and the compressive strength, as the performance of concrete depends on the nature of the aggregates. More the compressive strength values, denser will be the concrete mix and more will be the UPV values. In general, the UPV value for SCC mixes has been decreased with the incorporation of RCA at 28 days of curing. For example, minimum value of UPV has been observed for SCC mix CBF-R100 followed by SCC mix made with 75% of RCA (CFB-R75) compared to control SCC mix. The SCC mix CFB-R25 has showed better results than control SCC mix, whereas comparable performance for SCC mix CFB-R50 has been noticed for the same curing period. Similar trends have been observed at 90 days of curing. It has been revealed that the increasing rate of UPV values has been found to be sufficiently higher at the early ages; correspondingly, on the other hand, the rate becomes gradual after 28 days of curing. The fact has been consistent with that of the compressive strength of RCA based SCC mixes obtained at higher curing periods. From the results, it is clear that SCC mixes containing RCA as replacement of natural coarse aggregates perform satisfactorily, as most of the UPV values fall under the ‘Good’ category which indicates the worthy quality of concrete.

5 Conclusions

The experimental results show that the replacement of CNA with RCA yields an ample change in the compressive strength of SCC. Overall, the compressive strength has been found to decrease with the addition of RCA in all SCC mixes at all curing periods. A substantial reduction in compressive strength has been witnessed in SCC mixes after increasing content of RCA from 50 to 100% of CNA with RCA. Overall, the compressive strength has been found to comparable up to the level of 50% replacement of CNA with RCA along with CBA in SCC mixes at 90 days of curing. The SCC mixes having different replacement levels of RCA have been found to perform satisfactory relative to the control SCC mix at lower as well as at higher curing ages as seen in UPV tests. The maximum change in UPV figures has been varied from 3 to 4% with respect to control SCC mix at 28 days of curing. All UPV values of SCC mixes made with RCA and CBA have been observed in 'Good' category which indicates the worthy quality of concrete. The utilization of C&D wastes and industrial by-products in the form of RCA and CBA in concrete for various types of civil engineering applications can be an attractive approach for sustainable development of the construction industry worldwide.

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Compression and Shear Resistance of Self-compacting Concrete with Arch-Type Steel and Polypropylene Fibres

Kasilingam Senthil, Davinder Singh and Ivjot Singh

Abstract The experimental investigations were carried out on fibrous self-compacting concrete (SCC) elements subjected to monotonic loading to study the influence of arch-type steel fibre (AF) in terms of shear and compressive properties. The influence of polypropylene fibres (PF) at varying proportions was also studied along with arch-type steel fibrous self-compacting concrete. The tests were carried out on both fresh concrete as well as hardened concrete. In fresh concrete, slump and L-box tests were carried out and the results thus measured against varying combinations of both the fibres have been compared. In hardened concrete, compressive strength and shear strength test was conducted and their behaviour was compared. It was observed from slump test as well as L-box tests, the workability of hybrid fibre-reinforced self-compacting concrete was found to be reduced with increase in the volume of fibres. It is also observed that arch-type steel fibres showed exceptional post-cracking behaviour along with the polypropylene fibres for each mix.

Keywords Compression · Shear resistance · Self compacting concrete · Arch-type steel · Polypropylene fibers

1 Introduction

Concrete is widely used orthotropic systems, however, the system have its own limitations. Concrete has low ductility, low brittle in nature and also it has low tensile strength. To overcome this, the most common way is to add reinforcement. Reinforcement, usually in the form of steel reinforcing bar, is provided where tensile stresses are expected in the structure. Another way to overcome this limitation is by using a technique called prestressing. In addition to that, concrete may exhibit low structural integrity against impact and repeated loads.

These deficiencies of concrete may be removed by reinforcing it with small, discrete fibres, randomly oriented, uniformly distributed throughout the concrete. In

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_20

the case of fibrous-reinforced concrete, it is observed that one of the major problems that are to be faced related to concrete is at the time of placing is congestion. Proper compaction of concrete is very much required to achieve its desirable hardened properties for which it is known to be an excellent construction material. These limitations can be taken care of by a special type of concrete, known as fibrous self-compacting concrete. There has been a lot of experimental work which is related to the fibrous-reinforced concrete. Hsie et al. (2008) explored the mechanical properties of hybrid fibre-reinforced concrete containing two types of polypropylene fibres-staple and monofilament fibres. Results depicted that the hybrid fibre-reinforced concrete containing polypropylene fibres had 14.60–17.31% more compressive strength, 8.88–13.35% splitting tensile strength and 8.99–24.60% flexural strength than the ones with single fibre-reinforced concrete. Aslani and Nejadi (2013) developed a prediction model to determine the mechanical properties of four types of SCC mixes—plain SCC, polypropylene, steel and HFRSCC. Hybrid fibre-reinforced SCC mix proved to be the best among the other mixes for the elasticity modulus and quite similar results were given in agreement with the model prediction. Ponikiewski and Katzer (2014) was concentrated on self-compacting concrete (SCC) modification by the addition of polymer and steel fibres to depict the maximum amount of fibre composition allowed to achieve flowing properties of self-compacting concrete. It is observed that the varying length of the fibres used, we can extend this limit dosage while maintaining the self-compacting effect. Rambo et al. (2014) investigated hooked-end and straight steel fibres with unlike diameter and lengths at volume fractions of 1 and 1.5% to examine the consequences of hybridization of steel fibres on the mechanical and rheological properties of concrete which requires no vibration for compaction. The observations indicated that crack width control increased the limit of serviceability by introducing the concept of fibre hybridization. In addition, researchers have been working on the structural performance in RC members with self-compacting concrete under monotonic loads in the past few years (Afroughsabet and Ozbakkaloglu 2015; Won et al. 2015; Tabatabaeian et al. 2017; Lee et al. 2016; Senthil et al. 2016a, b; Senthil et al. 2017; Yoo et al. 2017). Based on the literature survey, it is observed that the fibres can enhance various properties of self-compacting concrete. Different shapes of steel fibres are coming up to improve the anchorage properties of the fibres but still, their pull out at a lower force had been observed in most of the fibre shapes. A lot of research has been done on the concept of hybridization of fibres but still there are chances of exploring some new things. We also know that the SCC is comparatively weak in shear but limited research has been carried out on shear resistance of fibrous-reinforced self-compacting concrete. Thus, in the present study, the authors tried to consider all these aspects as authors are chosen arch shape fibres along with the polypropylene fibres by making a hybrid mix of self-compacting concrete to study its fresh properties and hardened concrete properties. The fresh properties of hybrid fibre-reinforced self-compacting concrete containing arch-type steel fibres and polypropylene fibres have been studied at different proportions, using slump test and L-box test. The compressive strength and shear strength of hybrid fibre-reinforced self-compacting concrete containing different proportions of arch and polypropylene fibres have also been studied.

2 Methodology

In this section, there is an elaborate depiction of the materials which has been used in the experimental work. The method that has been adopted to carry out the work has also been described. The experimental program included the testing of slump flow test, L-box test, compressive strength test and shear strength test and discussed here.

2.1 Materials

Arch-type steel fibre (AF)-reinforced cementitious composites exhibited higher flexural performance to composites formed using hooked-end-type steel fibres. Curvature radius can augment the performance of an arch-type steel fibre. Interfacial toughness increases with the decrease in the curvature radius. There was a pronounced effect of bend length for a given curvature radius for the arch-type steel fibres. Figure 1 shows the schematic diagram of arch-type steel fibre to have a proper look at those two parameters. Additionally, the bond strength and interfacial toughness increased with increasing bend length regardless of the curvature radius. Optimal dimensions of the arch-type steel fibre, chosen on the behalf of previous studies were: radius $R = 35$ mm, aspect ratio $(l/d) = 72$, diameter of the fibre 0.7 mm, circular in shape, l_e is 1.5 mm. The total length of the fibre = 50.4 mm and tensile strength of the fibre = 1300 MPa.

Polypropylene is made through polymerization of the monomer propylene. It has high strength and high resistance to fatigue. The melting point and elastic modulus are low compared to many other fibres. Due to this, these fibres may not be fit for certain situations, however, in most of the situations, these fibres have been used. Polypropylene fibres had been proved the best among the synthetic fibres available in the market in terms of strength characteristics properties of the polypropylene fibres used: length of the fibre is 19 mm, diameter 0.5 mm, shape of fibre is straight and circular in crosssection and tensile strength of fibre is 570–660 MPa.

Ordinary Portland Cement (OPC) grade 43 (UltraTech) was used in the present study. The fine aggregates were available locally and used to carry out the experimental investigations. The sand was dry and free from any unwanted materials. Sieve analysis tests were performed to find the fineness modulus, for fine and coarse

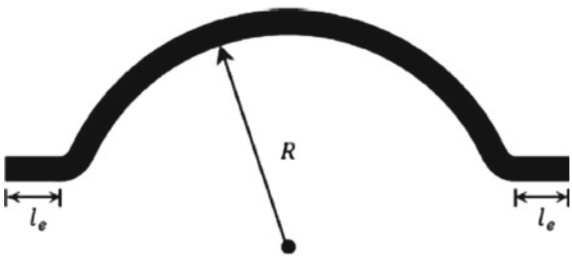

Fig. 1 Schematic diagram of arch-type steel fibre

aggregate, i.e. 2.89 and 7.07, respectively. The specific gravity test has been conducted for coarse and fine aggregates are 2.67 and 2.62, respectively. Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. The aim of adding silica fume to the mix was to influence its viscosity in the fresh state. The used silica fume was characterized SiO_2 content equal to 92.8%. When silica fume is added to concrete, initially it remains inert.

2.2 Experimental Program

The influence of arch-type steel fibre (AF) and polypropylene fibres (PF) at varying proportions were studied along with arch-type steel fibrous self-compacting concrete shown in Table 1. The arch-type steel fibres with aspect ratio 72 and polypropylene fibres of 19 mm length were considered in the present study. The length and diameter of polypropylene fibres is 19 and 0.5 mm, respectively was considered. The combination of fibres were named as: SCC0 (0% fibre), SCC1 (0.8% of 0.5% AF and 0.3% PF), SCC2 (1.6% of 1.0% AF and 0.6% PF) and SCC3 (2.4% of 1.5% AF and 0.9% PF).

2.3 SCC Mix Proportion

The SCC mixes were prepared according to the ratios proposed by Ponikiewski and Katzer (2014), is shown in Table 2.

2.4 Tests on Fresh Concrete

The slump flow and L-box test have been conducted to study the fresh properties of self-compacting concrete. For each proportioning of the fibres, we conducted three trials for the slump flow test. The slump flow test was used to assess the horizontal free flow of self-compacting concrete in the absence of obstructions. About 6 L

Table 1 Fibre volume proportions

S. no.	Description	Arch-type steel fibres (%)	Polypropylene fibres (%)
1	Plain SCC	0	0
2	SCC1	0.5	0.3
3	SCC2	1	0.6
4	SCC3	1.5	0.9

Table 2 SCC mix composition, Ponikiewski and Katzer (2014)

S. no.	Ingredient	Quantity (kg/m^3)
1	Cement (OPC 43 Grade)	485
2	Fine aggregates (0–2 mm)	810
3	Coarse aggregates (2–8 mm)	457.7
4	Coarse aggregates (8–16 mm)	457.7
5	Water (tap water)	202
6	Super plasticizer	18.6
7	Silica fumes	48.5

of concrete was needed to perform the test, sampled normally. Moistened the base plate and inside of slump cone, place base plate on level stable ground at least 700 mm square, marked with a circle marking the central location for the slump cone and a further concentric circle of 500 mm diameter or marking on the four sides symmetrically on the square plate denoting the same circle could be made and the slump cone held down firmly centrally on the base plate. Fill the cone with the help of scoop and without tamp, simply struck off the concrete level with the top of the cone by using trowel. Then removed surplus concrete from around the base of the cone. After that, the cone was raised vertically and allowed the concrete to flow out freely. Then, the reading was noted along the longest line of the flow in any direction.

The L-box test is also one of the tests for workability ,which assessed the flow of the self-compacting concrete and also the extent to which it is subjected to blocking by reinforcement. The apparatus consisted of rectangular section box in the shape of an ‘L’, with a vertical and horizontal section, separated by a movable gate, in front of which vertical length of reinforcement bar was fitted. The vertical section was filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. When the flow stopped, the height of the concrete at the end of the horizontal section was expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars was restricted.

2.5 Casting

Originally, the moulds available were of size 100 × 100 × 500 mm, however, with the help of wooden piece and thermocol pieces, the length of mould reduced to 300 mm and made the grooves, respectively. The mould 100 × 100 × 300 mm for shear test were prepared and tested for shear in a compression testing machine by making two symmetrical grooves of 25 × 50 mm and applying the load in the direction as shown in Fig. 2a. The mould used for casting is arranged on a clean flat and non-absorbent

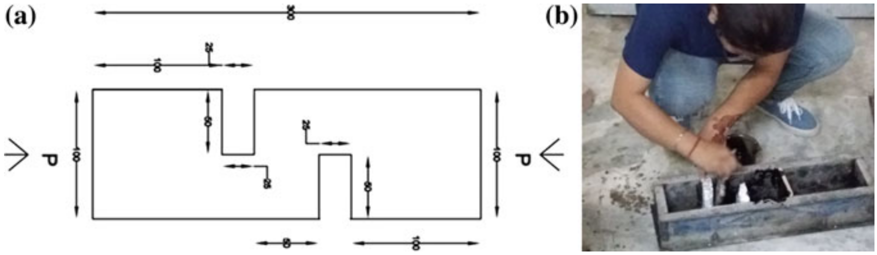

Fig. 2 **a** Schematic shear test specimen and **b** oiling on mould

surface. The exact quantities of materials are kept ready on another platform for preparing specimen and after mixing, the concrete is filled in three layers in the mould. Compressive strength moulds were of standard size cubes, i.e. 150 × 150 × 150 mm. After getting the moulds of the required size and their oiling was done as shown in Fig. 2b, all the materials were mixed in the drum mixer properly, poured into the wide square plate and then the specimens were casted.

2.6 Testing of Specimens

The specimens of 150 × 150 × 150 mm cube were casted and for compression test after 28 days of curing. The cubes with various volumes of fibre additions were casted and tested to check whether it had some appreciable effect on its compressive strength or not. The specimen was wiped off its surface moisture and grit on the previous day of its testing date and it is white washed. After the white wash, the surface was dried, the surface of the frame was marked with lines to study the crack pattern. The compression tests were carried out on hydraulic compression machine having the capacity of 1000 kN at a loading rate of 0.1 mm/min. Shear strength test was also carried out under compression testing machine as explained earlier by keeping all the other parameters same as shown in Fig. 2a. All the shear specimens were tested at 7 and 28 days of curing. During the testing of the specimens, deflection at various intervals was noted. During testing, the onset of shear cracking was also observed until the ultimate failure of the specimen.

3 Results and Discussion

In fresh concrete, slump and L-box tests were carried out and the results thus measured against varying combinations of both the fibres have compared. In hardened concrete, compressive strength and shear strength test were conducted and their behaviour was compared. Slump flow and L-box test along with compressive and shear test results for various proportions of arch-type steel and polypropylene fibres have been discussed in this Section.

3.1 Comparison of Slump Results of PF and AF Concrete

It is observed from Fig. 3 that slump flow of the concrete composite kept on decreasing as we increased the percentage of fibres to be incorporated in the mix. Conventional SCC0 mix showed the maximum slump flow with a value of 800 mm which can provide an excellent self-compacting effect. Generally for a good flowing ability, minimum value for the slump flow is to be taken as 650 mm, Ponikiewski and Katzer (2014). Thus from our experimental results, it is observed that the SCC3 mix containing a total of 2.4% fibre addition (1.5% arch fibres and 0.9% polypropylene fibres), could not offer the self-compacting effect as the value is much lower, i.e. 508 mm. Even the SCC2 proportion has the slump flow of 610 mm, however, it is acceptable to some extent because in that case, compensation can be made by increasing the amount of plasticizer or by decreasing the volume of polypropylene fibres because the main reason behind the decline in the slump flow values was the incorporation of polypropylene fibres as their capacity of water absorption is quite significant. This decline was also supported by the arch shape fibres as they anchor themselves very well in the mix because of their geometry. Therefore, it is concluded that the fibres more than 1.6% by volume in total may not be used in the self-compacting concrete composite as they may hamper the basic property of the SCC.

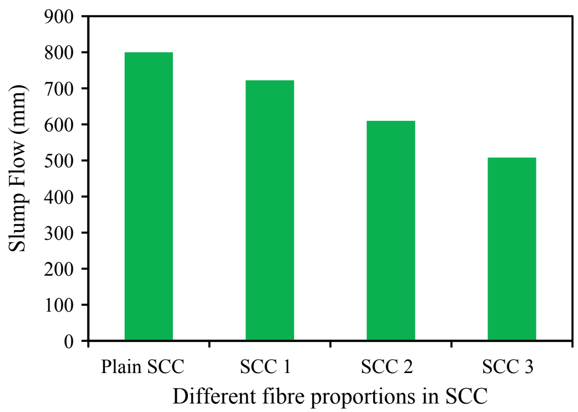

Fig. 3 Slump values against varying fibre volume proportions

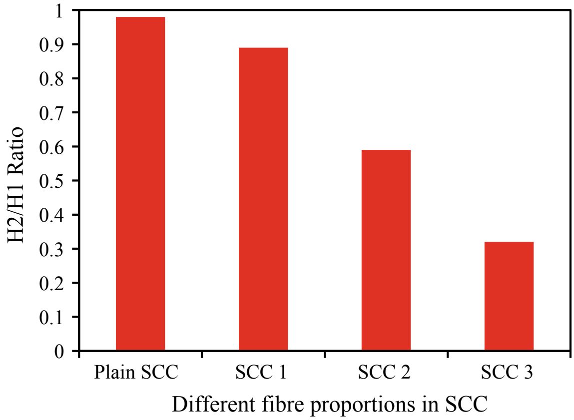

Fig. 4 H_2/H_1 ratio values at various fibre volume proportions

3.2 Comparison of L-Box Results of PF and AF Concrete

The L-box test results found similar to that of slump tests and it was also noticed that the workability of SCC mix decreases with increasing fibre content, see Fig. 4. For a good workable mix, a range of 0.8–1.0 of H_2/H_1 ratio is acceptable, Ponikiewski and Katzer (2014). The mixes SCC0 (0% fibre addition) and SCC1 (0.8% fibre) have shown very good results to ensure a good workable mix at the time of pouring. SCC2 mix of 1.6% fibre addition showed a bit different behaviour in the L-box test having 0.59, much lesser than the acceptable limit for the mix to be in a good workable condition. The maximum percentage addition of fibres mix, i.e. SCC3 has a very low 0.32 which signifies a very poor mix.

3.3 Comparison of Compressive Strength of PF and AF Concrete

The compressive strength of hybrid fibre-reinforced self-compacting concrete containing different proportions of arch and polypropylene fibres have been studied. It is observed from Table 3 that the compressive strength has found to be increased considerably up to SCC2. The compressive strength of SCC2 was found to be maximum among the chosen mix proportion. However, the compressive strength of SCC3 mix was found dropped significantly. The reason may be due to the presence of polypropylene fibres in large amount which absorbs water significantly and also because of the fact that concrete alone also shows an excellent behaviour under compression which could have been affected by the more fibre addition that covers the space earlier filled by the basic ingredients of concrete. Therefore, it is concluded that the compressive strength of concrete was found to be increased up to 1.6% fibre content including AF and PF fibres, whereas in case of fibre content increase beyond 1.6%, the compressive strength is found to be decreased significantly.

Table 3 Compressive strength of hybrid fibre-reinforced self-compacting concrete

Description	Compressive strength (MPa)
SCC0	86.5
SCC1	95.8
SCC2	98.5
SCC3	90.7

3.4 Comparison of Shear Strength of PF and AF Concrete

The shear strength of hybrid fibre-reinforced self-compacting concrete containing different proportions of arch and polypropylene fibres have also been studied for both 7 and 28 days. It is observed from Fig. 5 that the shear strength of SCC0 was found lowest among the other mixes as the cracks easily grew widened in the mix containing no fibres. SCC1 showed a drastic improvement in the shear strength of the SCC mix as the value increased from 2.3 to 3.6 N/mm^2 at 7 days curing and 4 to 6.1 N/mm^2 at 28 days curing. This was due to the incorporation of fibres which provided the bridging effect between the crack openings and delayed the failure of the concrete. SCC2 mix had also given superior strength than the previously tested SCC1 mix as the fibre percentage was further increased, however, the increase in the shear stress resistance from SCC1 to SCC2 was found less as compared to the increase from SCC0 to SCC1. Also, it was observed that maximum shear stress 8.2 MPa at 28 days in case of SCC3 mix which has maximum shear strength among the selected cases.

More than one and a half times (52.5%) strength improvement was observed from SCC0 to SCC 1 mix because of the fibre hybridization as the addition of two different fibres enhanced the shear strength much more by complementing each other as a matter of the fact that the steel fibres prevent the growth of macro-cracks whereas polypropylene fibres reduces micro crack width. There was a decrease in the rate of

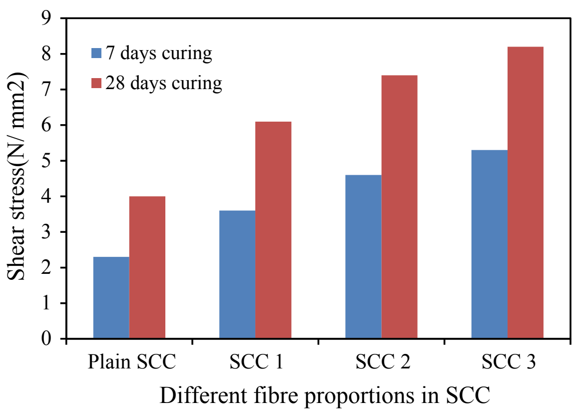

Fig. 5 Shear strength of 7 and 28 days cured shear specimens

Table 5 Average shear load at first crack and ultimate failure

Description	Shear load at first crack (kN)	Ultimate shear load at failure (kN)
SCC0	–	19.8
SCC1	10.8	30.4
SCC2	14.1	36.8
SCC3	19.9	40.8

increase in ultimate shear stress on increasing the amount of fibres as only 21.3% enhancement was monitored in case of SCC2 mix. The reason may be due to high volume of fibre replacement from the normal SCC concrete causes utmost importance in the chemical reactions to be occurred during the reaction period. 10.8% hike in the shear strength was examined from SCC2 to SCC3 mix subjected to a maximum value of 8.2 N/mm^2 ultimate shear stress after 28 days curing sample. The reason behind the further decrease of rate of increase has already been explained in the above-mentioned point.

The shear load of hybrid fibre-reinforced self-compacting concrete containing different proportions of arch and polypropylene fibres have been studied in terms of first crack as well as ultimate failure load as shown in Table 5. It is observed from Table 5 that all the fibre volume proportions showed an excellent post-cracking behaviour. SCC1 had 10.8 kN shear load at first crack whereas it actually failed at a very high ultimate load value of 30.4 kN. The difference between first crack and ultimate failure shear loads of SCC1 mix was 19.6 kN. The same was observed in the case of SCC2 and SCC3 mix configurations, showing a difference of 22.7 kN and 20.9 kN between the first crack and ultimate failure shear loads. It is observed that the post-yield behaviour of chosen mix, i.e. SCC1, SCC2 and SCC3 was found to be almost similar.

Improvement in post-cracking behaviour in shear was observed with the addition of arch and polypropylene fibres. The shear strength of SCC0 was found lowest and failed by brittle in nature and maximum displacement of 0.35 mm as shown in Fig. 6a. A trend of load versus deflection of specimens was found almost similar to all fibre volume fractions as shown in Fig. 6b–d. The load deflection curve follows an approximately straight, steep ascending portion followed by a sudden change in slope at point of appearance of first crack as shown in Fig. 6b–d. This was followed by an increase in load-carrying capacity for some extend, at this point load reaches its peak. This point is called as maximum post-cracking load or ultimate load. The trend was further followed by a descending portion and from this point load-carrying capacity of member decreases with increasing deflection. The maximum deflection of specimen SCC1, SCC2 and SCC3 was found to be 17.4, 22 and 25 mm, respectively.

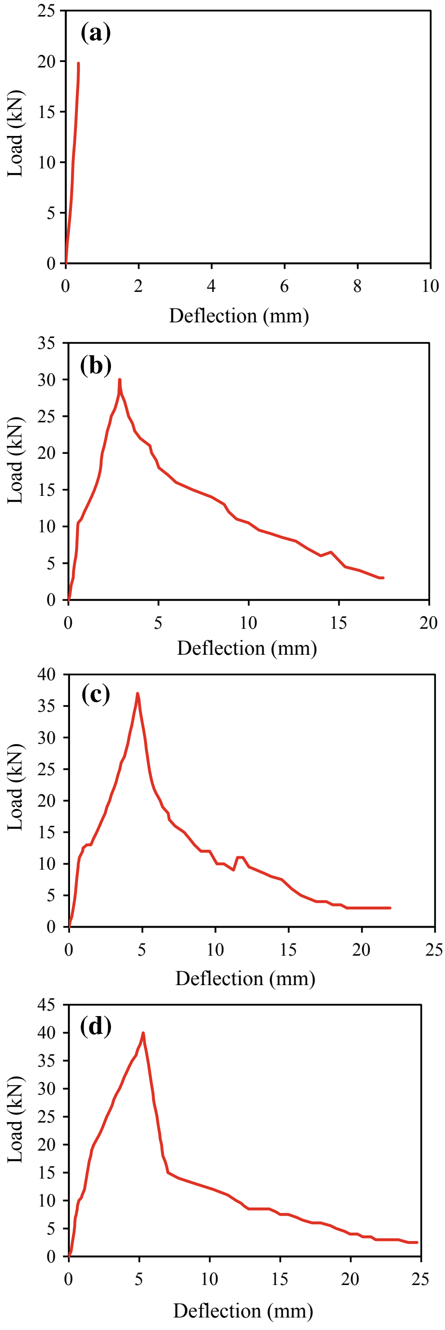

Fig. 6 Load versus deflection of **a** SCC0 **b** SCC1 **b** SCC2 and **c** SCC3

4 Conclusions

The experimental investigations were carried out on fibrous self-compacting concrete (SCC) elements subjected to monotonic loading to study the influence of arch-type steel fibre (AF) in terms of shear and compressive properties. The influence of polypropylene fibres (PF) at varying proportions was also studied along with arch-type steel fibrous self-compacting concrete. The tests were carried out on both fresh concrete as well as hardened concrete and the following conclusions were drawn:

- Workability of hybrid fibre-reinforced self-compacting concrete found to be reduced both in slump flow and L-box tests with increase in the volume of fibres. It is concluded that the fibres more than 1.6% by volume in total may not be used in the self-compacting concrete composite as they may hamper the basic property of the SCC.
- It is concluded that the compressive strength of concrete was found to be increased up to 1.6% fibre content including AF and PF fibres whereas in case of fibre content increase beyond 1.6%, the compressive strength found decreased significantly.
- It is also concluded that the shear strength characteristics showed an excellent improvement with the introduction of fibre hybridization at each fibre volume proportion. The addition of 0.8, 1.6 and 2.4% of combination of steel and polypropylene fibres in the mix was found to increase the shear strength by 52.5, 21.3 and 10.8%, respectively as compared to the conventional SCC mix.
- Arch-type steel fibres showed exceptional post cracking behaviour along with the polypropylene fibres for each mix. The SCC1, SCC2 and SCC3 mix carried 1.8, 1.6 and 1.05 times more load, respectively, after the onset of shear cracking than the load carried by them till the appearance of first crack.

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Prediction of Flexural Behavior of Fiber-Reinforced High-Performance Concrete

Umesh Chand

Abstract The availability of ultra-fine materials, mineral, and chemical admixtures have made an easy design of concrete mix of high and ultra-high strength. Many investigators have developed methods to predict the flexural strength of fiber-reinforced concrete composites assuming different stress distribution over the crosssection. However, it has been observed that the use of fibers throughout the crosssection is structurally inadvisable and economically wasteful, as the tensile stresses are developed in one portion of the crosssection, depending on loading and end conditions. The beams having fiber reinforcement in only tension region are found to possess higher flexural load capacity and higher initial stiffness in comparison to the corresponding beams with fibers throughout the section. Based on this approach of tension reinforcement, the concept of partial depth fiber-reinforced high-performance concrete beams has been established by incorporating fibers in tension zone only. The typical results obtained experimentally are analyzed in the light of load–deflection behavior, failure pattern, cracking and ultimate moment capacity, and ductility associated parameters have demonstrated that Fiber-Reinforced High-Performance Concrete (FRHPC) is extensively used as a construction material because of fact that the composite provides better mechanical, rheological, and durability properties.

Keywords Load–deflection behavior · Ultimate moment capacity · Failure pattern · Toughness

1 Introduction

High-performance concrete (HPC) is designed to give performance characteristics satisfying comprehensive list of requirements based on hardened properties Kumar Bharat et al. (2001), high strength is made possible by reducing porosity, non-homogeneity, and microcracks in concrete, whereas HPC mix proportioning relies on the concept of densified system with ultra-fine particles, effective combination

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_21

of mineral additives, and chemical admixtures in addition to the use of very low water–cement ratio. Therefore, reduction in total concrete volume due to slenderness of structural member and improvement in material and structural durability by the use of high-strength high-performance concrete is evident. Su and Miao (2003) and Lim et al. (2004). Research conducted on high-performance concrete concluded that the inclusion of steel fibers in concrete increases ductility, toughness, and strength of flexural members. The concrete that needs special performance and uniformity requirements that cannot always be achieved routinely by using conventional material, normal mixing, placing, and curing is termed as high-performance concrete.

2 Published Work

Several researchers have studied the behavior of steel fiber-reinforced high-strength concrete (SFRHPC) in flexure, predicting flexural strength of full depth fiber-reinforced concrete composites assuming different stress distribution over the section. Hannant (1978), Narayanan and Green (1981), Ghalib (1980), Rajagopalan et al. (1974), Snyder and Lankard (1972), Shah (1991) and others have developed models to predict the flexural strength of FRHPC. Gunasekaran (1975), however have demonstrated that the use of fibers throughout the section is structurally inadvisable and economically wasteful in all of the cases of the beams tested, as tensile stresses are normally developed in the lower half of the beam only. The beams that had fiber reinforcement in the lower half (tension region) were found to possess higher flexural load values and higher initial stiffness than the corresponding beams with fibers throughout the section. Padmarajaiah and Ramaswamy (2002) have studied the full and partial depth steel fiber high-strength concrete beams and showed that for partial depth concrete beam for a specified fiber volume showed similar load––deflection behavior corresponds to full depth steel fiber-reinforced concrete beams. Dwarkanath and Nagaraj (1992) have studied conventionally reinforced concrete beams tested under pure bending condition and they have shown that the half depth fiber inclusion is equally effective in improving the behavior of beam in flexure, and found half depth fiber inclusion as economical.

The review of the published literature has demonstrated that significant research has been conducted on conventional, normal, and high-strength concrete with full depth of fiber inclusion and partial depth inclusion, to investigate flexural behavior and load–deflection pattern of beams. Several investigators have attempted the problem by considering the stress distribution in compression and tension as triangular and rectangular in nature. The influence of the tensile strain enhancement factor, which is the ratio between the ultimate tensile strength of FRC and the ultimate flexural tensile strain of concrete without fiber have also been studied. Most of the investigators have used circular steel fibers in fiber volume content varies from 0.5 to 3%. However, the influence of inclusion of steel fibers on high-performance concrete of higher grades has not been studied by any researcher. The variation of fiber content in SFRHPC has also not been investigated. In the present study, therefore, experimental investigations have been conducted by incorporating circular crimped steel fibers of 0.5 mm diameter and 30 mm length with aspect ratio of 60 in SFRHPC beams to full depth, half depth, and quarter depth of the beam crosssection, to investigate flexural characteristics, load–deflection behavior, and ductility associated parameters of such SFRHPC beams, in an attempt to optimize application of fiber in the beam crosssection.

Extensive experimental investigations have been conducted in the present study to investigate the behavior of high-performance concrete for M90 grade in flexure using circular crimped steel fibers of aspect ratio 60. The experimental work consists of determining the basic mix proportioning of constituent materials, casting, curing, and preparing the specimens including instrumentation and testing of these specimens.

3 Analytical Study

Steel fiber-reinforced high-performance concrete beams with fibers up to different depths have been studied in flexure. Several investigators have studied the problem analytically, considering different variables and assumptions. Some derivations were based on strain compatibility and equilibrium conditions for fully and partially SFRHPC sections with suitable idealized tension and compression stress blocks.

3.1 Flexural Analysis of Conventionally Reinforced High-Performance Concrete Beams Without Fibers

The ultimate moment capacity of the singly reinforced HPC is based on the stress–strain distribution for the crosssection of singly reinforced plain concrete beam as given in ACI 318M-11 (2011). The equation for nominal moment of a singly reinforced HPC beam is given as

$$M_n = A_s f_y (d - a/2) \quad (1)$$

$$\text{and } a = A_s f_y \big/ (\lambda f_C' b) \quad (2)$$

where

A_s Area of tensile steel bars (mm^2),
f_y Yield strength of tensile reinforcement bar (MPa),
c Neutral axis depth (mm),
b Width of beam crosssection (mm),
h Height of beam crosssection (mm),
λ Concrete stress block parameter, (equal to 0.86 for $f_c' \geq 55$ MPa),
f_C' Compressive strength of plain concrete, (MPa),
β_1 Concrete stress block parameter, (equal to 0.65 for $f_c' \geq 55$ (MPa),
a Depth of the equivalent compressive block (mm).

3.2 Flexural Analysis of Full Depth Steel Fiber-Reinforced High-Performance Concrete Beams

The ultimate moment capacity of the SFRHPC beams has been calculated using the empirical formulae derived by Hwan Oh (1992) for the full depth fiber inclusion in the beam crosssection for singly reinforced beam. The value of ultimate moment (M_n) for full depth SFRHPC beams is given by the equation as

$$M_n = A_s f_y(d - a/2) + \sigma_t b\,(h - c)\,(h + c - a)/2 \tag{3}$$

$$\text{and } a = \left(A_f f_y + \sigma_t bh\right) / \left(\lambda f_{cf} b + \sigma_t b\right) \tag{4}$$

where

f_{cf} compressive stress of fibrous concrete.

3.3 Flexural Analysis of Half Depth Steel Fiber-Reinforced High-Performance Concrete Beams

The ultimate moment is derived from the simplified stress distribution in which the compressive and the tensile stress blocks are simplified as rectangular blocks. The value of the stress block is assumed as $0.85 f_c{}'$. The depth of the tension zone stress block is *h*/2. The ultimate moment capacity (M_n) is given as Hwan Oh (1992),

$$M_n = A_s f_y(d - a/2) + \sigma_t bh(3h - 2c)/8 \tag{5}$$

$$\text{and, } a = \left(A_f f_y + \sigma_t bh/2\right) / \left(\lambda f_c' b\right) \tag{6}$$

3.4 Flexural Analysis of Quarter Depth Steel Fiber-Reinforced High-Performance Concrete Beams

Since none of the researchers has analyzed SFRHPC beams with quarter depth fibers in beam crosssection, the ultimate moment capacity for such cases has been derived based on stress distribution pattern considered for full and half depth fibers. Accordingly, the ultimate moment (M_n) for the quarter depth SFRHPC beams has been obtained on the basis of assumed stress distribution. The depth of tension block is taken as *h*/4. The ultimate moment capacity (M_n) is given as Hwan Oh (1992)

$$M_n = A_s f_y(d - a/2) + \sigma_t bh(7h - 4a)/8 \tag{7}$$

$$\text{where, } a = \left(A_f f_y + \sigma_t bh/4\right) / \left(\lambda f'_c b\right) \tag{8}$$

3.5 Flexural Analysis of Normal Strength Fiber-Reinforced Concrete to Full Depth

The ultimate moment capacity of the full depth normal strength fiber-reinforced concrete (NSFRC) beam can be calculated according to the method given by the ACI 318-11C (2011). The equation for the ultimate moment capacity (M_n) of the steel fiber-reinforced normal strength concrete beam is given as

$$M_n = A_s f_y(d - a/2) + \sigma_t b(h - e)(h + e - a)/2 \tag{9}$$

$$\text{where, } e = (\varepsilon_f + 0.0035)C/0.0035 \tag{10}$$

$$\text{and } \sigma_t = 0.772 V_f \left(l_f / d_f\right) F_{be} \tag{11}$$

F_{be} bond efficiency factor, taken as 1.2 for hooked and crimped steel fibers.
e the distance from the extreme compression fiber to the top of the tensile stress block of fiber concrete.

The expressions obtained above in analytical investigations may conveniently be used to obtain moment capacity of fiber-reinforced high-performance concrete beams without fibers and with fibers up to different depths.

4 Conclusion

On the basis of analytical and experimental study conducted on beam specimens, the following conclusions can be drawn.

1. The addition of fibers in HPC does not significantly improve first crack load, as fibers play role in resisting tensile stresses in post-cracking region only.
2. The fiber content in full depth has been found most effective as first crack load, ultimate load, resilience, ductility, and toughness values are found to be maximum at this value.
3. In case of partial depth SFRHPC beams, specified fiber volume fraction having an appropriate thickness of the fiber zone, load–deflection patterns have been found to be practically similar to those of corresponding full depth SFRHPC beams. Fibers in half depth of beam crosssection, in many situation are found to be more effective and at par with the corresponding value of fiber in full depth of beam cross-section.

4. Full depth SFRHPC beams is more effective in concrete elements subjected to high strain rate, repeated loadings, stress reversal, and in support regions of continuous members.
5. The ultimate moment capacity of most of SFRHPC specimens (half depth and quarter depth dispersion) are generally lower than those corresponding to full depth SFRHPC beams.

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Mechanical and Durability Properties of Recycled Aggregate Self-compacting Concrete Along with Basalt Fibers

Davinder Singh, Kasilingam Senthil and P. C. Emmanuel

Abstract The experimental investigations were carried out on recycled aggregate concrete to study the influence of basal fiber through mechanical and durability tests. The mechanical tests like compressive strength and split tensile strength were conducted on recycled concrete aggregate along with basalt fiber of various proportions. The durability tests like carbonation properties were conducted on recycled concrete aggregate along with basalt fiber. The percentage of recycled aggregate replacement was varied as 0, 50, and 100%, whereas the percentage of basalt fiber was varied as 0, 2, and 4 kg/m^3. In hardened concrete, compressive strength, split tensile strength test, and carbonation tests were conducted against 7, 28, and 90 days after casting and their behavior was compared. It is observed that the basalt fiber does not contribute much in case of compressive strength of the concrete. It is observed that the split tensile strength has found to be increased considerably with increasing basalt fiber. The split tensile strength of R50B0 has been found to be increased 14% as compared to conventional SCC, R0B0 concrete, however, the strength of R50B0 concrete was found to be decreased by 22% as compared to R100B0 mix. It is observed that the carbonation depth of concrete was found to be increased with increase of recycled concrete aggregate as well as basalt fiber.

Keywords Mechanical property · Durability · Recycled aggregates · Self compacting concrete · Basalt fibers

1 Introduction

Recycled aggregate concrete provides an effective way to use industrial waste as well as construction waste and due to problems of land filling which lead to ecological and environmental destructions, (Xiao et al. 2005; Breccolotti and Materatti 2010). Recycled aggregate concrete (RAC) has an important and wide application in engineering community, social, economic, and environmental benefits. To make this methodology

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_22

feasible, a significant amount of experimental works has been carried out by various research groups, (Chen et al. 2013; Khoshkenari et al. 2014). It has been found that due to the lack of bonding between recycled aggregate, cement matrix, and also the high water absorption capacity, in light of mechanical properties, durability, and deformation ability of the recycled aggregate concrete is always lower than that of conventional concrete. These deficiencies of concrete may be removed by reinforcing it with small and discrete fibers of randomly oriented, uniformly distributed throughout concrete, (Senthil et al. 2016a, b). In the case of fibrous-reinforced concrete, it is observed that one of the major problems that are to be faced related to concrete is at the time of placing is congestion. Proper compaction of concrete is very much required to achieve its desirable hardened properties for which it is known to be an excellent construction material. These limitations can be taken care of by a special type of concrete, known as fibrous self-compacting concrete. Although a variety of fiber reinforcing materials exist, fiber-reinforced concrete used for structural applications is most often made with steel fibers, since the most beneficial properties of steel fiber-reinforced concrete (SFRC) are improved flexural toughness, flexural fatigue endurance, and impact resistance. However, SFRC poses several issues like increased dead load, reduced workability, fiber balling at high dosages, and susceptibility to corrosion.

Therefore, basalt fiber is a new material, which has the advantages of lightweight, high tensile strength, endurance of corrosion, high temperature, crack resistance as well as good capability, so it is a proper substitution of other fiber materials, (Dias and Clelio 2005; Sim et al. 2005; Li and Xu 2009). Several experimental investigations have been done in the past to study the behavior and mechanical properties of basalt fiber-reinforced concrete, (Wei et al. 2010; Yang and Lian 2011; Jiang et al. 2014; Branston et al. 2016; Shafiq et al. 2016; Dong et al. 2017; Liu et al. 2017). Based on the detailed literature survey, it is observed that the studies focused on the mechanical properties of the concrete with different replacement ratios of recycled coarse aggregates and basalt fiber content. It has been found that with increasing the proportion of RCA there is a decrease in the concrete density, splitting tensile strength, and flexural strengths. Addition of basalt fiber leads to an increase in concrete density and the compressive strength. It was pointed out that although the mechanical properties of the RAC were decreased with increasing RCA replacement ratio, however, they could be enhanced by using of basalt fiber in its optimum volume fraction. Therefore, it is concluded that the previous studies conducted on basalt fiber-reinforced concrete were mostly confined to its mechanical property, thermal property, electrical property, and the chemical property, whereas the durability of the basalt fiber-reinforced concrete is found to be limited. Also, it is observed that the previous studies mainly focused on normally vibrated concrete whereas the studies on self-compacting concrete along with basalt fiber were found limited. The single length of fiber was used by various researchers, however, the possibility of hybridization is not been explored heretofore. Therefore, the present study is based on experimental investigations in the combination of basalt fiber and recycled aggregate along with self-compacting concrete to explore the mechanical and durability properties. The studies were carried out to find the optimum percentage for replacing natural aggregate with recycled aggregate, as well as basalt fiber in light of effective utilization of basalt fibers along with recycled concrete aggregate for reducing the construction waste.

2 Materials and Methodology

In this section, there is an elaborate depiction of the materials which has been used in the experimental work. The method that has been adopted to carry out the work has also been described. The experimental program includes compressive strength test, split tensile strength test, and durability tests presented in this section.

2.1 Materials

Basalt fiber has good hardness and thermal properties, and has various applications as construction materials. The basic characteristics of basalt materials are high-temperature resistance, high corrosion resistance, resistance to acids and alkalis, high strength, and thermal stability. Basalt materials have been used as a reinforcing composite material for the construction industry, specifically as a less expensive alternative to carbon fiber. When the fiber is in contact with other chemicals, they produce no chemical reactions that may damage health or the environment. Basalt base composites can replace steel (1 kg of basalt reinforces equals 9.6 kg of steel, Shafiq et al. 2016) as lightweight concrete can be got from basalt fiber. Basalt rock is melted at high temperature and rapidly drawn into a continuous fiber. The tensile strength and elastic modulus of basalt fiber was 2600 MPa, and 90 MPa, respectively, Wei et al. (2010) (Fig. 1).

Ordinary Portland Cement (OPC) grade 43 (Shree Cement) was used in the present study. The fine aggregates were available locally and used to carry out the experimental investigations. The sand was dry and free from any unwanted materials. Specific gravity tests were performed to find the specific gravity of fine and coarse aggregate (includes natural aggregate (NA) and recycled concrete aggregate (RCA)).

Fig. 1 Typical image of basalt fiber

The specific gravity of fine aggregates is 2.63 whereas the coarse aggregate of NA and RCA was found to be 2.59 and 2.44, respectively. Superplasticizers, also known as high-range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. The fly ash has been used as cementitious materials in concrete and a detailed proportion are given in the next section.

2.2 Plan for Experimental Investigations

For assessing the mechanical properties of the concrete, tests on compressive strength, split tensile strength, and durability tests has been carried out. Similarly, carbonation test has to be conducted for obtaining the durability aspects of the concrete. The overall performance of the concrete has to be evaluated by varying both basalt fiber and recycled concrete aggregates. Dosage of basalt fiber was varied as 0, 2, and 4 kg/m^3 by keeping recycled concrete aggregate at 0, 50, and 100% replacement levels. The percentage replacement level of recycled concrete aggregate and basalt fiber are named as “R” and “B” respectively according to the dosage of recycled aggregate and fiber content. Different combinations and designation of the mix proposed were shown in Table 1. The number describes in the name of mix is directly related to the dosage of basalt fiber and RCA content.

Compression test of the concrete was carried out with 100 mm × 100 mm × 100 mm size specimen and is tested at 7 days, 28 days, and 90 days. Similarly, split tensile strength test was conducted with 100 mm × 100 mm × 100 mm size cubical specimens at 28 days, 56 days, and 90 days. Accelerated carbonation test was conducted after 28 days of curing with an exposure period of 28 days on 100 mm × 100 mm × 50 mm size specimens. The repetition was carried out for compression and split tensile test is two whereas the number of repetitions for and accelerated carbonation test is three.

Table 1 Designation of the mix

Name of mix	R0B0	R0B2	R0B4	R50B0	R50B2	R50B4	R100B0	R100B2	R100B4
BF (kg/m^3)	0	2	4	0	2	4	0	2	4
RCA (%)	0	0	0	50	50	50	100	100	100

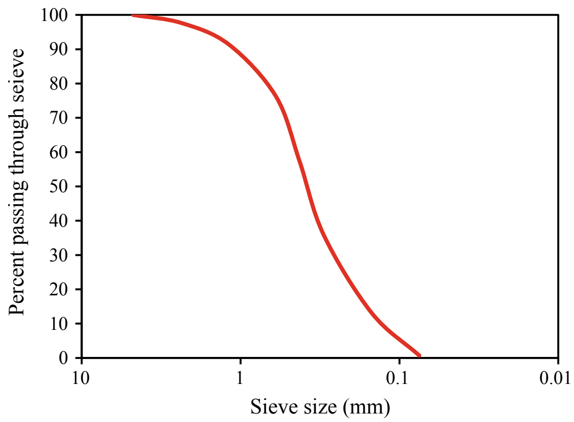

Fig. 2 Gradation of fine aggregate

2.3 SCC Mix Proportion

The SCC mixes were designed as per Su et al. (2001) is shown in Table 2. The mixes were proposed here were further modified through several trial mixes. The size of natural aggregates as well as recycled concrete aggregate was considered in the range of 10–4.75 mm and it is considered as well-graded aggregate. The proportion of NA was kept fixed, i.e., 10 mm aggregate was 20%, 6.3 mm aggregate was 60%, whereas the 4.75 mm aggregate was 20% for all the mixes. Similarly, the proportion of RCA was kept the same as natural aggregate. Therefore, the gradation of coarse aggregate was not studied. The particle size of sand was kept below 4.75 mm, however, the gradation of fine aggregate was studied and shown in Fig. 2. The fineness modulus of sand was 2.98 and it is used for conducting the experiments.

2.4 Tests on Fresh Concrete

The workability tests (V-funnel flow time, Slump flow, and T500mm flow time) prescribed by EFNARC (2005), were performed in accordance with SCC specification. The result of the workability test for various mixes is given in Table 3.

2.5 Test on Hardened Concrete

Compressive strength of all the specimens was tested on 100 mm × 100 mm × 100 mm size cubes in accordance with Indian Standards, **IS 516:2004**. Compressive strength tests were performed on various mixes after 7, 28, and 90 days of curing period. Split tensile strength of all the specimens were on 100 mm × 100 mm ×

Table 2 Mix proportions for various mixes

Description	R0B0	R0B2	R0B4	R50B0	R50B2	R50B4	R100B0	R100B2	R100B4
Cement (kg/m^3)	420	420	420	420	420	420	420	420	420
Fly ash (kg/m^3)	180	180	180	180	180	180	180	180	180
Water ($w/c = 0.41$) (kg/m^3)	246	246	246	246	246	246	246	246	246
Sand (kg/m^3)	890	890	890	890	890	890	890	890	890
10 mm NA (kg/m^3)	124.58	124.58	124.58	62.29	62.29	62.29	0	0	0
6.3 mm NA (kg/m^3)	373.75	373.75	373.75	186.875	186.875	186.875	0	0	0
4.75 mm NA (kg/m^3)	124.58	124.58	124.58	62.29	62.29	62.29	0	0	0
10 mm RCA (kg/m^3)	0	0	0	58.6	58.6	58.6	117.2	117.2	117.2
6.3 mm RCA (kg/m^3)	0	0	0	175.8	175.8	175.8	351.6	351.6	351.6
4.75 mm RCA (kg/m^3)	0	0	0	58.6	58.6	58.6	117.2	117.2	117.2
Super Plasticizer (kg/m^3)	15	15	15	15	15	15	15	15	15
Basalt fiber (kg/m^3)	0	2	4	0	2	4	0	2	4

Table 3 Workability properties of various mixes

Mix designation	Slump flow		V-funnel test (s)
	T500mm (s)	Diameter (mm)	
R0B0	2.4	695	6.4
R0B2	2.8	688	6.8
R0B4	3.1	685	7.1
R50B0	2.6	690	6.8
R50B2	2.9	685	7.2
R50B4	3.3	682	7.6
R100B0	3.1	685	6.9
R100B2	3.3	683	7.4
R100B4	3.6	680	8

100 mm size cubes in accordance with Indian Standards, **IS 516:2004**. Split tensile strength tests were performed on various mixes after 28, 56, and 90 days of curing period. For accelerated carbonation test, the prisms of size of 100 mm × 100 mm × 50 mm were prepared. The casted specimens were cured for a period of 28 days. Then the samples were oven dried for conditioning of specimens. The concentration of CO_2 was maintained at 4% with relative humidity was between 40% and 70% and the temperature was kept at 25 ± 2 °C. The specimens were exposed to CO_2 for a period of 4 weeks. The depth of carbonation was measured in accordance with RILEM recommendations, **CPC-18**.

3 Results and Discussion

In hardened concrete, compressive strength, split tensile strength test, and accelerated carbonation test were conducted and their behavior was compared with the various combinations of RCA and basalt fiber on self-compacting concrete. The compressive and split tensile strength results for various mix combinations have been discussed in this section. The typical testing and failure pattern of the specimens are shown in Fig. 3a–c.

3.1 Comparison of Compressive Strength Results

The compressive strength of hybrid fiber-reinforced self-compacting concrete containing different proportions of basalt fiber and recycled concrete aggregate has been studied. The compression tests were carried out at 7, 28, and 90 days curing period. It is observed from Fig. 4a–c, the compressive strength of conventional SCC has been

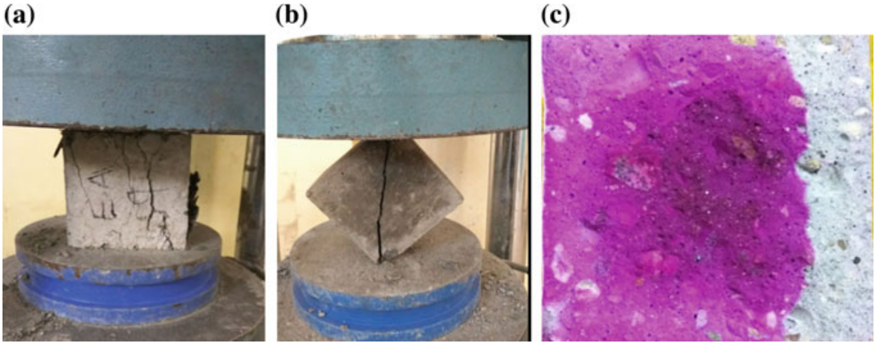

Fig. 3 Typical failure pattern under **a** compression, **b** split tensile and **c** accelerated carbonation test

found to be increased marginally with increase of basalt fiber up to 2 kg/m^3, however, the compressive strength of concrete was found to be decreased by 14% as compared to R0B2 mix. The compressive strength of R0B2 was found to be maximum among the chosen mix proportions. The reason may be due to the presence of porosity in large amount which leads to reduce the density of concrete. Overall, it is observed that the compressive strength of concrete was found to be achieved 65% of target mean strength at 7 days. However, it is observed that the 28 days strength was found to be almost same to that of 90 days. Therefore, it is concluded that the basalt fiber does not contribute much in the case of compressive strength of the concrete. The highest compressive strength was found to be R0B2 mix.

3.2 Comparison of Split Tensile Strength Results

The split tensile strength of hybrid fiber-reinforced self-compacting concrete containing different proportions of basalt fiber and recycled concrete aggregate have been studied. The split tensile tests were carried out at 28, 56, and 90 days curing period. The split tensile strength of hybrid fiber-reinforced self-compacting concrete containing different proportions of basalt fiber and recycled concrete aggregate have been studied. It is observed from Fig. 5a–c that the split tensile strength has found to be increased considerably with increasing basalt fiber. The split tensile strength of R50B0 has been found to be increased 14% as compared to conventional SCC R0B0 concrete, however, the strength of R50B0 concrete was found to be decreased by 22% as compared to R100B0 mix. Overall, it is observed that the split tensile strength of concrete was found to be decreased after 56 days except the mix R100B0. It is also observed that the strength was found to be reduced small amount at 90 days. As the fiber content was increased, the split tensile strength was found to be increased. Therefore, it is concluded that the basalt fiber shows significant improvement against the addition of fiber.

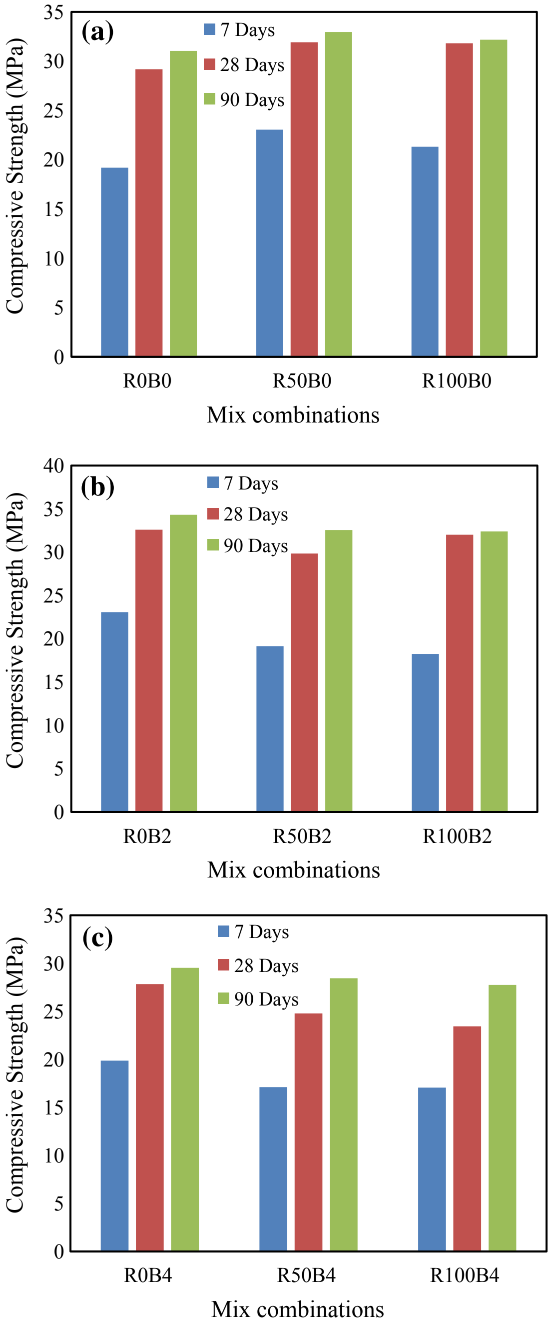

Fig. 4 Compressive strength of recycled aggregate concrete of **a** 0, **b** 2 and 4 kg/m^3 basalt fibers

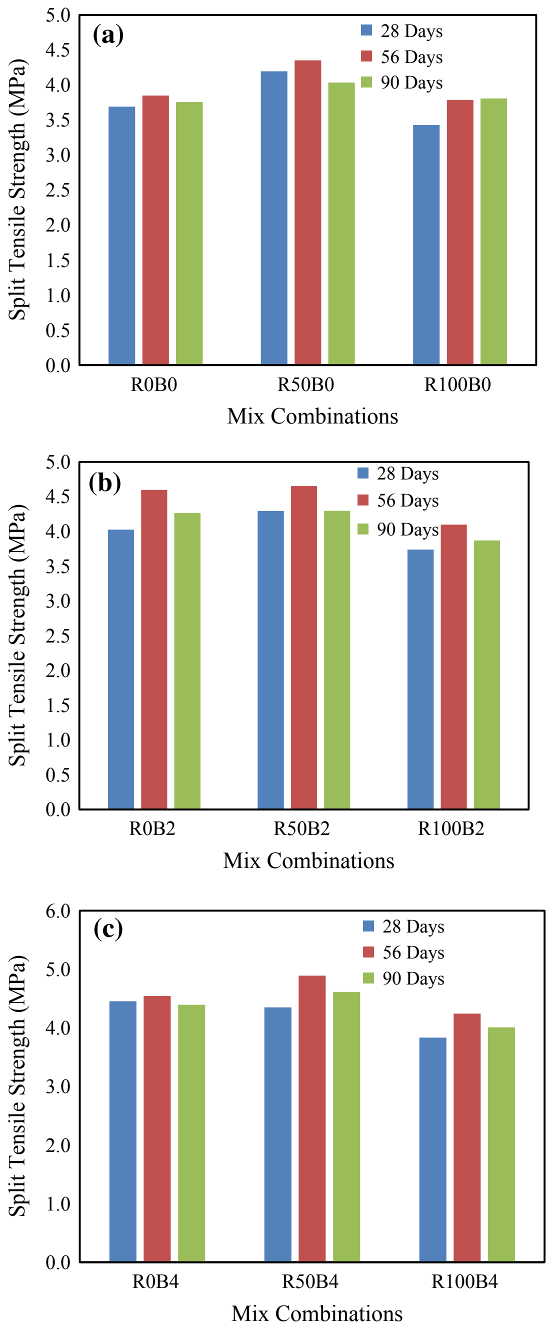

Fig. 5 Split tensile strength of recycled aggregate concrete of **a** 0, **b** 2 and 4 kg/m^3 basalt fibers

3.3 Comparison of Carbonation Test Results

The accelerated carbonation test was conducted on prisms of size of 100 mm × 100 mm × 100 mm. The casted specimens were cured for a period of 28 days. Then, the samples were oven dried for conditioning of specimens. The concentration of CO_2 was maintained at 4% with relative humidity was between 40% and 70% and the temperature was kept at 25 ± 2 °C. Then, the specimens were exposed to CO_2 for a period of 28 days using accelerated carbonation chamber. After 28 days, the specimen surface was prepared which is freshly broken surface and phenolphthalein solution has been applied over the surface. The carbonation depth of concrete was measured where the colorless portion exist in the chosen surface. Based on the measurement, the average carbonation depth for varying mix proportions was shown in Fig. 6. It is observed that the carbonation depth of concrete was found to be increased with increase of recycled concrete aggregate as well as basalt fiber. The minimum value of carbonation depth was found to be conventional SCC concrete R0B0 and the maximum value was for R100B4. The increase in both RCA and basalt fiber, in turn, increase the carbonation depth of the concrete.

4 Conclusions

The experimental investigations were carried out on fibrous self-compacting concrete (SCC) elements subjected to monotonic loading to study the influence of basalt fiber in terms of compressive and split tensile strength tests. Also, the durability properties of fibrous self-compacting concrete (SCC) elements were studied in terms of carbonation depth. The tests were carried out on hardened concrete as well as fresh concrete and the following conclusions were drawn:

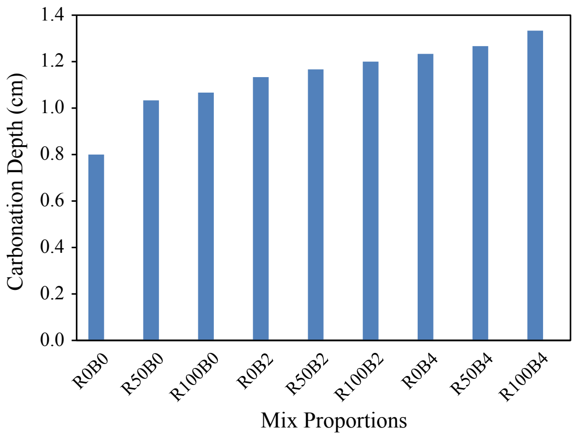

Fig. 6 Carbonation depth of recycled aggregate concrete along with **a** 0, **b** 2 and 4 kg/m^3 basalt fibers at 28 days

- Basalt fiber does not contribute much in the case of compressive strength of the concrete. The highest compressive strength was found to be R0B2 mix.
- Basalt fiber shows significant improvement in the case of split tensile strength. It is also observed that the strength getting reduced a bit at 90 days. As the fiber content was increased, the split tensile strength is getting increased. An addition of 50% RCA gave better result as compared to other cases.
- The increase in both RCA and basalt fiber, in turn, increase the carbonation depth of the concrete. The minimum value was found to be a control mix of R0B0 and the maximum value was for R100B4.

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Soft Waste Management in Spinning Industry

Sukhvir Singh and Alok Kumar

Abstract During yarn manufacturing at short staple ring spinning system, cotton has been considered as "White Gold" because of fiber characteristic features. Yarn manufacturing involves many intermediately processes, starting from blow room stage to ring-frame stage where finally fibers get converted into yarn structure. Cotton processing over various machines in spinning preparatory section leads to soft waste generation at different stages and that can be reused again in an acceptable proportion using waste management techniques. The present study reviews some imperative methods of soft waste management and minimization in cotton spinning industry.

Keywords Soft waste management · Spinning industry · White gold · Blow room · Waste optimization

1 Introduction

In short staple spinning of cotton yarn, spinning machineries produce soft waste as well as hard waste. Soft waste is the waste in which fibers are in a relatively open structure and can be reused directly at an earlier feed stage. On the other hand in case of hard waste, fibers are packed in a closed structure and need additional operations before reusing them with soft waste in blow room section. The major stage where soft waste is produced is blow room, carding, draw frame, comber and speed frame.

Soft waste optimization and its management is an imperative issue for yarn manufacturer and spinners across the globe. It has been found that waste removed on every stage can be minimized by practicing standard operating procedures provided by the manufacturer while working with the latest machines. Machine speed and setting along with the work practices play a vital role in optimizing soft waste at various intermediate stages of cotton processing.

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_23

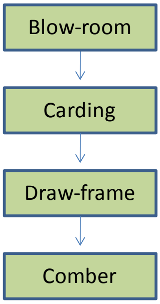

Fig. 1 Material sequence at spinning preparatory

The present work is an attempt to review the soft waste management in cotton spinning industry. For this purpose, many existing review works and latest methods were studied in order to have a clear idea about the soft waste management in a spinning industry. Most influential factors contributing in soft waste generation has been highlighted while going through literature review.

2 Material Flows at Spinning Preparatory

Every stage in spinning preparatory eliminates predetermined amount of short fibers which has been considered as soft waste. The spinners always try to reuse this processed soft waste effectively again at blow room feed. For instance, at blow room and carding machines 3–5% cotton goes to waste and 0.2% can be used again at blendomat feed (Purushothama 2016) (Fig. 1).

3 Waste Optimization at Blow Room Section

The main objective of blow room machines including the opening of fiber to small tuft, cleaning of fiber tuft, blending and removal of micro-dust (Purushothama 2016). Blow room section has been considered as the most crucial stage in spinning preparatory section as the amount of waste generated at the blow room is highest among all other subsequent processes. Blow room section generating soft waste of cotton fiber tufts but also giving spinner a chance to reuse the soft waste in adequate proportion. There are many factors influencing the waste generation at blow room section including speed and settings of beaters, exhaust suction pressure in pipeline, air current, and position of machines in blow room (Karthik and Thilagavathi 2016). In order to minimize the soft waste produced at various machines at blow room section speed of beater should be monitored precisely because increased beater speed can

Table 1 Reason for higher card waste (Senthil 2015)

Cause	Remedy
Lap licking	Correct process parameters in the lap-forming unit of the blow room. Use of roving ends between layers
High suction pressure in the waste extractor, which sucks part of the carded web	Optimizes the suction pressure in the waste extractor
Disturbance of air currents in the web-forming zone	Proper control of air currents

not only cause harsh action on dedicated fiber but also increase the amount of soft waste generated (Lawrence 2010). Adequate suction pressure in pipeline will ensure the smooth processing of material and avoid excessive feeding on subsequent blow room machines and lesser amount of soft waste.

4 Waste Optimization at Carding Section

The carding process is generally used to individualization of fibers from the bunch of fibers and producing softly twisted rope-like structure called sliver. During the individualization, some of the fibers are released as the waste and contribute to soft waste. Licker-in and cylinder along with flats droppings contribute substantially high in the generation of soft waste at carding machine. Most imperative factors and checkpoints for minimizing soft waste at carding machine including optimum speeds and setting depending on the type of feed material, adequate attenuation of sliver at optimized pre-tension and good condition of storage can. Usually, waste at carding increase with increase in cylinder speed and licker-in speed. It also deteriorates the quality of delivered sliver due to harsh action of cylinder wire points on cotton fibers at relatively higher speed. Grinding of flats, cylinder, licker-in and doffer wire points should be done as per the schedule provided by the machine manufacturer (Klein 1987; Klein 1993; Lord 2003) (Table 1).

5 Waste Optimization at Draw Frame Section

The major working objectives of draw frame includes attenuation of carded sliver, removal of hooks, fiber blending and reducing carded yarn unevenness through doubling. Soft waste generated at both breaker and finisher draw frame including broken sliver ends, fiber fly generated at high-speed drawing and unutilized sliver parts at the end of the batch which contributes the major portion of soft waste generated at draw frame. However, there are a few crucial checkpoints which help in minimizing soft waste at draw frame-like adequate drafting rollers and calendar roller pressure to avoid frequent end breakages. Amount of pre-tension tension in sliver at creel section and delivery side should also be optimized while processing combed cotton. Spring pressure should be as per the norms in order to avoid any coiler blockage and for minimizing soft waste generated at the end of the batch (Kothari and Majumdar 2013). Moreover, speed and setting of rollers should be optimized depending on the feed material in order to minimize soft waste generated at draw frame (Miao et al. 1998; Ishtiaque et al. 2008).

6 Waste Optimization at Comber Section

The process of straightening and parallelizing of hooked fibers along with the removal of short fibers and impurities is called combing. The combing process has been carried out in order to improve the quality of the carded sliver. During the combing process by eliminates short fibers, it achieves better parallelization of fibers, it straightens hooked fibers, and it removes neps. Combing process generate very high amount of short fibers in the form of noil or waste fibers and that can be reused to some extent again at blow room section. Moreover, some invisible loss of spunable fiber has been observed while working at high nips/min due to fiber fly formation. Combed sliver due to low interfiber cohesion have more chances of failure when compared with carded sliver of same sliver hank and made of similar material (Senthil 2015; Kothari and Majumdar 2013).

7 Conclusions

It has been observed that during the course of conversion of fibers into sliver and then yarn, it has to pass through many subsequent machines. Each intermediate process releases some quantity of soft waste at every stage of yarn formation. Spinners should always compare the soft waste obtained with the quality norms for waste in order to monitor actual soft waste generated. Standard operating procedures and optimization of speeds and setting according to the type of material being processed has been found effective in soft waste optimization on different preparatory machines.

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Application of Solar Energy in Wastewater Treatment

Lekha Patil, Savan Sachpara and Divya Dixit

Abstract The consumption of water in domestic, commercial and industrial sectors is massive and the generation of wastewater is even greater. The availability of clean water resources is limited, its uses are endless and its need is ever increasing. With the increasing demand of water and rising energy consumption, the treatment of this quantity of wastewater poses a great challenge. The present study involves the use of a model to harness solar energy by a fabricated lab-scale parabolic tough collector to treat textile wastewater and the optimization of the observations. Solar wastewater treatment using non-concentrating/concentrating collectors is an upcoming promising technology to be applied as evaporators. Concentrating collectors like parabolic trough collectors use mirrored surfaces curved in a linearly extended parabolic shape to focus sunlight on an absorber tube running the length of the trough. The project includes treatment of textile wastewater (COD = 566 mg/L, TSS = 3500.67 mg/L, pH = 10.66) using parabolic trough reactor and study of factors effecting the process like natural light source, pH, temperature, contaminant concentration, etc. 30% reduction in COD of textile wastewater was observed after the treatment.

Keywords Parabolic trough collectors · Solar energy · Wastewater treatment

1 Introduction

The growing global textile industry has put a toll on all the available freshwater resources. The textile industry is the third largest consumer of water in the world (Laili et al. 2013) and the fourth largest industry in India. The Indian textile industry uses almost 425,000,000 gallons of water every day (Tripathi et al. 2014). Textile industry uses different types of artificial dyes and a huge amount of dark coloured wastewater is discharged into water bodies. The adverse effects of textile wastewater include poor photosynthetic function in aquatic plants due to low penetration and oxygen consumption. It proves to be fatal for specific organisms due to the presence

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_24

of component metals and chlorine in dyes. Thus, textile water treatment with the help of renewable sources of energy is the need of the hour (Desai et al. 2017). Toxic chemicals of concern are drugs, solvents, volatile organics, synthetic dyes, chlorinated volatile organics, heavy metals, pesticides, PCBs, chlorophenols and arsenic compounds. They have high chemical stability and low biodegradability.

Evaporation of industrial wastes has been used as a method for reduction of water content from liquid-based effluent. An evaporator raises the water temperature till evaporation of the liquid content from waste occurs, and the high boiling point waste components are then treated.

To accelerate the process of natural evaporation, solar concentrators are used which focus sunlight on a smaller area. Concentrating collectors like Parabolic-trough collectors use mirrored surfaces curved in a linearly extended parabolic shape to focus sunlight on an absorber running the length of the trough. Solar water and wastewater treatment using the technique of concentration of solar energy is a promising technology. The objective of this project is to implement concentrating solar collectors in advanced wastewater treatment of textile effluent, record the changes and optimize the results. The treatment includes simultaneous evaporation and degradation of recalcitrant chemical compounds.

2 Methodology

The treatment experiments were carried out on effluent from the textile industry. The wastewater was greenish blue in colour, with high turbidity.

Experiments for the analysis of the pre- and post-treatment samples were conducted using standard procedures of the American Public Health Association (APHA 2005), Standard Methods for the Examination of Water and Wastewater. The parameters tested were pH, Conductivity, TDS, TSS, COD and DO. The experiments were conducted in batch runs for the concentrated textile wastewater for a fixed duration of time.

A lab-scale parabolic trough collector (Fig. 1) used for treatment was constructed using wood and aluminium sheets and designed using the equation of parabola. Aluminium sheets were used to create the reflective surface and a clear glass tube running across its length was installed. The length of the curved reflective surface is 52 inches, the diameter of the glass tube is 1.2 inches and the distance of glass tube from reflective surface is 6 inches. A submersible pump was used to convey the water through the reactor.

The following setup was used for 7 h cycles runs for the testing of the wastewater characteristics.

Fig. 1 Setup of parabolic trough collector

2.1 Geometry of Parabolic Trough Solar Collector (Dixit et al. 2014)

As the collector is parabolic in shape, as per the definition of parabola, the equation can be written as

$$y = 4ax^2 \tag{1}$$

Height of focal point is

$$f = 1/4a \text{ from origin} \tag{2}$$

The radius of parabola at an arbitrary location is defined by r, and is called the "mirror radius". The maximum mirror radius occurs at its outer rim and is fittingly called "rim radius" or parabolic radius. The rim angle, θ_r, corresponds to beam radiation reflected from the outer rim of the concentrator. The focal length, f, is related to rim angle, and aperture width, W:

$$W = 4f \tan(\theta_r/2) \tag{3}$$

The diameter D of a cylindrical receiver is

$$D = 2r \sin\theta_a \tag{4}$$

The concentration ratio (C) is related to θ_r can also be defined as

$$
\begin{aligned}
C &= \sin\theta_r / \prod \sin\theta_a \\
&= \text{Aperture area/Receiver area} \\
&= A_a/A_r \\
&= (W - D)L/DL
\end{aligned} \tag{5}
$$

where

D Diameter of receiver tube;
L Length of tube.

3 Results and Discussion

The wastewater used for experimentation was brought from a textile industry; the sample was greenish blue. The initial characteristics of the wastewater were pH = 10.66, TSS = 3500.67 mg/L, TDS = 10,000 mg/L, BOD = 100 mg/L, COD = 566 mg/L, Conductivity = 6.95 mS/cm and DO = 0.5 mg/L. The experimental setup conditions and the data obtained are as shown in Table 1.

The solar evaporation technique has been used in many wastewater treatment plants for sludge drying or as lagoons for wastewater evaporation (Holkar et al. 2016). Concentrating solar techniques can be used as an advanced tool for wastewater treatment, achieving higher temperatures faster and increasing the rate of evaporation (Patil et al. 2018). 35% reduction of volume was observed after 7 h of irradiation. Reduction in volume and mineralization was observed in the experiments conducted with the textile wastewater. High temperature (75 °C) was achieved which lead to evaporation while 30% mineralization (Fig. 2) was also observed in the wastewater run for the duration of 7 h.

Table 1 Experimental setup conditions and data

Date	Ambient temperature (°C)	Solar irradiance (kWh/m^2/day)	Cycle duration (h)	Volume of sample used (L)	Volume reduction (L)
31 December 2017	28	6.35	7	5	1.75
6 January 2018	26	6.35	7	5	1.7

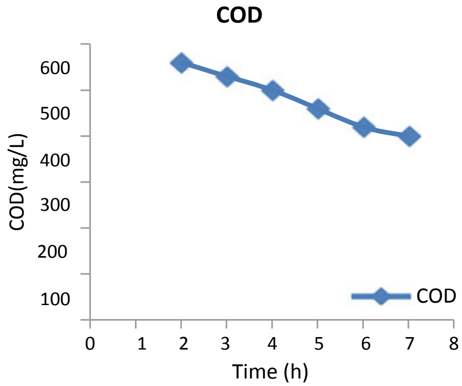

Fig. 2 COD reduction in textile wastewater treatment

4 Conclusions

The use of a parabolic trough collector to concentrate solar energy on a glass tube through which wastewater is conveyed in batches, yielded evaporation and mineralization after 7 h of treatment. Evaporation occurred in the sample with no dilution and the concentration of solids was observed, while in the diluted sample, solar energy facilitated mineralization of the organic content.

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Optimizing Waste Material: Slum Development

Manpreet Singh, Rajvir Singh and Sohrab Chatrath

Abstract At this random pace of urbanization going on in every developing country of the world, the most lagging part of the city in getting even basic infrastructure is the slum area. Missions like smart city in India are redefining urban facilities in every aspect but the slum areas have still not been brought into the spotlight for development and providing infrastructure. The foremost objective of this study is to provide a basic home to every slum dweller with basic amenities along with the secondary aims of usefulness of every available material to its fullest and recycling the materials for the conservation of the environment. After the documentation and analysis of the topographical features along with road hierarchy, sewer lines, and water supply, a house model is to be proposed providing every basic facility along with aesthetically sound environment for the inhabitants of the area. Along with a proper plan of the area, majority of the material to be used in new construction must be of recycled type. This model proposed will surely lie under the norms of the Indian government scheme of "Housing For All By 2022" and will also be in the economical budget of this project that has been launched to eradicate slums. The principal construction materials to be used for construction, flooring, roofing, and laying down pavements for the road hierarchy will mainly emphasize on recycling of materials.

Keywords Waste material · Optimization · Slum development · House hold material · Construction materials

1 Introduction

Optimization of waste material has become a necessity of the present scenario of the prevailing urbanization in the world and recycling of the waste material is the present need for a sustainable environment. Heaps of dumps on the outskirts of the mega infrastructural and modern technology equipped cities are like a stain on

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_25

the lavishing lifestyle of the inhabitants of the city. In our modern world, waste and its management is the most important need of time with a combined effort from private and public sectors. As per the waste distribution criteria, the existing wastes are biodegradable and non-biodegradable from which the management of non-biodegradable is the major challenge faced because of its higher vulnerability to the environment. Industry being the core of all development of the area is the major source of waste generation in a city or a town and thus making it a challenge faced by the city planners towards making the environment sustainable.

Industrialization and urbanization are the key factors in the development of the area because of the employment generation for the masses and upgrading their lifestyles. Along with the development, a migration from rural to urban areas is also an effect of the employment availability because of the industrialization. This migration lays down the foundation of the slums in the outskirts of a city and along the industrial regions or focal points. Lacking the basic infrastructural and facilities for a sustainable livelihood slum area are far away from the concepts of medically fit environment and the latest smart city concept prevailing in India thus making it an impossible task for the realization of this concept.

Starting from lacking sewer system facility to inefficient waste disposal, these places lack every basic facility required by any inhabitant for living. These regions also pay homage to the dumping sites of the waste generated from the cities, thus risking the health of the masses of these regions and deteriorating the environment.

Indian government on 15 June 2015 announced the scheme of “Housing for all by 2022” for providing home to every individual of the country. The initiation of this scheme has brought a ray of hope for the slum dwellers across the major cities and every other area having slum population in the entire subcontinent. Smart city project, which was launched prior to this scheme must have been a complete failure with slums being the major asset in its failure because after the complete redevelopment of the slum area a smart city can be made. The optimization of the waste material will play a significant role in the development of the slum area and also the recycling of the waste within the city.

Jalandhar city is the heart of the Doaba region of Punjab which lies between Sutlej and Beas rivers. The city is at a random pace of industrialization being a hub for the sports and leather industry. Being a central job magnet of the region, a lot of migrants shift to the city every year as low wage earning people which contribute to the slum incremental and summation of slum dwellers in the city. This deteriorates the planning and acts as a stone in the way of mass urbanization on its way. The tailor model has been developed as a solution to this problem of slums as a part of urban planning and development.

2 Research and Documentation

As per the research, we choose the area of new beant nagar near chuggitti bypass to study the prevailing condition in the local slums and the problems faced by them. As per the study, the centre main road of the area which facilitates the mobility of

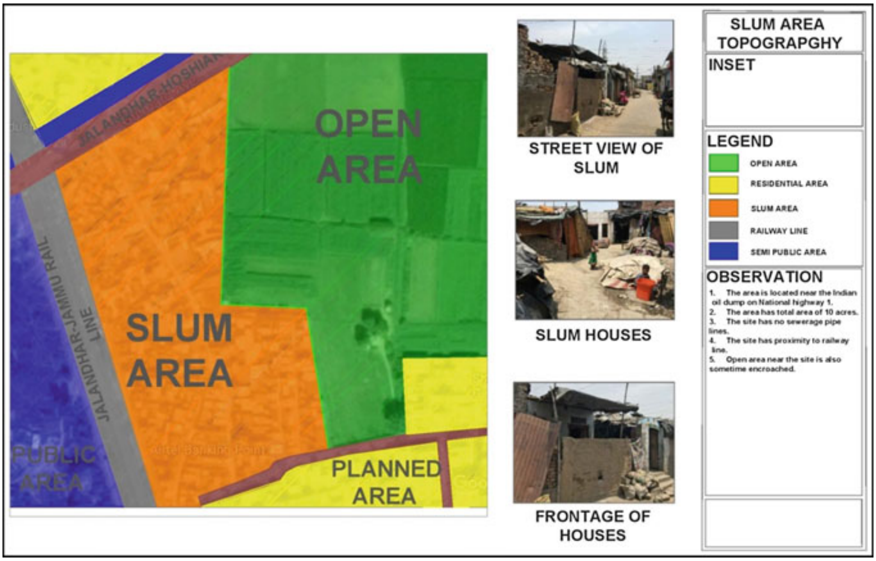

Fig. 1 Topography of the area

four wheelers is connected to water supply and sewer line and the adjoining roads, which only facilitates two wheeler mobility lacks these amenities. The maximum houses of the area are kutcha and are mud plastered from outside and also constitute mud flooring in the hoses. The bricks are adjoined by mud and lime mortar and the roofing of the houses is done by steel or cement sheets or either by wooden sticks combined (Fig. 1).

High-tension wires pass over houses with a voltage of 11,000 kWh which are a direct danger to the houses and the slum dwellers of the area. Electricity thefts are open in the area by the local residents and some houses even scan the facility of electric metre in their houses. The area is adjoined by a railway line on one side thus prohibiting further expansion of the area to any side. The garbage is littered in the area and the whole area acts a waste bin for the locality. Poor road hierarchy scans the narrow streets from sewer facility and water supply line. The expansion of slum is blocked by railway line on one side and on the other side, other physical infrastructure exists. Houses scans the facility of water supply. Household's fetches water from hand pumps which is not fit for drinking purposes and is catered by earthen pots.

2.1 *Tailor Model*

The model we should apply in redevelopment of slum area (tailor made model)

- The existing slum area must be redeveloped on the same existing area by providing the basic physical infrastructure.

- Streets in the slum area must be realigned and interlocking tiles must be used, so that it gives a clean and hygienic look to the area.
- Houses front portion must be retrofitted and aligned properly in way it gives a symmetrical look.
- Government-linked account must be opened and small amount of money should be transferred every month into the account for carrying out basic amenities work.
- Self-financed project at local level should also be initiated but they must not be linked with the government account holder.

Initiation of a construction project as planned by the municipal corporation of Jalandhar is a very tedious task to achieve. Taylor model counters the problems in the way of new construction project for apartments in a more practical manner and reducing the economic load of the project. Taylor model emphasizes on redevelopment of the existing area rather than constructing a new project from the foundation level. In this report, the feasibility of the project with respect to its location and existing features has been studied.

Taylor model aims to redevelop the area by providing all basic amenities under sustainable terms and environment friendly methods.

2.1.1 Landscaping

Landscaping of the area must be done at an extensive pace for the whole locality to give a good aesthetic look. The aesthetics look of the area is improved and the garbage disposal norms have been brought under the Swach Bharat Yojna initiated by the central government. The road hierarchy of the area has been redefined and recreational sites such as parks and gardens are also brought in. Green belt has also been given considerable place in the plan for a better environment to live in.

2.1.2 Water Supply and Sewerage System

Water supply and sewerage system has also been defined on the basis of the improved road hierarchy. Each and every house scanning this facility will be joined to this network. High-voltage cables will be laid underground and electric poles will be eliminated from their positions (Fig. 2).

2.1.3 Electric Connection

Electric connection will be provided to every house so that nobody lacks this facility. Electric metres will be installed at commonplace for a street to eliminate the threat of electricity thefts.

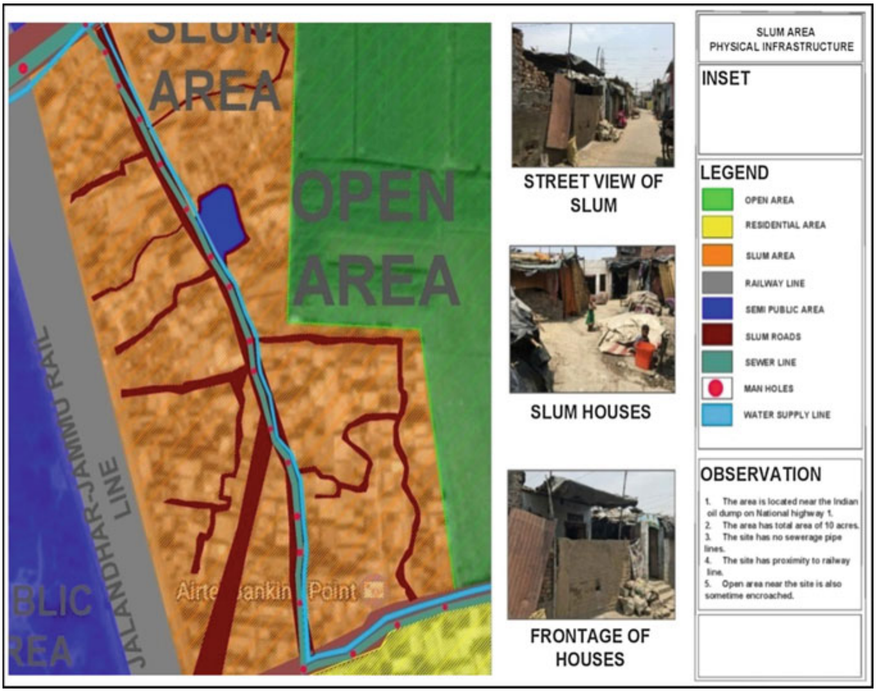

Fig. 2 Physical infrastructure of the area

2.1.4 Disposal of Waste

For the disposal of waste material, particular sites must be provided away from residential area and this must be strictly implemented. It must be mandatory for every slum dweller to plant two trees in their own area in addition to the green belt.

2.1.5 Provision of Pucca House

The most important part of the redevelopment is providing pucca houses to the slum dwellers. This is the task to be fulfilled before providing the abovementioned basic amenities. Taylor model presents an optimistic view of the picture of the slum to be redeveloped in accordance to the integration point of view, that is, increase of family size and increase of slum population in the area (Fig. 3).

Fig. 3 Pucca houses in the area

2.2 *House Model*

In the model, a room of dimension 18 × 18 feet is selected or any suitable dimension according to the location is chosen front facing towards road. Using low-cost building material and techniques, a suitable and aesthetically sound structure is constructed. The material chosen is also eco-friendly and easily available from nearby sites. Taylor model is fulfilling all norms of central government scheme "Housing For All By 2022" which aims at providing house to every slum dweller by year 2022. This scheme uses land as a resource for rehabilitation of people in participation with private developers and promotion of affordable housing for weaker section by credit-linked subsidy. Moreover, affordable housing in partnership with private and public sectors and subsidy for beneficiary-led individual house construction is aimed (Fig. 4).

2.3 *Design Ideas*

In accordance to providing houses for slum dwellers at their own place, the existing structures are retrofitted at their facing towards the road. Every unit to be constructed is given a bedroom, a kitchen, a toilet and living area that are roofed. The remaining place is left open for further integration if possible in the future on increase of

Fig. 4 Tailor model

family size. The size of the constructed room and other infrastructure can be adjusted according to the variation of the size of the plot or area where the structure is purposed to be built upon.

3 Construction Materials

Material selection is a major asset in the redevelopment of any area as the chosen material must be eco-friendly and in the boundaries of the budget to be implemented. There are different materials which are chosen for road hierarchy, for construction of rooms, roofing material, floor material. The material selected must be available from nearby to the location so as to reduce the transportation cost and for the completion of the project at faster pace. Moreover, the material must be selected that must be climate adaptable and affordable at low cost. Now, the selection of the construction material and its classification has been discussed below.

3.1 Road Hierarchy

In the road hierarchy, redefining the pavement material chosen must be adaptable to the climatic changes in the northern region as there are four prevailing seasons so the material chosen must be adaptable to every climate. The pavement to be laid down can be made up of interlocking blocks that are made up of the waste material of the construction debris and other waste material. Other alternatives for road pavement can be of concrete but it is a costly material to be chosen (Fig. 5).

Fig. 5 Interlocking blocks

3.2 Construction of the Room

For the construction of the room for the slum dwellers, the material chosen can be fly ash bricks which are available from Goindwal Sahib 40 km from Jalandhar. Other material that is also used by CBRI Roorkee is prefab brick panel system which can be adjoined to make the walls of the houses. The walls constructed by either of the materials can be plastered by mud plaster that is also used by CBRI Roorkee in their projects Fig. 6.

Fig. 6 Pre cast walls

Fig. 7 Rubber flooring

3.3 Flooring

Flooring of the houses can be done by using concrete flooring. The merits of choosing concrete are that it can be polished for the aesthetic beauty of the floor and moreover, it is durable and easy to clean and never needs to be replaced. The other option for the flooring material is rubber which can be obtained from recycled tyres thus adding to the eco-friendly merit of the rubber by recycling it (Figs. 7 and 8).

3.4 Roofing

The last part for the construction of house for the dwellers of slums is roofing of the standing infrastructure. Slate tiles are one of the options that can be considered for roofing materials because of their durability which lasts long with little maintenance and its reflective properties adding to the resistance towards heating of the roof by sunlight thus adapting according to the climate. Other materials that can be used is white metal sheets because of their reflective properties and very low maintenance over the time period. These both roof materials are easily available and budgeted for a speedier construction process (Figs. 9 and 10).

Fig. 8 Concrete flooring

Fig. 9 Slate tiles

3.5 Foundation Filling

For filing up the foundations of the houses, the general material used is natural existing soil. As an alternative fly ash can be used along with soil for fill-ups of foundation which is easily available from the Goindwal Sahib thermal power plant. The transportation cost is also low with just a distance of 40 km between both locations. Fly ash being a waste material from thermal power plants has adverse effects on the environment because of the problem of its disposal.

Jalandhar being the hub of sports industry in whole of Asia is a large producer of rubber material as waste, which can be used as an alternative in foundation fills of the houses to be made after processing it accordingly to the need and the properties required for foundation filling. The rubber tyre can also be processed for the same

Fig. 10 White sheets

purpose stated above which are also a major threat to the environment because of their flammable nature because of which it is most of time used as a fuel in some industries.

3.6 Open Spaces

For creation of a healthy environment for the inhabitants of the area, a park is made in midst of the area. Open space or a park pays homage to green and healthy environment for slum dwellers. Along with the plantation of trees which aims towards sustainable environment, recycling of materials for the boundary walls and interior park infrastructure by metallic waste recycling along serves the same purpose as mentioned before.

The park benches can be made by recycling of plastic bottles by filling them with fly ash or other waste material and then joining them by cement mortar in a rectangular shape. After a proper finishing by cement plastering, an eco-friendly bench can be made.

For the outlining of the recreational park, fly ash bricks can be used as stated earlier in the construction of the house model. The recycled metal can be used to making swings and sides for the playing of children and also for making playgrounds in the open parks.

3.7 Rainwater Harvesting

Fall in the groundwater level is a major problem faced by the environment these days. The groundwater is depleting and is not being recharged at the same pace due to which various bores of hand pumps and tube well are failing. A provision of rainwater harvesting has been provided in the roofs of the housing units to be constructed which will add on to the recharging of the groundwater after being collected to pit.

The roofs of the houses are provided with lining along with a collecting pipe running along the boundaries of the roof which supplies the rainwater to the main supply pipe running from roof to the collection pit. From this pit the collected rainwater add on to the groundwater after passing through various layers of filter media before percolation of water.

4 Conclusion

Tailor model is an eco-friendly innovation in reshaping slum societies and habitats with the introduction of construction material generated from waste. Goindwal Sahib thermal plant dumps a massive amount of fly ash which is a major setback to the ecosystem of the surroundings. Usage of fly ash in filling up the foundations introduces a solid ground for the management to discover fresh ideas regarding safe and efficient disposal of fly ash. Jalandhar being the Asian hub for the sports industry equipment so it generates rubber as its major waste product which can be recycled to be used in the flooring with the advantages of corrosion resistant and rough surface beneficial in washroom and kitchen.

Rainwater harvesting techniques also add on to the environmental sustainability of this model with each roof acting as collector of rainwater. The parks or gardens which serve as a centre of refreshment for the residents are eco-friendly and pays homage to aesthetic as well as sustainable environment.

With the complete restructuring of the road hierarchy and other supplies such as water supply and sewage, slums can be upgraded into a sustainable and developed locality with the implication of the tailor model. The threats related to emergency evacuation of the area in case of disaster will also be minimized with complete reframing of the area and on the development of basic infrastructure.

Moreover, the utmost advantage of rehabilitation of the people without being shifted is the brightest perk of this model and the active participation and coordination of slum dwellers will increment in the success points of the implication of this model.

The result of the study defines the usage of different materials in construction by considering eco-friendly merits first. For the overall development and upgrading of the cities, slums need to be developed first by making the way of every basic amenities to the doorsteps of these areas.

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Sustainable Solid Waste Management in Indian Cities

Amandeep Kaur and Surinder Deswal

Abstract Municipal Solid Waste Management (MSWM) is a big problem Indian cities are facing these days. Total waste generated by the cities is around 135198.27 ton/day. This review paper aims in providing a comprehensive review of the characteristics, generation, collection, transportation, disposal, and treatability of Municipal Solid Waste (MSW) in the cities, through a collection of secondary data from Government agencies, Interviewing Stakeholders, and Questionnaire Survey and technologies for the effective management of MSW in the cities. The paper also aims at proving various types of waste generated by the cities and their major source of generation, and its composition and source segregation. The paper also presents the current status of solid waste management, waste generation rate, collection efficiencies, refuse derived fuel, waste to energy, and recycling initiatives taken by various cities of India and prospects of introducing improved means of disposing and treating MSW for achieving sustainable management of waste in the cities.

Keywords MSWM · Sustainable management · MSW · Indian cities

1 Introduction

Among top 10 countries in the world, India is also generating the highest amount of MSW and MSWM is one of the worst environmental problem all cities in India are facing. The total waste generated by the cities is approximately 1351978.27 TPD (CPCB Report 2015–16). And, there is no proper arrangement, activities, practices, infrastructure for the effective management of MSW in the cities and the problem is increasing at the alarming rate due to rapid growth in the population of the cities, as Waste generation is directly proportional to the population of the country. India ranks in the second position, in the list of countries by population, having no of Individuals more than 1.2 billion (Population of India 2017). Sustainability in Management of

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A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes
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Waste in Country like India is very difficult to achieve as the country is facing a huge challenge of development in the field of Urbanization, Industrialisation, and Economic Growth, which has resulted in the generation of Million tons of MSW (Kumar et al. 2017). Management Condition of MSW is foremost more critical in the megacities of India like Delhi, Mumbai, Calcutta, Bangalore, etc. Due to an inefficient and inappropriate collection and disposal practices by the Urban Local Bodies (ULBs) of these cities. ULBs are unable to upgrade facilities required for effective handling of MSWM practices comprising of Proper Segregation of Waste, Collection and Transportation of waste, Processing, Recycling and Disposing of the waste to landfill sites.

The Problem is becoming a serious issue because there is lack of Awareness among the people, No involvement from Private Sector, No participation of nongovernment authorities and poor financial support to the Municipalities (1,00,000 metric TPD 2017). Sustainable MSWM in cities can be attained considering all the subjects such as Public Health of individuals, environmental impact, present, and future waste generation in the cities and its disposal (Sudhir et al. 1997). These review papers reveal the current picture of, how the MSWM practices are being done in various cities of India and Recommending new treatability and disposal techniques for achieving sustainable management of waste in India.

2 Analysis of MSW of Indian Cities and Its Characterization and Composition

2.1 Classification of MSW

MSW can be commonly said as garbage, which consists of all the material, people throw away after they were used, such as product packaging, clothes, gardening waste, newspaper, paints, batteries, etc. (Table 1).

2.2 Analysis of MSW

Annual waste produced by one person is 36.8 kg (i.e., 100 gm/day). As per CPCB survey conducted in 2015–16, it is found that about 135198.27 TPD waste is generated from the Indian cities, 111027.55 TPD waste is collected, only 25572.25 TPD is treated and 47415.62 TPD is landfilled (CPCB: Central Pollution Control Board 2015). Based on CPCB Annual Reports: 2015–16 (CPCB: Central Pollution Control Board 2015).

States: Solid Waste Generation Status (TPD) (Table 2).

Table 1 Sources, types, and generators of MSW (Agarwal et al. 2016)

Sources	Waste generators	Waste type
Residential sources	Families	Food waste, cardboard, wood, glass, food waste, paper, textiles, electronics items, batteries, tires
Industrial sources	Manufacturing and construction sites power and chemical plants	Housekeeping wastes, packaging waste, ashes
Commercial source	Offices, buildings, stores, etc.	Plastic waste, wood, food waste, glass, metals, cardboards, paper
Municipal services	Street cleaning, landscaping parks, waste treatment	Street sweepings, tree trimmings, general wastes from parks, beaches, etc.
Institutional sources	Schools, hospitals, prisons	Paper, plastic, cardboard, special wastes, glass, metals, wood, food wastes, etc.

2.3 Composition of MSW

The MSW in the cities is mainly composed of the following constituents (Garg and Prasad 2003; CSIR-National Environmental Engineering Research Institute, Annual Report 2012; Sharholy et al. 2007). The composition of Municipal Waste varies with population density (Table 3).

3 Need to Bring About Sustainability in Management

- Reducing antagonistic impacts on the land, water, and atmosphere.
- Reducing harmful effects on public health of individuals residing in the cities.
- Due to the tremendous growth of population, urbanization, industrialization leading to significant increase in MSW.
- Enforcing proper MSWM practices of collection, storage, segregation, transporting, and disposing of the waste.
- Reducing bad odor, and possibilities of diseases and improving the esthetic view of the cities.
- Increasing awareness among the citizen of India regarding source segregation and reduction, waste treatment, and new disposal techniques.
- Encouraging new technologies innovation in waste processing and disposal facilities.

Although this sustainability is difficult to achieve but with the support of modern means of eco-friendly technologies, this can be made possible.

Table 2 Statewise generation, collection, and treatment of MSW

States	Solid waste generation status (TPD)			Landfilled
	Generation	Collection	Treated	
Andaman Nicobar	70	70	5	0
Andhra Pradesh	6440	6331	500	143
Arunachal Pradesh	13	11	0	0
Assam	7920	6336	200	0
Bihar	1670	0	0	0
Chandigarh	370	360	0	230
Chhattisgarh	2245.25	2036.97	828.18	1294.97
Daman Diu	85	85	0	0
Delhi	9620	8300	3240	5060
Goa	450	400	182	
Gujarat	10480	10480	2565	7730
Haryana	4837.35	3102.51	188	2163.18
Himachal	276	207	125	150
Jharkhand	3570	3570	65	3505
Jammu Kashmir	1634.5	1388.7	3.45	425
Karnataka	8842	7718	3584	3946
Kerala	1339	655	390	0
Nagaland	344	193	0	0
Lakshadweep	21	0	0	0
Madhya Pradesh	6678	0	0	0
Maharashtra	21867.27	21867.27	6993.2	14993.07
Manipur	176	125	0	0
Mizoram	552	276	0	0
Meghalaya	187	156	36	122
Orissa	2574.7	2283.9	30	0
Punjab	4456.2	4435	3.72	3214
Puducherry	513	513	10	503
Rajasthan	5037	2491	490	0
Sikkim	49	49	0.3	0
Tamil Nadu	230	210	0	207
Telangana	6628	6625	3175	3050
Tripura	414	368.2	250.4	164.4
Uttarakhand	917	917	No facility	No landfill
Uttar Pradesh	15192	11394	1857	0
West Bengal	9500	8075	851	515
Total	**135198.27**	**111027.55**	**25572.25**	**47415.62**

Table 3 MSW composition (CSIR-National Environmental Engineering Research Institute, Annual Report 2012; Sharholy et al. 2007)

• Organic matter	40–60%	• Compostable material	40–60%
• Ashes and earth	30–40%	• Inert material	30–50%
• Paper waste	3–6%	• Nitrogen	0.64–0.8%
• Plastic and glass	<1%	• Phosphorous	0.67–0.15%
• C/N ratio	20–30	• Potassium	0.68–0.15%
• Calorific value	800–1000 kcal/kg		

4 How to Achieve Sustainability in Management

- To achieve sustainable approach Detailed Database related to the amount of MSW generated, collected, waste storage, waste transported, should be prepared by municipalities on Daily/Weekly/Monthly/Annual basis. So that, required number of Manpower, Authorities, Equipment and other services can be made available for the cities as per the prepared database.
- Proper Amount of engineered Landfill site should be made available in each ward of every small city of India by the GOI.
- Main reasons behind unsustainability in the cities, is due to unprofessional technique followed in Collection and Waste Disposal due to lack of Scientific Methodologies.
- Sustainability of Management also nourishes with the participation of stakeholder, NGOs, Private Sector, Community Organization, to bring about the change in their environment.
- Open Dumping is practiced must be banned, by imposing fine on illegal dumping in nearby areas in order to protect severe contamination to the groundwater and soil.
- Resource Recovery should be given more attention, instead of waste disposal to achieve the ultimate goal.
- Mandatory waste segregation should be imposed on the householder to make recycling practices more successful.
- The approach should be to achieve, “Zero waste Municipalities Network” in the Indian Cities like in Europe to ensure Resource Recovery and minimizing Waste disposal in dumping and landfilling sites (Zero Waste Cities 2015).

A study was done on sustainable MSWM of Allahabad city. In the study, three main modules was recognized namely Technical Module, Institutional Module, and Financial Module. Technical module includes the involvement of Computer-based software like GIS technology in preparing the ward-wise database related to the collection, storage, Transportation, Treatment of MSWM, etc.

Institutional Module includes in finding out the strength, threats, weakness, in the Government, bodies which deal with the management of MSW so that the management system can be redesigned.

Financial module includes in determining the monetary burden on the municipalities of the city and providing them financial support by the Government (Sharholy et al. 2007). The similar can be practiced in other states also.

5 Initiative Taken by GOI Toward Sustainability

- UoEF notifies revised MSWM Rules 2016, which replaces SMW Rules 2000 and gives more emphasis on Source Segregation, collection and Disposal of sanitary waste, collect back packaging scheme, the User fee for collection, Waste to Energy Conversion, etc. (CPCB: Central Pollution Control Board 2015).
- GOI has installed Waste to Compost and Biomethanation plants (Bhopal, Maharashtra) that have reduced burden over existing Landfill sites (India's Challenges in Waste Management 2017).
- The opening of Micro-Compost processing Centers by the ULBs and Municipalities of Avadi, Poonamallee (Chennai) to prevent the Biodegradable waste to reach to the dump yard (Local Composting gets filled up 2017).
- Delhi Plastic Bag (Manufacture and Usage) and Garbage (control) act 2008, passed by National Capital Territory Delhi in order to impose the ban on plastic bags.
- Two separate Bin waste segregation system launched by GOI to collect dry (Blue bins) and wet(Green bins) waste separately.
- Clean Kerala Mission 2002 and Malinya Mukta Keralam Campaign 2007 were launched by GOI.
- EPR [Extended Producers Responsibility] Program is implemented and restraints for Recycling of E-waste is made mandatory (Joshi and Ahmed 2016).
- Other Rules launched by GOI, prevalent in MSWM are CPCB: Central Pollution Control Board (1974);
  - Hazardous Waste (Management and Handling) Rules 2016.
  - Biomedical Waste (Management and Handling) Rules 2016.
  - Plastic Waste management Rules 2009.
  - E-waste Rules 2016.
  - Batteries (Management and Handling) Rules 2001.
- GOI has also established 13 waste to energy conversion Plants, 56 Biomethanation Plants, 22 RDF Plants, and 553 Compost and Vermicompost Plants till 2014 (CPCB: Central Pollution Control Board 2015; Joshi and Ahmed 2016).

6 Functional Components of MSWM

There are six main components of MSWM and the Interrelationship among the various Components is shown in Fig. 1:

Waste Generation: Waste Generation incorporate all the used material thrown or disposed of away. This activity is difficult to be controlled out and is expected to be increasing more rapidly in the future. Factors including Solid waste Generation Rate, Waste Volume, and Composition all depend upon the amount of Waste generated in the cities and this component is Dynamic Stage that determines the Existing MSWM practices and making New initiatives decisions and plans in controlling the waste production (Hayat and Sheikh 2016; Dawane and Gawande 2015). It is Estimated that by 2030, the Waste generation From Indian Cities will rise up to 165 million ton (Joshi and Ahmed 2016) (Table 4).

Waste Handling, Sorting, and Storage: It includes all those activities which are carried out for handling the waste before it is being stored. Sorting is the vital step in handling out the waste because the best way to segregate the waste is a source of generation itself. Lack of proper sorting may arise problems in disposing of waste (Joshi and Ahmed 2016; Hayat and Sheikh 2016). Also, suitable MSW storage system should be there, for the public in order to protect public health and esthetic view of the cities.

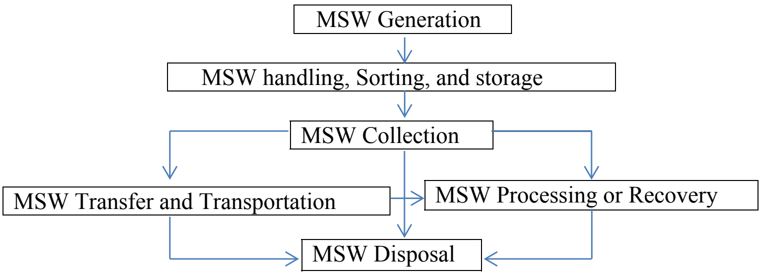

Fig. 1 Interrelationship among the various components of MSWM

Table 4 Generation rates of cities

Population of the city (million)	Generation rate (kg/capita/day)
<0.1	0.17–0.54
0.1–0.5	0.22–1.59
1–2	0.19–0.53
>2	0.22–0.62

Waste Collection: It comprises of compiling the MSW from various collection points and transferring the waste to the MRF, transfer stations or at the disposal sites. Cost is the important factor to be taken care of the efficient collection (Dawane and Gawande 2015).

Waste Transfer and Transport: The transportation of waste is done in two steps;

Transportation of MSW from the Smaller Collection points to the Larger Collection points (Transfer stations). Transportation of the MSW from the Transfer stations to the disposal Sites. The cities like Delhi, Mumbai, Madras, there is proper Transfer station butt in small cities there was no transfer station the vehicle used for collecting waste from Dustbins, are again used for transporting the waste to disposal sites (Saxena et al. 2009; Colon and Fawcett 2006). Transporting activities contribute about 80–90% of Budget of MSWM (Neema 2004).

Waste Processing and Recovery: This includes sorting out of comingled waste material, done at MRF, Transfer stations, RDF, etc., for separating out useful or recyclable material, ferrous and nonferrous or Bulky Items using Screening, Manual sorting. In many cities like Delhi, Mumbai, Biomethanisation, and composting plants are set up to make the best use of waste into the useful form (Sharholy et al. 2007; Local Composting gets filled up 2017).

Waste Disposal: Final components of MSWM system comes to the disposal of waste. Disposal in almost every city of India is done in an unscientific manner, i.e., Uncontrolled Dumping on the Illegal sites or on roads, on low lying areas, etc. (Joshi and Ahmed 2016).

Various disposal practices in Indian Cities are:

Open Dumping on the sites: Almost 90% of disposal is done in the form of open dumping on low lying areas and in outskirts of city roads due to lack of suitable Sanitary Landfilling in the cities. Open dumping is leading to contamination of groundwater and soil through leachate and ill effects on health (Joshi and Ahmed 2016).

Landfilling: In the large Metropolitan Cities of India like Delhi, Mumbai, there is a good option for construction of Sanitary Landfills, which is nothing but proper compaction and leveling of waste and covering in with earthen material with proper leachate and gas collection equipment (Sharholy et al. 2007). New sanitary landfill is being developing in the cities namely, Okhla, Ghazipur (Delhi), Sirsa and Ambala (Haryana), Patiala and Adampur (Punjab), Indore (MP), Sharholy et al. (2007). In India, about 59 landfills were constructed and 376 were under planning and development condition [CPCB 2013], (CPCB: Central Pollution Control Board 2015).

Vermicomposting: It is processed in which Organic matter is turned into compost by the earthworms, In Bengaluru (India) about 100 million TPD capacity vermicomposting (largest in India) is installed, while many other smaller plants are located in cities of Hyderabad, Faridabad, Mumbai, etc. (CPCB: Central Pollution Control Board 2015).

Aerobic Composting: It is processing in which Organic matter is turned into compost by the microorganism living in biomass in the presence of oxygen. About 50–85% of the waste volume is reduced by this process. In the big Cities of India, composts plants (Power Driven) are installed, e.g., Indore (MP). In Bengaluru, Kanpur, Delhi, Mechanical composting plants with capacities of 150–300 TPD are installed (Joshi and Ahmed 2016; CPCB: Central Pollution Control Board 2015).

Biomethanation: Also known as anaerobic digestion, in which biogas is produced from the conversion matter. Above 60% of methane gas is liberated in the process which can be used as energy for the various purpose, like Power generation. Test done by Western Paques in India resulted that 150 TPD of MSW can produce biogas of 14,000 m^3 having 55–65% content of methane, that can help in generation of 1.2 MW of power (Sharholy et al. 2007).

Incineration and Gasification Methods: these are thermal treatment Techniques of MSWM that help in MSW destruction using heat energy. About 2000C temperature is maintained in the incinerators to reduce the volume up to 80–90%. Practices of Incinerator Plants are very less in India. Timarpur, having first large-scale incinerator plant is installed with 300 TPD capacity, second incinerator plant is in BARC Trombay (Mumbai) for burning the institutional waste.

Gasification is same as Incineration, butt is done in the absence of Oxygen, its main objective is to produced fuel gas. There are very fewer gasifier units available in the cities of India, The gasification units NERIFIER is installed at Nohar (Rajasthan) for burning of agricultural waste and forest wastes. And, the second unit TERI is installed at Gaul Pahari Campus, New Delhi (Sharholy et al. 2007; Joshi and Ahmed 2016).

Refused Derived Fuel (RDF): This method is practiced to make pallets from MSW. In 1999, RDF is installed in Hyderabad in Golconda dumping site having Capacity of 1000 TPD. Processing MSW if done with this method proves effective in producing enriched fuel, which can further used in processes like Incineration or in Industrial thermal power plants, etc. The volume of waste is reduced by 90% and only 10% of remaining waste is left out to be disposed of easily in sanitary landfilling. 400 Ton of MSW is converted into fluff by SELCO and then mixed with 30% rice husk, helps in generation of power (Shahjee 2007).

7 Management Issues in Different Indian Cities

See Table 5.

Table 5 Different case studies done in the cities (Saxena et al. 2009; Shahjee 2007; Puri et al. 2008; Hazra and Goel 2009; Yadva 2010; Rathi 2004; Shalendra 2016; Vikas et al. 2007)

S. no	Case study	Objective of study	Results and discussions	References
1	Kurukshetra	A case study on municipal solid waste management in Kurukshetra city	Study in Kurukshetra is done in the form of Questionnaire Survey done in 1500 houses, 50 market shops, and some schools of the city. 98% of families produce 15 kg/day MSW and schools 5 kg/day. About 85% of householders were aware about the MSWM services. No proper dustbins were there in the city. No proper treatment methods were practiced in the city. 78% of householder 30% shopkeepers and 60% schools were aware about the segregation of MSW	
2	Allahabad	Towards sustainable MSWM in Allahabad City	Local householders, markets, and commercial establishments are the key sources generating biodegradable & non-biodegradable waste. Open trench of Buxi Band has been used for disposal of MSW along with undesignated dumps and Rag pickers. Survey conducted found that 0.42 kg/capita/day waste is generated by the city as per Allahabad Nagar Nigam	Saxena et al. (2009)
3	Gwalior	Solid waste management of Gwalior City	The major sources of waste are carcass, slaughter house waste, bio-medical waste, E-waste and MSW generating 283 ton/day. 460 collection bins and 1300 sweepers have been employed in the city. 25% of total waste is disposed off by incineration and by hydroclave technique is used for 75% of sewage treatment. Open dumping is done in city and no treatment and processing is done	Shahjee (2007)
4	Delhi	Municipal solid waste recycling and associated markets in Delhi	Highest per capital expenditure of Rs 431 is spent on MSWM in Metro City, 1.5 Crore population generating 6500 ton/day waste is generated but waste actually lifted is 6000 ton/day. 52000 workforce is there, only 1% are tactful for their duties. Emission of Methane has projected to elevate at 254 Gg/year. No door to door collection, No disposal techniques exist	
5	Mumbai	Alternatives approaches for better MSWM in Mumbai	500 ton of MSW/day is generated in the city. Bins with 4.5 &1 cum capacities are placed in different localities.190 metric ton waste is transported for dumping. 10 biomethanisation plants are establish in the city. Illegal dumping is quite common and this has vanished the ecological balance in the city	Rathi (2004)

(continued)

Table 5 (continued)

S. no	Case study	Objective of study	Results and discussions	References
6	Kolkata	Solid waste management in Kolkata, India: practices and challenges	Waste generation in Kolkata is 0.632 kg/cap/day. 51–71% waste has been surveyed from registered houses, 3 disposal sites exist in Kolkata. i. Dhapa, Garden Reach and Naopara. KMC trying to Explore the utilization of Global clean Development Mechanism. More than 70% of KMC budget is consumed for waste collection	Hazra and Goel (2009)
7	Jalandhar	Solid waste management in Jalandhar City and its impacts on community health	The MSW generation is 85% from residential areas, 10% industrial areas, 5% from mixed Zones. In all 320 Garbage bins are placed in the city and the waste is 85% non hazardous, 10% infectious and 5% non infectious. Trained collectors for garbage separation into recyclable/non-biodegradable are strongly required	Puri et al. (2008)
8	Kanpur	Urban solid management in Kanpur: opportunities and perspectives	Average per capita MSW generated has been surveyed to be 0.14 kg waste generated is disposed of in Panki site and a compost plant is also constructed with tendency of 250 ton/day. 3 different facilities are provided by Kanpur Nagar Nigam, i.e., Rubbish depot, open deport, and containers of different sizes, disposal of MSW is in haphazard, random and unsystematic	

8 Conclusion and Recommendations

Municipal corporations and ULBs of Indian Cities are responsible for achieving the sustainability in management. Proper collection and disposal of MSW are the two major issues prevailing in the cities due to lack of adequate manpower, financial stability, equipment facilities. The collection system is not effective because of no system door to door collection, no coordination between Kabariwalas and residents, No source segregation or sorting of waste by the Residents. Municipalities are lacking in transferring the waste to suitable dumping sites. Limited Transfer station exists in the cities thereby imposing great threat for the secondary collection of waste and making residents prone to severe ailments. Substantial quantum of waste has been dumped into illegal dump sites, road sites, etc., as there is no arrangement of Sanitary Landfilling in the outskirts of Indian cities. Stakeholders, Ragpicker, Safai Karamcharis, and commercial enterprises do not participate in waste management practices. For clean and eco-friendly Environment in the Indian cities contribution of each and every citizen is required along with the efforts of Municipalities. Proper Public Awareness Programs must be conducted at ward level in the cities that will help in sustainable approach for the betterment of future waste management practices.

Abbreviations

CPCB	Centre Pollution Control Board
GOI	Government of India
MRF	Material Recovery facility
MSW	Municipal solid waste
MSWM	Municipal solid waste management
RDF	Refused Derived Fuel
SWM	Solid Waste Management
TPD	Ton Per Day
UoEF	Union Ministry of Environment and Forest Climate change.
ULBs	Urban Local Bodies

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