Lecture Notes in Civil Engineering

Arvind Kumar Agnihotri
Krishna R. Reddy
H. S. Chore *Editors*

Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2

Springer

Lecture Notes in Civil Engineering

Volume 281

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering—quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

– Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
– Swati Meherishi at swati.meherishi@springer.com (Asia—except China, Australia, and New Zealand);
– Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

Arvind Kumar Agnihotri · Krishna R. Reddy ·
H. S. Chore
Editors

Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2

Springer

Editors
Arvind Kumar Agnihotri
Department of Civil Engineering
Dr. B. R. Ambedkar National Institute of Technology
Jalandhar, Punjab, India

Krishna R. Reddy
Department of Civil, Materials and Environmental Engineering
University of Illinois at Chicago
Chicago, IL, USA

H. S. Chore
Department of Civil Engineering
Dr. B. R. Ambedkar National Institute of Technology
Jalandhar, Punjab, India

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-19-4730-8 ISBN 978-981-19-4731-5 (eBook)
https://doi.org/10.1007/978-981-19-4731-5

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

Organizing Committee

Patron

Prof. R. K. Garg (Director)

Chairman

Prof. Arvind Kumar Agnihotri

Co-chairman and Principal Organizing Secretary

Dr. H. S. Chore

Convener

Dr. Davinder Singh

Organizing Secretary

Dr. Mrs. Rupali S.

Joint Organizing Secretaries

Dr. K. Senthil
Dr. Kanish Kapoor

Advisory Committee

Prof. N. K. Samadhiya (President, IGS), IIT Roorkee
Prof. G. L. Sivakumar Babu (Immediate Past President, IGS), IISc Bangalore
Prof. J. T. Shahu (Honorary Secretary, IGS), IIT Delhi
Prof. Krishna R. Reddy, University of Illinois, Chicago (USA)
Prof. D. M. Dewaikar (Retd. Emeritus Fellow), IIT Bombay
Prof. J. N. Mandal (Retd. Emeritus Fellow), IIT Bombay
Prof. A. P. Singh, NIT Jalandhar
Prof. S. P. Singh, NIT Jalandhar
Prof. Raman Parti, NIT Hamirpur
Prof. S. K. Tiwari, MNIT Jaipur
Prof. B. V. S. Visvanadham, IIT Bombay
Prof. R. K. Ingle, VNIT Nagpur
Prof. G. R. Dodagoudar, IIT Madras
Prof. G. Madhavi Latha, IISc Bangalore
Dr. Sanjay Kumar Shukla, Edith Cowan University, Perth, Australia
Dr. Prabir K. Kolay, Southern Illinois University, Carbondale (USA)
Prof. Deepankar Choudhary, IIT Bombay
Prof. K. G. Guptha, GCE, Farmagudi, Goa
Prof. Vasant Matsagar, IIT Delhi
Dr. Sanjay Nimbalkar, University of Technology, Sydney, Australia
Dr. S. K. Mukherjee, Retd. Secretary, PWD, Maharashtra
Dr. I. K. Pateriya, NRRDA, New Delhi
Dr. S. K. Ukarande, KJSIEIT, Mumbai (University of Mumbai)
Dr. Sunil Basarkar, AFCONS, Mumbai
Dr. C. R. Parthasarthy, Sarathy Geotech, Bangalore
Dr. V. B. Ashtankar, MCGM, Mumbai

Technical Committee

Prof. R. K. Sharma, NIT Hamirpur
Prof. Vishwas A. Sawant, IIT Roorkee
Prof. C. H. Solanki, SVNIT, Surat
Prof. P. T. Ravichandran, SRMIST, Kattankulathur

Dr. Kousik Deb, IIT Khargpur
Dr. Mrs. Sunita Kumari, NIT Patna
Dr. Nilima Satyam, IIT Indore
Dr. M. D. Goel, VNIT Nagpur
Dr. Sreevalsa Kolathayar, NITK Surathkal
Dr. G. Kalyan Kumar, NIT Warangal
Dr. Sharbony Adhikary, VNIT Nagpur
Dr. Purnachandra Savoikar, GCE, Farmagudi, Goa
Dr. V. B. Deshmukh, VJTI Mumbai
Dr. Mrs. Smita Patil, DMCE, New Mumbai (University of Mumbai)
Dr. R. B. Magar, AIKTC, Panvel (University of Mumbai)
Dr. Rajiv Chauhan, IKGPTU, Kapurthala
Prof. Amit Srivastava, LPU, Phagwara
Dr. Sanjeev Naval, DAVIET, Jalandhar
Dr. Sudhir Arora, DAV University, Jalandhar
Dr. Rajiv Bhatiya, MCP Jalandhar
Mr. K. K. Kanji, K. K. Spun Pvt. Ltd., Delhi
Mr. S. K. Gupta, Mega Metro Pvt. Ltd., Delhi
Mrs. Minimol Korulla, MACCAFERRI ENVIROME. Sol. Pvt. Ltd., Gurugram
Dr. Dulal Chandra Saha, Infrastructure Design Consult. Pvt. Ltd., Mumbai
Mr. Hemant Gor, Petrofac International Ltd., Sharjah (UAE)

Preface

Indian Geotechnical Society's Jalandhar Chapter was established in February 2020. After inception, the chapter conducted few workshops, seminars and expert lectures. As a major initiative in furthering the activities of the chapter, it in association with the Department of Civil Engineering of Dr. B. R. Ambedkar National Institute of Technology Jalandhar recently organized "First Indian Geotechnical and Geoenvironmental Engineering Conference-2021 (IGGEC-21021)". The conference was organized from 19 to 20 November 2021.

The conference aimed at bringing together leading academicians, scientists, researchers, field professionals including research scholars to exchange and share their ideas, experiences and research inputs pertaining to all aspects of geotechnical and geoenvironmental engineering, waste management and sustainable engineering. It also aimed at providing the premier interdisciplinary forum for researchers, practitioners and educators to present and discuss the most recent innovations, trends and concerns, practical challenges encountered and the solutions adopted in this field.

The papers received for the conference and selected after thorough review are grouped together under the following six themes.

The papers on the following themes have been called and received:

- Theme 1: Behaviour of Geomaterials and Geotechnical Investigation
- Theme 2: Soil–Structure Interaction, Earthquake Engineering and Computational Geo-mechanics
- Theme 3: Ground Improvement and Transportation Geotechnics
- Theme 4: Environmental Geotechnology
- Theme 5: Recycled Waste Materials
- Theme 6: Sustainable Infrastructure Engineering and Others

Apart from the keynote lecture, total 96 papers covering the wide spectrum of the geotechnical engineering and the allied fields contributed by the authors are included in the proceedings.

Jalandhar, India — Arvind Kumar Agnihotri
Chicago, USA — Krishna R. Reddy
Jalandhar, India — H. S. Chore

About the Institute

Dr. B. R. Ambedkar National Institute of Technology was established in the year 1987 as Regional Engineering College and was accorded the status of National Institute of Technology (Deemed to be the University) by the Government of India on 17 October 2002 under the aegis of Ministry of Education (Shiksha Mantralaya), New Delhi. The institute has been declared as the "Institute of National Importance" by the Government of India vide act of parliament 2007. A large number of reputed industrial houses in the country visited the institution and selected the final year students as engineers/management trainees. As one of the National Institutes of Technologies (NIT), the institute has the responsibility of providing high-quality education in engineering, technology and sciences to produce competent technical and scientific manpower for the country. The institute offers B.Tech., M.Tech., M.Sc., MBA and Ph.D. programmes in the several disciplines of engineering, technology and sciences.

About the Department

The Department of Civil Engineering offers B.Tech. in the discipline of civil engineering ever since its inception in the year 1989. The department has been offering M.Tech. programme in the field of structural and construction engineering since 2004 and in geotechnical and geoenvironmental engineering from academic session 2019–20. In addition to this, fulltime doctoral programmes in different specializations were started in the year 2006. The department has established state-of-the-art laboratories with sophisticated equipment for undergraduate and postgraduate courses and the research work leading to the doctoral degree. The department has got the well-qualified faculty members having specialized in various fields and diverse spectrums of civil engineering. The board of faculty members of the Department of Civil Engineering comprises the combination of senior faculty members with rich experience in the field of teaching and research and the young faculty members infused with enthusiasm. The department has been providing the consultancy and testing services to the various government and private agencies. The department is instrumental in organizing the Continuing Education Programmes in the form of short-term courses, faculty development programmes, seminars and workshops. In addition to this, the department has played the pivotal role in the organization of the international conferences such as EGRWSE and UKIERI Concrete Congress. The faculty members have been publishing the research papers in peer-reviewed journals having been indexed in prominent databases such as Web of Science (SCI/SCIE/ESCI) and SCOPUS. Besides, the faculty members keep on filing intellectual property rights; few IPRs have been granted recently.

About IGS Jalandhar Chapter

The Indian Geotechnical Society (IGS) was established in the year 1948 with the purpose of advancement and dissemination of knowledge in different fields of geotechnical engineering. IGS Jalandhar was established recently, i.e. in February 2020, under the flagship of IGS, New Delhi. The chapter was inaugurated by Prof. G. L. S. Siva Kumar Babu, erstwhile President of Indian Geotechnical Society, and Prof. N. K. Samadhiya (current President of Indian Geotechnical Society). Prof. Arvind Kumar Agnihotri, founder Chairman, and Dr. H. S. Chore, founder Secretary, along with their executive committee members have put in their best efforts to establish the chapter as the medium for disseminating knowledge in the field of geotechnical engineering and allied fields through workshops, seminars, short-term courses by inviting the eminent personalities in the field from country as well as from abroad. The group of the academicians led by Prof. Arvind Kumar Agnihotri in association with Prof. Krishna R. Reddy of the University of Illinois, Chicago (USA), was instrumental in initiating the Environmental Geotechnology Recycled Waste Materials and Sustainable Engineering (EGRWSE).

Contents

About the Editors

Prof. 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 32 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 12 Ph.D. Thesis and 4 more are in progress. He has guided 52 M.Tech. dissertations. He has published more than 135 papers out of which about 85 in referred international and National journals and 50 in conferences and 5 edited books/conference proceedings. 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.

Dr. Krishna R. Reddy is a Professor of Civil, Materials 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, Materials and Environmental Engineering at the University of Illinois at Chicago. Dr. Reddy received Ph.D. in Civil Engineering from the Illinois Institute of Technology, Chicago, USA. He received gold medals for being first in his class of B.S. (Civil Engineering) at Osmania University, India, and M.S. (Civil Engineering) at the Indian Institute of Technology, Roorkee.

Dr. Reddy is the author of four major books: (1) Geoenvironmental Engineering: Site Remediation, Waste Containment, and Emerging Waste Management Technologies, (2) Sustainable Engineering: Drivers, Metrics, Tools, and Applications, (3) Sustainable Remediation of Contaminated Sites, and (4) Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater. He is also author of 262 journal papers, 27 edited books/conference proceedings, 2 book chapters, and 226 full conference papers (with h-index of 65 with over 14,000 citations). Dr. Reddy has given 231 invited presentations in the USA and 21 other countries (Argentina, Brazil, Canada, China, Colombia, France, Germany, Greece, Hong Kong, India, Italy, Japan, Kuwait, Macedonia, Mexico, Spain, Sri Lanka, South Korea, Turkey, Thailand, and UK). Dr. Reddy has served or currently serves as an Associate Editor or Editorial Board Member of over 10 different journals, including *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, *ASTM Geotechnical Testing Journal*, *ASCE Journal of Hazardous*, *Toxic and Radioactive Waste*, *Journal of Hazardous Materials*, among others. He has also served on various professional committees, including the Geoenvironmental Engineering Committee and Technical Coordinating Council of Geo-Institute (GI) of the American Society of Civil Engineers (ASCE) and the Environmental Geotechnics Committee of International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE). Dr. Reddy has received several awards for excellence in research and teaching, including ASCE Wesley W. Horner Award, ASTM Hogentogler Award, UIC Distinguished Researcher Award, University of Illinois Scholar Award, and University of Illinois Award for Excellence in Teaching. He is a Fellow of the American Society of Civil Engineers (FASCE), a Diplomate of Geotechnical Engineering (DGE), and a Board Certified Environmental Engineer (BCEE). He is also a registered Professional Civil Engineer (PE) and an Envision TM Sustainability Professional (ENV SP).

Dr. H. S. Chore, Associate Professor and Head of Civil Engineering Department at NIT Jalandhar, received his B.E. from Nagpur University, Completed Masters from IIT Bombay and Doctoral Studies from VNIT Nagpur. His total teaching experience spans over 26 years. He has 244 publications to his credit with 58 research papers in the reputed refereed Journals; 91 papers in International Conference and 95, in National Conferences. He has guided 06 Ph.D. students and 06 more are in progress. He has guided 44 M.Tech. dissertations. He is member of many professional organizations like ACI, IGS, ISTE, Institution of Engineers, and Indian Roads Congress. He is reviewer of many international journals of repute.

Environmental Geotechnology

Performance of Geosynthetic Encased Stone Columns in Sandwiched Solid Waste Layer at Saturation Condition

J. Sudheer Kumar

1 Introduction

In India, hundreds of sq.m area solid waste dumps occupied the land with height varying from 3 m to several meters. They create environmental problem and land scarcity in every Indian city. It has very less amount of bearing capacity and higher settlement. And it also offers very less amount of lateral support. To make use of these sites for small-scale construction, one should modify the engineering properties. The granular columns are very extensively accepting to strengthen the weak soil deposits to improve the load-carrying capacity and reduce the settlement. With the advancement of the installation techniques, these granular columns are an alternative improvement technique for low rise structures in highly soft soils. Stone columns (SC) are promising techniques to improve the loose and soft ground at its deeper depths. The load-carrying capacity of the granular columns depends on the amount of lateral support offered by the surrounding soil. Moayed and Zade [1] studies conducted on plaxis 3D are used to determine the load-carrying capacity of dry conventional piles without binder in cohesionless soils. The result gives the inference that, by changing the axial load and size of stone pile, significant shear resistance increases. (Ng [2]) 2D numerical analysis and the presented results showed that a bulging and punching combination increases the chances of failure for the conventional stone pile. Load-carrying capacity was affected by the friction angle of column aggregates and shear resistance of the circumferential soil. (Muzammil et al. [3]) Oil storage tank is designed with circular mat foundation supported with

J. S. Kumar (✉)
Department of Civil Engineering, DAV Institute of Engineering and Technology, Jalandhar, Punjab, India
e-mail: sudheeriitd@gmail.com; sudhir.jala@davietjal.org

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_1

the 1000 to 10,000 kN/m strength of geogrid encased stone pile, and the considerable improvement was noticed in terms of the settlement reduction and lateral deformations.

The granular columns support embankments in compressible soils, the performance of dry stone pile was excellent in reducing settlement, and the use of geotextile encasement to the ordinary column has significantly enhanced the strength of dry stone pile in compressible soil [4]. The behavior of a encased dry stone pile in a compressible soil affected the stiffness of geotextile (300 to 10000 kN/m), stiffness and angle of shearing resistance aggregates in pile ϕ is 35°, 40° and 45°, the size of the pile is varied as 0.5, 0.8, 1.0, 1.2 and 1.5 m of diameter, and stiffness was improved [5]. Dry aggregate columns are highly effective and accelerate the consolidation rate by reducing the drainage path distance [6, 7].

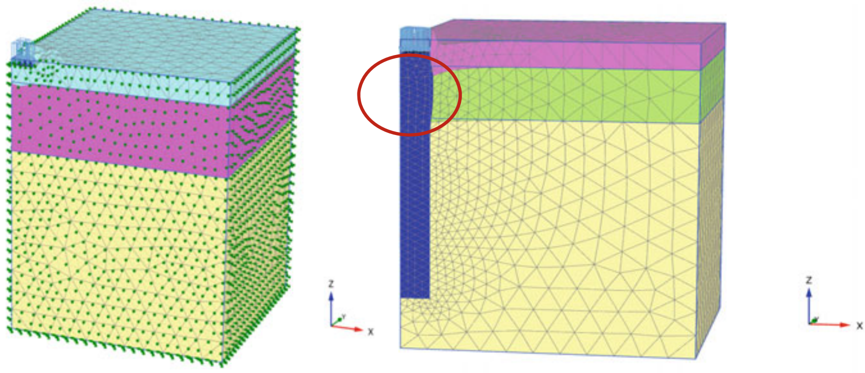
The significant enhancement of the strength was found from experimental studies conducted on various stone columns with and without encasement [8]. The dry stone column is used in layered soils where the top layer was found to be weak in undrained strength, and hence, it needs encased stone columns to reduce the excessive bulging and to improve its load-carrying capacity [9]. Hence keeping the research gaps in mind, the author attempted the current study to understand the behavior of the ordinary and encased stone columns in multilayered soil system where peat is sandwiched between the sand and compressible clay soils.

2 Material Properties and Numerical Modeling

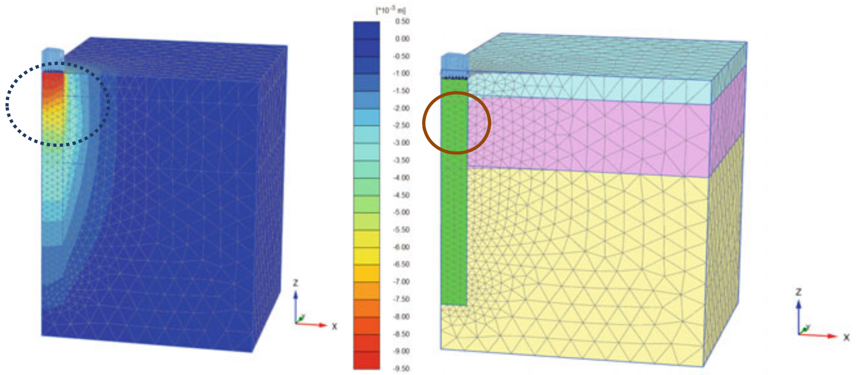
To perform the three-dimensional numerical model analyses in the Plaxis program, three layers of various thicknesses are considered [10]. Layer one is sand blanket of 1 m thickness, the second layer is peat of thickness is 1.5 m, and the third layer is clay soil of 2 m thickness (as shown in Fig. 1a). The Plaxis is allowed to select the model criterion based on the material property. In the present study, peat and soft clay are modeled using the soft soil model, whereas the sand and granular material used the Mohr–Coulomb constitutive model. The encased material stiffness tensile strength is modeled as linear and perfectly plastic. The material properties are listed in Table 1.

The numerical domain zone of the model was fixed based on the trial calculations. The boundaries of the soil model were fixed in x, y and z directions till the dispalcements and stresses are negligible effect due to the boundary conditions. The prescribed displacement is fixed in z-direction ($u_z = 0.01$ m), and the displacement in x and y directions is free ($u_x = u_z =$ free). Top surface is free, and bottom is fully fixed ($u_x = u_y = u_z = 0$). The soil represents a continuum, which was discretized by using 15-noded wedge elements [11]. Soil discretized with elements of a six-nodded triangle and stone column comprised 10-nodded tetrahedral elements with rotational degrees of freedom at each node with an average element mesh size of 0.3.

The permeability (K, m/day) is the input parameter and it required for doing the consolidation anaysis. K values of peat, soft clay, sand and stone column fill material



(a) Unreinforced (b) Ordinary stone column



(c) Vertical deformation (d) Geosynthetic encased stone column

Fig. 1 3D modeling of the weak soil deposit sandwiched between the sand and soft clay

Table 1 Layers of soil properties

Material properties	Peat	Soft clay	Sand	Granular column
Model	Soft soil (SS)	Soft soil (SS)	Mohr–Coulomb (MC)	Mohr–Coulomb (MC)
γ_{unsat}	8	15	17	18
γ_{sat}	12	18	20	20
C' (kN/m^2)	2	1	0	1
ϕ'	23	25	31	45
Ψ'	0	0	3	15
Permeability K (m/day)	0.1	0.0475	6	7

is presented in the Table 1. The geometry of the model, boundary conditions, mesh generation, ordinary stone column and encased columns are shown in Fig. 1. Further compression load applied the vertical deformation zone is also observed in Fig. 1c.

3 Results and Discussion

3.1 Load-Carrying Capacity

The results are presented in terms of applied pressure–settlement relation. The peat soil sandwiched between the sand and clay result analysis is carried in three different cases. The first is unreinforced ground, the second is the multilayer system reinforced with the ordinary stone column and encased with the geotextile, and the third case is while increasing the vertical stiffness of the geotextile. The load settlement curves are presented in Fig. 2. It is evident that the unreinforced soil beds show very less resistance against applied stress at low settlement values; thereafter, it continuously sinks into the ground.

The composite soil layers are reinforced with the conventional stone column and GESC, and it is evident that a significant amount of stress is carried at 10 mm settlement (as shown in Fig. 2). The amount of load carried by the composite bed reinforced with OSC and GESC's are 90 kPa and 100 kPa at 10 mm settlement. Peat soil bulges excessively in the radial direction due to the inadequate lateral support that is less amount of undrained shear strength. These peat soil/decomposed solid wastes are prone to have high total and differential settlement because of the higher void ratio, organic content and high water-retaining capacity.

From Fig. 3, the radial displacement was measured along with the vertical depth of the proposed dry granular pile. The following change was noticed and calculated the

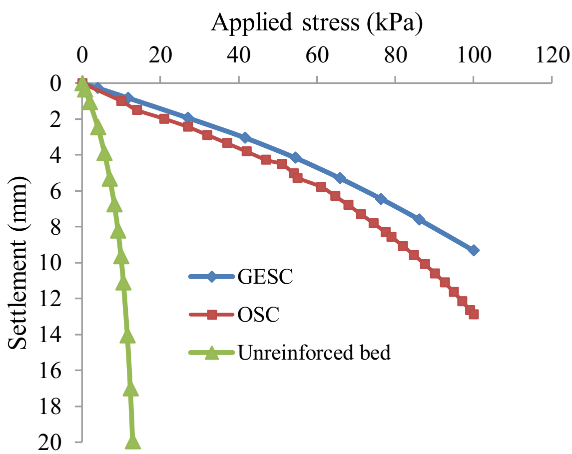


Fig. 2 Applied stress–settlement performance of the unreinforced bed and reinforced with the OSC and GESC

applied pressure of 100 kPa, and the radial displacement was reduced considerably and, that is, occurs in the top portion granular pile. In the case of regular conventional column, radial displacement is 18.21 mm, whereas in encased stone column, it is 3.36 mm that is almost more than five times lesser. It may be due to the peat soil deposits which show very less surrounding support to the regular conventional column, subsequently squeezing of the aggregates, the integrity of the aggregates in the column distressed therefore lateral failure, and thereby decreasing the ultimate bearing capacity. This problem can be fixed with the various tensile stiffness of the encased materials by encasing the stone column aggregates.

The axial deformation and radial displacement of the granular column decreased very effectively because of laterally confined geogrids as presented in Fig. 4. The amount of benefit calculated was up to 65% in terms of axial deformation, and also deformation in the lateral direction up to 70% reduction occurs.

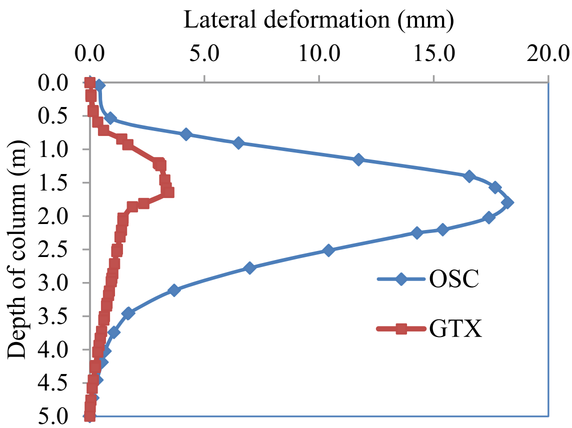


Fig. 3 Effect of geotextile encasement to the column on lateral deformation

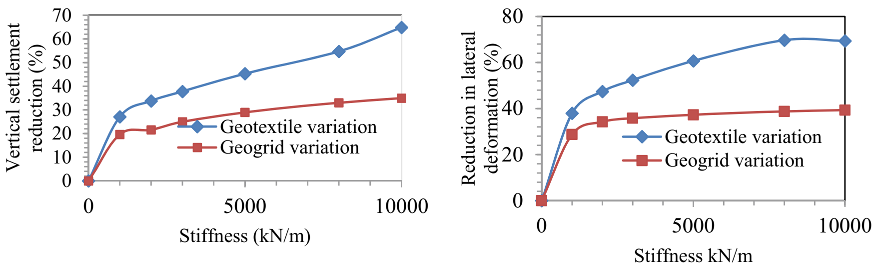


Fig. 4 Variation of reduction in the vertical and lateral settlement with stiffness encased material

Consolidation studies

The embankment is constructed without and with the support of stone columns and measured the consolidation effect through the three-dimensional Plaxis program (shown in Fig. 5). In the first stage of loading, the excess pore pressure increases linearly up to a value of 20 kN/m^2. During the consolidation time, the excess pore water pressure dissipates considerably in 35 days. During the second stage of loading, the excess pore pressure gets generated and reaches linearly to a value of 27 kN/m^2. The excess pore pressure dissipates in 30 days and taking the total time of 75 days for both stages as results are presented in Fig. 6.

The provision of OSC column in the multi-soil layers offers the drainage path for the pore water to dissipate. In the first stage of loading, the excess pore pressure increases linearly up to a value of 6.5 kN/m^2. During the consolidation time, the excess pore water pressure dissipates in 17 days. During the second stage of loading, the excess pore pressure is generated and reaches linearly to a value of 9 kN/m^2.

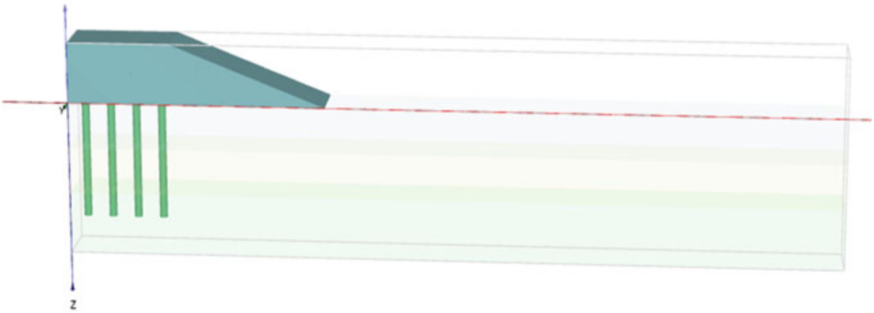


Fig. 5 Schematic sketch of the embankment resting the multilayered soil

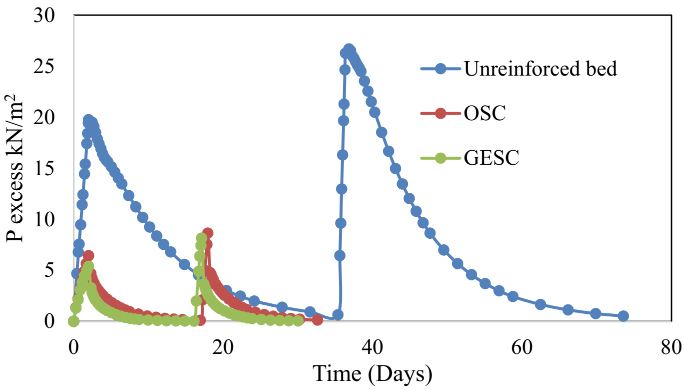


Fig. 6 Effect of ordinary and geosynthetic encased columns on consolidation

The excess pore pressure dissipates in 19 days by total time of 34 days for both stages (as shown in Fig. 6). A similar trend is followed in the case of GESCs. In the first stage of loading, the excess pore pressure increases linearly up to a value of 5.6 kN/m^2. During the consolidation time, the excess pore water pressure dissipates in 16 days. During the second stage of loading, the excess pore pressure gets generated and reaches linearly to a value of 8 kN/m^2. The excess pore pressure dissipates in 14 days taking the total time of 30 days for both stages as shown in Fig.6.

4 Conclusions

The load-carrying capacity of the multilayer soil system with a peat/solid waste of thickness equal to one diameter of column (*d*) has very low. It may be due to high void ratio, decomposed organic matter, high retention of the water, and high compressibility. The multilayer system contains the weak deposit modified with ordinary stone column, and geosynthetic encased columns yield satisfactory results in terms of bearing capacity and reduction in settlement significantly. From the consolidation studies it is evident that the excess pore water pressure generates with the application of the vertical pressure on composite soil. In the present study, before the treatment of composite layers, the excess pore water pressure is 27 kN/m^2 at the applied pressure of 100 kPa, and it reduces to 9 kN/m^2, 8 kN/m^2 and 10 kN/m^2 when using ordinary stone column and geotextile encased stone column.

References

1. R.Z. Moayed, M.H. Zade, Numerical analysis of geosynthetic-encased stone columns under laterally loads. Int. J. Civil Environ. Eng. **11**(1) (2017)
2. K.S. Ng, Numerical study on bearing capacity of single stone column. Int. J. of Geo-Eng. **9**(4) (2018)
3. S.P. Muzammil, R.M. Varghese, J. Joseph, Numerical simulation of the response of geosynthetic encased stone columns under oil storage tank. Int. J. Geosyn. Ground Eng. **4**(4), 1–13 (2018)
4. S.R. Lo, R. Zhang, J. Mak, Geosynthetic-encased stone columns in soft clay: a numerical study. Geotext. Geomem. **28**(3), 292–302 (2010)
5. M. Khabbazian, L. Christopher, A. Meehan, N. Victor, *Kaliakin: Numerical Study of Effect of Encasement on Stone Column Performance* (ASCE, Geotech. Geoenvi, 2010)
6. N.R. Alkhorshid, G.L.S. Araujo, E. Palmeria, M: Behavior of geosynthetic-encased Stone columns in soft clay: numerical and analytical evaluations. Soils Rocks **41**(3), 333–343 (2018)
7. Y.K. Tandel Y.K., Solanki C.H., Desai A. K: reinforced stone column: remedial of ordinary stone column. Int. J. of Adv in Eng. & Tech. **3**(2), 340–348 (2012)
8. K. Ali, J.T. Shahu, K.G. Sharma, Model tests on stone columns reinforced with lateral circular discs. Int. J. of Civil Eng. Res. **5**(2), 97–104 (2014)
9. R. Shivashankar, B.M.R. Dheerendra, S. Nayak, V. Rajathkumar, Experimental studies on the behaviour of stone columns in layered soils. Geotech. Geol. Eng. **29**(1), 749–757 (2011)

10. J.A. Black, V. Sivakumar, M.R. Madhav, G.A. Hamill, Reinforced stone columns in weak deposits: laboratory model study. J. Geotech. Geoenviron. **133**(9), 1154–1161 (2007)
11. R.B.J. Brinkgreve, W.M. Swolfs, Plaxis 3D version 2, Material Models Manual. Netherland, PLAXIS BV. (2016)

A Narrative Review on Emerging Nanobioremediation Toward Enhanced Environmental Sustainability

Shaid Yousuf and Arvind Kumar Agnihotri

1 Introduction

The swift advancement in science and technology sows the seeds of various environmental issues like soil and water pollution. Environmental issues have always been prominent in sustainable development and have become a serious matter of concern in the current times. Environmental sustainability is defined as a responsible interaction with the environment to elude reduction or degradation of natural resources and permit for long-lasting environmental quality. On the other hand, world understand sustainability as long-term development which results in environmental deterioration. The increasing rate of industrial development, urbanization and modernization has brought down unmanageable pollution burden on the environment [1]. With rapid modernization and development, achieving environmental sustainability is one of the major challenges of current times worldwide. Industries may be the fundamental drivers of the global economy, but are also the crucial soil and water polluters due to release of partially treated or untreated toxic and perilous wastes to the environment. Nowadays, it is widely accepted that contamination of soil and water is an imminent threat for the wellness of mankind [2].

Anthropogenic sources continue to release harmful substances into the environment all over the world, and this activity has grown in recent years due to increasing industrialization and industrialization. Anthropogenic activities discharge toxic compounds into rivers, and the accumulation of these dangerous chemicals in sediments enters the food web as bottom residues, affecting aquatic biota directly or

S. Yousuf (✉) · A. K. Agnihotri
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar 144011, Punjab, India
e-mail: Shai1914.ss@gmail.com

A. K. Agnihotri
e-mail: agnihotriak@nitj.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_2

indirectly (Wu et al., n.d.). The toxic contaminants are rising at a worrying rate in our surroundings, deteriorating the environment's quality, disrupting the ecosystem and having negative impacts on human health [3]. Heavy metals are essentially categorized as toxic soil pollutants, (i) in comparison with natural cycles, their rates of creation via man-made cycles are faster, (ii) metal concentrations in discarded items are considerably high as compared in receptor, (iii) they are easily transferable from one environmental location to another where direct or indirect contact is easily possible, and (iv) they can be swapped out for different species and become more bioavailable or poisonous, wreaking havoc on the environment and human health [4].

Among all the available remediation techniques, bioremediation is reflected to be an alternative technique for the reduction of pollutants [5]. Microbial assisted treatment methods are receiving attention as a green and long-term solution to contaminated areas [6]. Researchers have established and demonstrated various bioremediation methods; however, due to nature and/or type of pollutant, there is not a single bioremediation technique that serves as a 'silver bullet' to restore contaminated sites. The advantages of bioremediation such as its cost effectiveness, high competence, minimal generation of chemical and biological toxic waste, selectivity to specific metals, negligible requirements of adjunct nutrients, bio-sorbent regeneration and the possibility of metal recovery give it an edge over traditional remedial measures [7]. Despite its numerous benefits, this restorative approach is not advised for areas contaminated with high levels of hazardous chemicals such as heavy metals and salts, which are detrimental to microorganisms. Depending on specific site characteristics, some pollutants may not be transformed to nontoxic by-products rather result in more toxic and/or movable than source compounds like recalcitrant pollutants which are non-biodegradable in nature [8]. Furthermore, bioremediation is typically long-winded and treatment conditions (pH and temperature) must be favorable to microbes [9]. Therefore, the remediation of such contaminants by means of prevailing treatment methods is not very effective for environmental sustainability. Innovative research on the hazardous effects of metals, as well as new treatment methods for their remediation, is needed in order to achieve sustaining results using methodologies that employ innocuous reagents which are economical. The current study focuses on green synthesis of nanoparticles and why traditional remedial measures such as bioremediation and nano-remediation should be replaced by integrated and sustainable technology of nanobioremediation which upholds the above-discussed advantages for attaining greater environmental sustainability, as indicated by this current study.

2 Nanotechnology

Nanotechnology may be new for science but mankind has been using it for a long time. It is an area of research and innovation concerned with creating things particularly devices and materials at a nanoscale. Nanomaterials or nanoparticles generally known as engineered nanoparticles (ENP) possess size of 1–100 nm, at least in one dimension. Applications of nanoparticles can be considered almost in every single domain of science like automobiles, cosmetics, farming, food, textiles, space, defense, engineering, medical fields and environment.

Nanoparticles can be natural (volcanic dust, lunar dust, mineral composites, etc.), incidental (from the activities of human race, e.g., coal combustion, welding fumes, diesel exhaust) or engineered which may be either organic or inorganic [10]. It comprises the two sets either organic or/and inorganic. The first group includes carbon nanoparticles (fullerenes), while another includes noble metal (e.g., palladium, gold and silver) and magnetic and semiconductor nanoparticles (e.g., zinc oxide and titanium dioxide) [11]. The physio-chemical properties of nanoparticles are different from the source material. In recent times, application of nanoparticles (NPs) in contaminant eradication has become noticeable because of its tiny particle size, large surface area per unit volume ratio, easy injection to the site of action and flexibility for in situ and ex situ application. The accelerating practice and application of nano-based methods, devices or materials for the restoration of contaminated environment possibly originate from the urgent need of a technique which is efficient, economical, readily available and cost-effective and at the same time faster enough in delivering results without additional burden to the cleanup process in the form of residues and environmental persistence [12]. For that reason, the application of nanoscale particles or nanomaterials for remediation of soil contaminated by chemicals like heavy metals, pesticides and persistent organic pollutants, which are primarily non-biodegradable in nature, is being widely considered.

2.1 Synthesis of Nanoparticles

There are predominantly two methods for synthesizing nanoparticles. One is top-down approach, and the other is bottom-up approach [13]. When a bigger system breaks down to form small (nano-sized) particles, it is recognized as top-down approach like high energy ball milling, grinding, etching, laser pyrolysis, lithographic techniques, etc., whereas in bottom-up approach, atoms amalgamate to form clusters, and combination of clusters results in the development of nanoparticles. The top-down approach does not result in evenly shaped nanoparticles, and it is quite difficult to get a very small size of nanoscale particles even at high energy usages [14]. The main issue related to this approach is the change in chemical properties at interface and physio-chemical properties of nanomaterials [15]. A distinctive feature of the bottom-up approach is the enhanced possibility of obtaining nanoparticles with moderately lesser imperfections and more homogeneous chemical structure. Some of the factors which affect the synthesis of nanoparticles are pH, temperature, concentration of metal ion, dosage of capping/reducing agent and other physical conditions like stirring, reaction duration and peak wavelength [16]. Figure 1 demonstrates the approaches of synthesizing nanoparticles and various methods of synthesizes of nanoparticles. Researchers have explored an extensive range of green reducing and

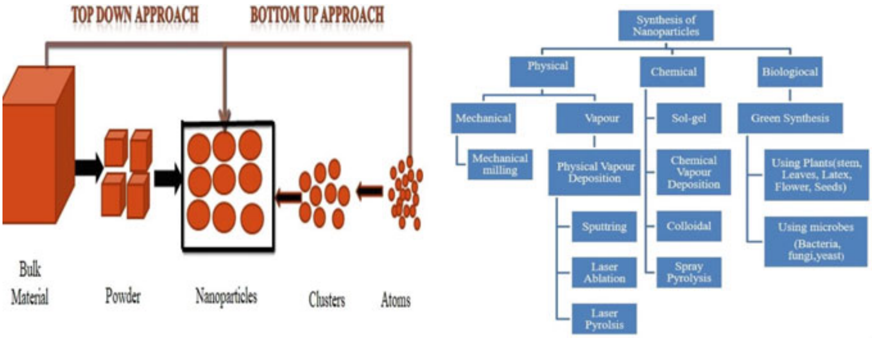


Fig. 1 Approaches and methods of synthesizing nanoparticles

capping agents, which can be economical, biocompatible, nontoxic and sustainable. Their use in the manufacture of NPs has drawn increasing attention. Table 1 reviews recent reports on the synthesis of NPs using plants, microorganisms, fungi, yeast and other materials. Synthesis of NPs using above-discussed sources is the green way of creating nanoparticles which targets to minimize waste generation using mild reaction conditions and nontoxic precursors.

3 Nano-Remediation: Solving Big Problems by Small Particles

Nanotechnology is practically a novel environmental technique which when used as a remedial measure for contaminated sites gives rise to nano-remediation. Nanomaterials have lately been used as a remedial measure for various contaminated sites around the globe and have been accepted as a remedial method by the scientific community, particularly for environmental remediation [20].

Nanoparticles were introduced as a remedial measure for contaminated water first time in the 1990's and are regarded as novel technology that is still growing. For the first time, the idea of using zero-valent iron for reclamation of water polluted with chlorinated organic contaminants was presented by [30]. Many studies have been conducted to check the viability of applying nanomaterials as remedy for various contaminants like organic halogenated hydrocarbons, dyes, nitrates, heavy metals and insecticides, and the results obtained were encouraging [56–58]. Remediation of organochlorine-contaminated groundwater was studied for the first time using nanomaterials by [58, 59]. In their study, they used bimetallic NPs like Pd/Fe, Ni/Fe and Pt/Fe/Zn and observed complete and rapid degradation of several aromatic chlorinated contaminants in water. It was revealed first time that zinc and iron NPs mainly serve as reducing agents, whereas Pd, Ni and Pt as catalysts. Also, research found out that nZVI (nanoscale) is 100 times more reactive than ZVI (macroscale).

Table 1 Synthesis of various nanoparticles

Nanoparticle type	Microorganism/material	Size, nm	Shape	References
Silver (Ag)	Aspilia pluriseta	1–20	Spherical	[17]
	Pomegranate seeds extract	19–54	…	[18]
	Coconut inflorescence sap	10–30	Spherical	[19]
	Pseudomonas deceptionensis	10–30	Spherical	[20]
	Sinapis arvensis	1–35	Spherical	[14]
	B. Monosperma	10–30	Spherical	[21]
	Streptomyces sp LK3	5	Spherical	[22]
	Schizophyllum commune	51–93	Spherical	[23]
	Silver nitrate, copper (II) chloride	80–120	…	[24]
Zinc (Zn)	Eucalyptus spp.	<40	Irregular	[25]
	Cumin	3–29	Spherical	[26]
	C. Albicans	15–25	Quasi-spherical	[27]
	Marine seaweed *C. Racemosa*	5–25	Spherical with few triangular	[28]
	A. Carnosus	20–40	Spherical	[29]
	Corriandrum	66	…	[30]
	Calotropis gigantean	30–35, 11–84	Spherical	[31, 32]
	Aeromonas hydrophila	45–75	Spherical	[33]
	(Physalis alkekengi) P. Alkekengi	50–200	Triangular	[34]
Gold (Au)	Saccharomonospora glauca	30	Spherical	[35]
	Longan polysaccharide	7.8–15.6	Spherical	[36]
	Banana pith extract	17–20	…	[37]
	Lemanea fluviatilis	5–15	Spherical	[8]
	Abelmoschus esculentus	45–75	Spherical	[38]
	Ocimum sanctum	30	Hexagonal	[39]
	Chenopodium album	10–30	Quasi-spherical	[40]
	Stenotrophomonas maltophilia	40	Spherical	[41]
	Fusarium semitectum	18–25	Spherical	[18]
	Pseudomonas aeruginosa	15–30	…	[42]
Iron (Fe)	Thunbergia grandiflora	25	Irregular spherical	[43]

(continued)

Table 1 (continued)

Nanoparticle type	Microorganism/material	Size, nm	Shape	References
	Bilberry waste residues (BWE) and False bilberry (FBE)[Vaccinium species]	2–10	…	[44]
	Green Tea	50–80	Spherical	[45]
	Green tea (*Camillis sinensis)*	75–100	Ellipsoidal	[46]
	Rice husk-derived biochar	100	…	[47]
	Laurus nobilis L	9	Hexagonal	[38]
	Spondias dulcis	11	Irregular	[48]
	Eichhornia crassipes	…	Rod shaped	[49]
	Daphne mezereum	6.5–14.9	Spherical	[44]
	Vaccinium floribundum (*Andean blueberry*)	5–10	Spherical	[50]
Copper (Cu)	Citrus limon	28	Spherical	[51]
	Eucalyptus (*Eucalyptus globulus L.*) and mint (*Mentha piperita*)	23–39	….	[52]
	Macrocystis pyrifera	2–50	Spherical	[53]
	Waste printed circuit boards	5–32	Spherical	[54]
	Ziziphus spina-christi(L.)	5–14	…	[55]
	Syzygium aromaticum	15	Spherical	[56]
	Eclipta prostrata	23 to 57	Spherical	[57]

Various types of NPs have been proposed for eliminating contaminants from environmental matrices such as nanoscale zeolites, metal oxides, carbon nanotubes and fibers, titanium dioxide, zero-valent iron, iron oxide nanoparticles, bimetallic nanoparticles and many more [60]. Among the nanoparticles, nZVI has received the attention of many researchers for decontamination of various contaminated sites around the globe due to its low toxicity. Other than nZVI, many more NPs found their way in remediating contaminated sites polluted with various contaminants. Table 2 shows various NPs which have been used for remediating various contaminants successfully. Studies suggested that there is a direct relationship between reactivity and degradation; i.e., highly reactive materials degrade contaminants at higher rates. Further, loss in reactivity with aging and agglomeration impacts the decontamination efficiency [61].

Nano-remediation has the advantage of being able to be used both in situ and ex situ for restorative procedures. In ex situ remediation, polluted soil and/or water is brought into treatment unit and NPs are applied to remove contaminants; on the other

Table 2 Various contaminants remediated with nanoparticles

Nanoparticle	Size (nm)	Contamin ant	Medium	Remarks	Citations
nZVI	61–71	Heavy metals (Pb, Zn and Cd)	Soil	nZVI decreased mobility of Pb and Zn in short term. However, over longer period (120 days), the efficiency was low, and toxicity values were comparable between treated and untreated soil	[62]
Ferrous sulfate modified nano-silica	18	Lead, cadmium and arsenic	Soil	Reduction in Pb, Cd and As was considerable; with dosage of 3%, reduction was by 97.1%, 85.0% and 80.1%, respectively	[63]
Nano-silica (NS-B and NS-W)	49–75	Nickel	Agricultural wastewater	The favorable conditions for maximum removal are pH 8, temperature 35 °C, contact time 65 min, agitation speed 1000 rpm and adsorbent dosage 10 mg	[64]
Zero-valent iron	– –	Diesel-contaminated Soils	Soil	Fe^0 showed better performance than Fe_3O_4. The diesel removal efficiency of Fe^0 (3.5 mg/l) nanoparticle for desert soil, coastal soil and clay was 94.6, 95.3 and 57.5%, respectively	[65]

(continued)

Table 2 (continued)

Nanoparticle	Size (nm)	Contamin ant	Medium	Remarks	Citations
Fe/Ni bimetallic nanoparticles	– –	Tetracycline (TC)	Groundwater	TC was removed by the cooperative of adsorption and degradation. The removal efficiency increased with the decrease of solution pH, and the optimal pH was 5. The co-existence of competitive anions (NO^{3-}, $H2PO^{4-}$, SO^{2-} and HCO^{-}) showed varying inhibitory effects on TC removal	[66]
Hematite nanoparticles	15–40	Carbamazepine	Water	Removal efficiency increased with time, and equilibrium reached within 150 min; even 100% removal was seen with increase in nanoparticle	[34]
Nano-zero-valent iron/Cu (GT-nZVI/Cu)	60–120	Chromium (Cr(IV))	Groundwater	Cr(IV) removal efficiency was 94.7% at pH 5, temperature 303 K and GT-nZVI/Cu dosage of 0.4 g/L	[16]
Zero-valent iron nanoparticles (nZVI)	70	Arsenic and mercury	Soil	• The effectiveness of treatment depends on type of nZVI, soil properties and concentration and characterization of containment • Best results were observed for nZVI even at the lowest dose (1%)	[67]

hand, in situ NPs are either directly injected to contaminated site or using permeable reactive treatment zone (PRTZ) where the contaminants are remediated. Generally, it is found that in situ treatment of soil and groundwater is more promising because of its cost effectiveness. In case of in situ application, it is necessary to create either PRTZ or a reactive NP plume that roams in contaminated zone. For remediating topsoil, NPs are applied to the surface using any agricultural practices. These different approaches are demonstrated in Fig. 2.

Even though several nanoparticles are available for soil decontamination, almost all the researchers have recommended zero-valent iron. The nZVI NPs have attained very fascinating and optimistic results that make them desirable particularly for the subsurface contaminant remediation. Further, it is interesting that most investigations have focused on cleaning up processes in saturated soils. In contrast, less literature is found debating on unsaturated soils.

Having discussed the wider applicability of nano-remediation, there are some limitations associated with it. Recent studies have indicated that the end products of most of the nano-remediation processes remain under toxic state, and in such a condition, they are posing significant threat to the environment. However, toxic levels due to the presence of various elements can be stabilized and detoxified by various microbes. So, it is worthy to mention here that if the both the techniques are applied together, it can lead to the accomplishment of long-term sustainable goals.

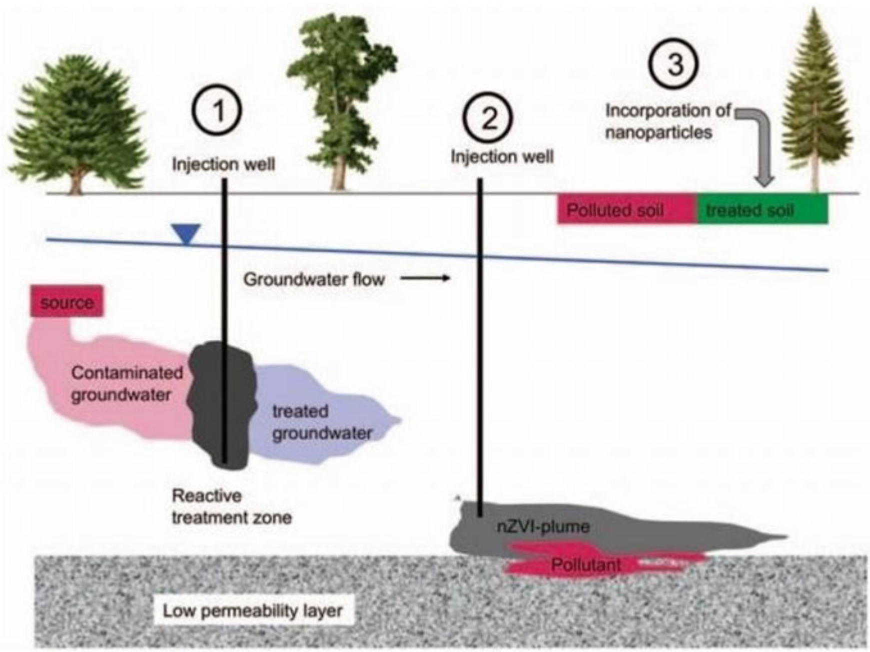


Fig. 2 In situ treatment: (1) injection of nZVI to form PRTZ; (2) injection of mobile nZVI to form an nZVI plume; (3) application of NP into topsoil [68]

4 Nanobioremediation: Integrating Nano and Bio for Sustainability

While deciding appropriate remediation technique for a polluted site, several aspects like cost effectiveness, efficiency, hazards, time required, complexity of technology and availability of both physical and human resources to implement are carefully evaluated and analyzed. Studies have revealed that use of individual technique for the remedial measure of recalcitrant pollutants may not be efficient, effective or sustainable and also may be expensive [69]. The demand for new technologies which can remediate the polluted sites efficiently and in a sustainable way is much needed in current times [70]. Nanobioremediation (NBR) is such a technique that is capable of remediating efficiently and sustainably. It is an integrated approach that applies nanotechnology and biotechnology together to attain a remediation that is more sustainable, time saving and ecofriendly than the processes when applied individually. NBR has received a considerable focus recently due to its ability to overcome the inadequacies of both the methods and provide better remedial outcomes. NBR usually works in two stages: (i) Nanoparticles break down the pollutants to such a level which is favorable to microbes; (ii) microbes then consume fewer toxic contaminants for complete degradation. In NBR, the NPs used are synthesized biologically usually.

Immobilization is a technique in which an enzyme or cells are physically contained in a specific location without changing their characteristics, therefore increasing their stability and activity. Immobilization is now gaining a lot of interest from the scientific community due to its advantages over soluble enzymes. Enzymes are highly sensitive in nature; their characteristics, activity and/or structure may be altered due to immobilization. Hence, their immobilization demands appropriate methodology in order to enhance stability and activity of enzyme. Some factors must be taken into consideration while selecting support material which include hydrophilicity, ease of derivatization, resistant to environmental attack, inertness toward enzymes, incompressible, biocompatible and cost. However, cell separation, substrate inhibition, high cost, time consuming and low rate of degradation are some reasons which make bioremediation inefficient. To overcome limitations associated with bioremediation, a convenient solution would be to utilize NPs for immobilization by selective procedures [71]. Several materials have been used for cell immobilization but most of them have disadvantages associated with them like limited transport of substrate and fragility of holding cells in response to adverse environmental changes. In recent times, using nanoparticles as immobilized carriers has received huge attention from the research community. Studies revealed that cells immobilized on nanoparticles significantly enhance the microbial mechanisms of environmental remediation and also provide ease of regeneration [72]. Due to high specific surface area, chemical inertness, low toxicity, biocompatibility, controllable synthesis, recyclability and property of super-magnetism, magnetic nanoparticles (MNPs) received considerable attention as stabilizing/immobilizing carriers for microorganisms and enzymes in treatment process [73–77]. Srinivasan et al. [78] demonstrates that MNPs are innovative candidates for immobilizing the laccase enzyme and revealed immobilized laccase degrades chlorpyrifos more efficiently than free laccase. Furthermore, immobilization enhanced the tolerance of laccase toward alkaline pH, high temperature and storage up to 100 h. The Fe3O4-bacterial system verified to be efficient for the remediation of wastewater contaminated by petroleum hydrocarbons within 24 h [79].

A pivotal work, conducted by Cao [63], demonstrated that integrated approach of polyvinylpyrrolidone (PVP) coated iron oxide NPs with the Gram-negative bacterium Halomonas sp. is able to eradicate Cd and Pd completely within 24 h and 48 h, respectively, while as for individual treatments, removal efficiency was only 60% and 80%, respectively, for same the same time period.

The recalcitrant compounds such as chlorinated aliphatic hydrocarbons (CAH) cannot be completely remediated by nZVI (nano-remediation) or individually by organochlorine respiring bacteria (bioremediation). Studies revealed that combining two could potentially create a solution which will be quick and complete at an optimum dosage for contaminants at chlorinated hydrocarbon impacted sites [80]. Triclosan (TCS) contaminant is usually present in self-care products; its concentration is increasing exponentially resulting in contamination of water and soil. A study was conducted to check the feasibility of remediating such contaminated sites with an integrated approach. The researchers proposed a sequential reduction–oxidation process in which dechlorination was achieved by Pd/Fe nanoparticles. Subsequently, oxidation of by-products using enzyme laccase. The complete remediation was attained in 20 min, and overall toxicity was also reduced [63]. A redox approach consisting of nZVI and bacterium (Sphingomonas sp. PH-07) was found to be efficient for an aqueous solution containing polybrominated diphenyl ethers (PBDEs). Kratochvil and Volesky [81] conducted a study, reduction of deca-BDE (5 g/L) was achieved using nZVI (100 mg) under aerobic conditions. After 20 days, under aerobic conditions nZVI-treated deca-BDE samples were subjected to degrading bacterium Sphingomonas sp. PH-07 and incubated for 4 days. This sequential method encourages treatment of sites contaminated with PBDEs. Reduction rate of deca-BDE was approximately two times for Pd/nZVI compared to nZVI. In another study, silver nanoparticle in combination of Aspergillus niger efficiently decolorizes 80.2% dye within 42 h and dye was fully removed in 78 h of incubation, while as individually Aspergillus niger was only 40% efficient for same time period [82].

Lindane (γ-HCH) is a pesticide that contaminates soil on a large scale due to its extensive use in the agricultural sector. Integrated approach was evaluated to investigate the effect of combining remediation abilities of both CMC-Pd/nFe0 and Sphingomonas sp. strain to degrade γ-HCH-contaminated soil. Research revealed that 99% of contaminant degradation was achieved in 6 days for combined approach and optimum dosage for NP was 40 mg/l [78]. Another study revealed that using nano-bio technique comprising catalytic dechlorination using iron sulfide (FeS) nanoparticles followed by microbial degradation, it is possible to eradicate lindane (5 mg/l) from system within 9 h [17]. Studies suggested that phenolic pollutants can be removed by a combined approach of Fe_3O_4 NPs and P. chrysosporium by the coupled mechanism of photocatalysis and natural process under lighting condition [83]. Zinc was efficiently removed by P. chrysosporium pellets [62].

EPA confirmed that 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD) commonly known as dioxin is carcinogenic in nature. Dioxin finds its way to the environment from waste-burning incinerators and leads to several diseases related with skin, immune system, endocrine system, nervous system and reproductive system [84]. Study revealed that dioxin being such a hazardous contaminant can also be eradicated from a given medium completely by this novel approach. [85] conducted a study in which bimetallic Pd/Fe (0.5 g) nanoparticles and Sphingomonas wittichii were sequentially added to a solution contaminated with 2,3,7,8-tetrachlorodibenzo-p dioxin. Results showed dechlorination process of dioxin in anaerobic conditions was completed using Pd/Fe nanoparticles in 10 h. Further, dibenzo-p-dioxin (by-product) was degraded by Sphingomonas wittichii. Table 3 presents nanobioremediation methods described for a variety of environmental pollutants. From the literature available till date, we can say that nanobioremediation could lead to sustainability in near future. Still, there are some areas which need to be thoroughly addressed before applying this novel approach in field like toxicity and agglomeration of nanoparticles, effect of medium constraints, transport, fate and bioaccumulation of nanoparticles last but not least compatibility between bioagent and nanomaterial. Some other issues are loss of reactivity with time, transportation and effect of nanoparticles on microorganisms. Although various studies have been conducted on such issues, results are still contradictory. By the time these obscure areas of research are explored, nanobioremediation will undoubtedly be an optimistic approach for attaining the environmental sustainable goals.

5 Conclusions

To address the challenges pertaining to a sustainable environment, the contaminants must be remediated using a sustainable approach. The sustainable tool of nanobioremediation resulting from the integration of nanotechnology and biotechnology has received tremendous attention recently. Nanobioremediation contributes toward enhanced sustainability because of its efficiency to counter new environmental threats, time saving, wider applicability and more importantly being economical compared to its individual counterparts. Furthermore, nanobioremediation offers sustainable solutions of reusability and recyclability to components such as (NPs) which are left out in soil. There are various challenges faced by the scientific community in implementing nanobioremediation as the ultimate solution to the contaminated sites with variable problems. Such issues can be addressed by encouraging research at global level. Furthermore, this paper draws the following conclusions:

Table 3 Remediation of contaminants by nanobioremediation

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
nZVI	5 mg/g		SRB	Cadmium (Cd)	nZVI could stimulate the SRB bio-immobilization possibly through providing electrons and enhancing enzyme activities	[36]
nZVI	2 g/l		A. xylosoxidans, S. maltophilia and O. anthropic	PCBs	Nanobioremediation was 99% efficient while as individually only 60% and 46% in removing PCBs for the same period of treatment	[86]
Fe3O4 MNP	….	10–20	Peroxidase enzyme	Textile wastewater dye	MNPs-immobilized enzymes show greater stability toward heat, pH, storage, reuse and other perturbations, than free enzymes along with successfully removing dyes from wastewater	[87]
nZVI	(50–200) mg/l	30	Desulfovibrio desulfuricans	Chromium Cr(VI)	Optimal dose was observed as 200 mg/L with 90 min of contact period. Removal efficiency decreased with increase in contaminant concentration	[88]

(continued)

Table 3 (continued)

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
α-Fe_2O_3 MNP	…	7	Bacillus spp.	Atrazine (ATZ)	Optimum values for pH, temperature, ATZ concentration and agitation speed were found to be 7, 30 °C, 200 mg/L and 150 rpm, respectively. Combined system is able to tolerate high acidic and alkaline conditions	[89]
Fe_3O_4/Biochar	0.05 g by wet weight	10 ± 20.5	R. capsulatus	Wastewater (COD, N and P)	This nanocomposite proves to be an ideal agent for wastewater treatments as efficiency of 100% was achieved along with significant reduction in treatment period	[90]
nano-Fe3O4	1-4 g/100 mL	…	Debaryomyces sp.	Phenol	Immobilized cells were 99.9% efficient and could tolerate harsher environment compared to free cells. The optimal dosage of nano-Fe3O4 was 2% and the immobilized cells could be used repeatedly	[88]

(continued)

Table 3 (continued)

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
nZVI	1 g/l	30	Bacillus subtilis, E. coli, Acinetobacter junii	Chromium Cr(VI)	The removal capacity of Cr(VI) was enhanced (97%) in the presence of a biofilm on nZVI −C−A beads compared with bare nZVI −C− A beads	[91]
Fe3O4	0.5 mg/l	8–20	Phanerochaete chrysosporium	Phenol	The maximal phenol degradation efficiency (93.41%) under solar light was detected at 0.5 g L1Fe_3O_4, while it reached a peak (40.36%) at 0.7 g L1Fe3O4 under dark	[86]
Pd/nFe	1 mg/l	…	Burkholderia xenovorans	Polychlorinated biphenyl (PCB) Aroclor	Pd/nFe effectively reduced PCB to its simpler forms which were then biodegraded by Burkholderia xenovorans. The dehalogenation efficiencies of tri-, tetra-, penta- and hexachlorinated biphenyls were 99%, 92%, 84% and 28%, respectively. Treatment period was reduced by combined method	[92]

(continued)

Table 3 (continued)

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
Fe3O4	…	20	Sphingomonas sp.	Carbazole	Not much increase in degradation was noticed than the free cells but showed amazing reusability. Biocomposite offers a promising technique	[2]
					for improving biocatalysts used in decontamination of hazardous organic compounds	
CNT	0–0.5%	10–30	Shewanella oneidensis MR-1	Cr(VI)	AL/CNT/cells were four times efficient than free cells and alginate/cells. Reduction rate increased (from 0.047 to2.431 mg/L/d) as the CNT content in the AL/CNT/cell beads was increased from 0% to 0.5%	[69]
CNTs			Pseudomonas aeruginosa	Cr(VI)	50% reduction was achieved within 84 h; also, such modified CNT immobilized cells can be reused up to 9 times with 90% efficiency	[93]

(continued)

Table 3 (continued)

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
Palladium(Pd-bio)	50 mg/l	50	C. Pasteuranium	Chromium Cr(VI)	Greater than 99% Pd(II) was reduced to Pd within one minute by C. Pasteuranium and stayed in the form of Pd-bio in cell membrane which successfully reduce Cr(IV) and also produce hydrogen gas	[25]
nZVI	100 mg/l	…	Dehalococcoides spp.	TCE	Dechlorinating organisms were inhibited by NZVI initially, but dechlorination activity resumed after a lag period and H2 evolved can be exploited as electron donor by methanogens and dechlorinating bacteria	[94]
Iron (Fe)	9 mg/l	20	Sphingomonas sp. Strain	Carbazole	Microbial cells immobilized in Fe3O4 NPs/gellan gum gel beads degraded carbazole than free cells. Integrated approach showed progressive increase in degradation when being recycled	[95]

(continued)

Table 3 (continued)

Nanoparticle	Dosage	Size (nm)	Microorganism	Target	Remarks	References
Palladium (0)	50 mg/l	…	Shewanella Oneidensis	Polychlorinated Biphenyls	More than 90% decrease was observed at 1 mg/l within 5 h at 28^0C and bioPd dechlorinated both highly and lightly chlorinated PCB congeners contaminated sediments within 48 h at 28^0C	[96]

(a) Despite being the safest treatment method, bioremediation is not suitable for the sites contaminated with high concentration of toxic substances like heavy metals and salts as they are harmful to microbes.
(b) Green synthesis of NPs is an eminent tool to reduce the negative impacts associated with the conventional approaches. It aims to minimize the use of toxic chemicals and solvents hence should be encouraged for promoting environmental sustainability.
(c) For the removal of PCBs, nanobioremediation is found to be 20–30% more efficient than its individual counterparts. Studies have also revealed that the nanobioremediation technique is a time-saving process usually 10–20% more expeditious.
(d) Immobilized cells using magnetite nanoparticles are highly efficient in the removal of contaminants such as dibenzothiophene, carbazole, phenol and atrazine. It is found that these immobilized cells possess a higher degree of efficiency (>90%) compared to free cells. Furthermore, immobilized technique possesses the property of reusability and is able to withstand adverse environmental conditions (high acidic and alkaline).
(e) Intractable compounds such as chlorinated aliphatic hydrocarbons (PCE, TCE and TCA) cannot be removed efficiently using traditional treatment methods. However, the combined approach of nanobioremediation can provide 100% removal efficiency for such contaminated sites along with considerable reduction in treatment period.

From the above discussion, we can deduce that nanotechnology has a wide applicability in various fields of science however; it has enormous applications in environmental remediation. Further, it is anticipated that its applications will increase at a great leap in near future and will play a crucial role in achieving environmental sustainability.

References

1. Y. Shih, Y. Tai, Chemosphere reaction of decabrominated diphenyl ether by zerovalent iron nanoparticles. Chemosphere **78**(10), 1200–1206 (2010). https://doi.org/10.1016/j.chemosphere.2009.12.061
2. Y. Li, X. Du, C. Wu, X. Liu, X. Wang, P. Xu, An efficient magnetically modified microbial cell biocomposite for carbazole biodegradation. Nanoscale Res. Lett. **8**(1), 1–5 (2013). https://doi.org/10.1186/1556-276X-8-522
3. J. Sivakumar, C. Premkumar, P. Santhanam, N. Saraswathi, Biosynthesis of silver nanoparticles using calotropis gigantean leaf. Science **3**(6), 265–270 (2011)
4. R.A. Wuana, F.E. Okieimen, "Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation", Int. Sch. Res. Not. 2011, Article ID 402647, 20 p (2011). https://doi.org/10.5402/2011/402647
5. M.P. Shahi, P. Kumari, D. Mahobiya, S. Kumar Shahi, Nano-bioremediation of environmental contaminants: applications, challenges, and future prospects, in Bioremediation for Environmental Sustainability (Issue Cd). Elsevier B.V (2021). https://doi.org/10.1016/b978-0-12-820318-7.00004-6

6. N. Bai, S. Wang, P. Sun, R. Abuduaini, X. Zhu, Y. Zhao, Degradation of nonylphenol polyethoxylates by functionalized Fe3O4 nanoparticle-immobilized Sphingomonas sp. Y2. Sci. Total Environ. **615**, 462–468 (2018). https://doi.org/10.1016/j.scitotenv.2017.09.290
7. T.T. Le, K.H. Nguyen, J.R. Jeon, A.J. Francis, Y.S. Chang, Nano/bio treatment of polychlorinated biphenyls with evaluation of comparative toxicity. J. Hazard. Mater. **287**, 335–341 (2015). https://doi.org/10.1016/j.jhazmat.2015.02.001
8. I. Sharma, Bioremediation techniques for polluted environment: concept, advantages, limitations, and prospects. IntechOpen (2019)
9. T. Garima, S. Sp, Application of bioremediation on solid waste management: A review bio r emediation & biodegradation 5(6) (2020). https://doi.org/10.4172/2155-6199.1000248
10. R.C. Monica, R. Cremonini, Nanoparticles and higher plants. Caryologia, **62**(2), 161–165 (2009)
11. R. Vinayagam, S. Pai, T. Varadavenkatesan, M.K. Narasimhan, S. Narayanasamy, R. Selvaraj, Structural characterization of green synthesized α-Fe2O3 nanoparticles using the leaf extract of Spondias dulcis. Surfaces Interf. **20**(August), 100618 (2020). https://doi.org/10.1016/j.surfin.2020.100618
12. B. Karn, T. Kuiken, M. Otto, Nanotechnology and in situ remediation: A review of the benefits and potential risks. Environ. Health Perspect. **117**(12), 1823–1831 (2009). https://doi.org/10.1289/ehp.0900793
13. C. Vidya, S. Hiremath, M.N. Chandraprabha, M.A. Lourdu Antonyraj, L. Venu Gopal, I., Jain, K. Bansal, Green synthesis of ZnO nanoparticles by Calotropis Gigantea. Int. J. Current Eng. Tech. Ncwse, 2012–2014 (2013). http://inpressco.com/category/ijcet
14. M. Khatami, S. Pourseyedi, M. Khatami, H. Hamidi, M. Zaeifi, L. Soltani, Synthesis of silver nanoparticles using seed exudates of sinapis arvensis as a novel bioresource, and evaluation of their antifungal activity. Bioresources Bioproces. **2**(1) (2015). https://doi.org/10.1186/s40643-015-0043-y
15. R. Hao, D. Li, J. Zhang, T. Jiao, *Green Synthesis of Iron Nanoparticles Using Green Tea and Its Removal of Hexavalent Chromium* (2021)
16. J. Anuradha, Use of some aquatic and terrestrial weeds in the green synthesis of gold nanoparticles. Centre for Pollution Control and Environmental Engineering (2013)
17. K.M. Paknikar, V. Nagpal, A.V. Pethkar, J.M. Rajwade, Degradation of lindane from aqueous solutions using iron sulfide nanoparticles stabilized by biopolymers. Science Tech. Advanced Mat. **6**(3–4 SPEC. ISS.), 370– 374 (2005). https://doi.org/10.1016/j.stam.2005.02.016
18. B.D. Sawle, B. Salimath, R. Deshpande, M.D. Bedre, B.K. Prabhakar, A. Venkataraman, Biosynthesis and stabilization of Au and Au-Ag alloy nanoparticles by fungus, Fusarium semitectum. Science Tech. Adv. Mat. **9**(3) (2008). https://doi.org/10.1088/1468-6996/9/3/035012
19. V.R. Ranjitha, V.R. Rai, Bioassisted Synthesis of Gold Nanoparticles from Saccharomonospora glauca: Toxicity and Biocompatibility Study. BioNanoScience (2021). https://doi.org/10.1007/s12668-021-00830-9
20. B. Karn, T. Kuiken, M. Otto, Nanotechnology and in situ remediation : a review of the benefits and potential risks A nanotecnologia e a remediação in situ : uma revisão dos benefícios e riscos em potencial, 165–178 (2009). https://doi.org/10.1289/ehp.0900793
21. V. Chaturvedi, P. Verma, Fabrication of silver nanoparticles from leaf extract of Butea monosperma (Flame of forest) and their inhibitory effect on bloom-forming cyanobacteria. Bioresources Bioprocess. **2**(1) (2015). https://doi.org/10.1186/s40643-015-0048-6
22. F.A. Khan, Applications of nanomaterials in human health. Appl. Nanomaterials Human Health (2020). https://doi.org/10.1007/978-981-15-4802-4
23. G. Arun, M. Eyini, P. Gunasekaran, Green synthesis of silver nanoparticles using the mushroom fungus Schizophyllum commune and its biomedical applications. Biotech. Bioproc. Eng. **19**(6), 1083–1090. https://doi.org/10.1007/s12257-014-0071-z
24. S. Tripathi, R. Sanjeevi, J. Anuradha, D.S. Chauhan, A.K. Rathoure, Nano-bioremediation: Nanotechnology and bioremediation. Biostimul. Remediation Tech. Groundwater Contamint., 202–219 (2018). https://doi.org/10.4018/978-1-5225-4162-2.ch012

25. D. Chidambaram, T. Hennebel, S. Taghavi, J. Mast, N. Boon, W. Verstraete, D. Van Der Lelie, J.P. Fitts, Concomitant microbial generation of palladium nanoparticles and hydrogen to immobilize chromate. Environ. Sci. Technol. **44**(19), 7635–7640 (2010). https://doi.org/10.1021/es101559r
26. W. Zhang, C. Wang, H. Lien, Treatment of chlorinated organic contaminants with nanoscale bimetallic particles. **40**, 387–395 (1998)
27. G.B. Shan, J.M. Xing, H.Y. Zhang, H.Z. Liu, Biodesulfurization of dibenzothiophene by microbial cells coated with magnetite nanoparticles. Appl. Environ. Microbiol. **71**(8), 4497–4502 (2005). https://doi.org/10.1128/AEM.71.8.4497-4502.2005
28. R. Khani, B. Roostaei, G. Bagherzade, M. Moudi, Green synthesis of copper nanoparticles by fruit extract of Ziziphus spina-christi (L.) Willd.: Application for adsorption of triphenylmethane dye and antibacterial assay. J. Mol. Liq. **255**, 541–549 (2018). https://doi.org/10.1016/j.molliq.2018.02.010
29. M. Anbuvannan, M. Ramesh, G. Viruthagiri, N. Shanmugam, N. Kannadasan, Anisochilus carnosus leaf extract mediated synthesis of zinc oxide nanoparticles for antibacterial and photocatalytic activities. Mater. Sci. Semicond. Process. **39**, 621–628 (2015). https://doi.org/10.1016/j.mssp.2015.06.005
30. D. Gnanasangeetha, D. Saralathambavani, One pot synthesis of Zinc Oxide nanoparticles via chemical and green method. Res. J. Mater. Sci. **1**(7), 1–8 (2013)
31. F. Šulek, M. Drofenik, M. Habulin, Ž Knez, Surface functionalization of silica-coated magnetic nanoparticles for covalent attachment of cholesterol oxidase. J. Magn. Magn. Mater. **322**(2), 179–185 (2010). https://doi.org/10.1016/j.jmmm.2009.07.075
32. C. Wang, W. Zhang, Synthesizing nanoscale iron particles for rapid and complete dechlorination of TCE and PCBs. **31**(7), 2154–2156 (1997)
33. Y. Jiang, T. Deng, Y. Shang, K. Yang, H. Wang, Biodegradation of phenol by entrapped cell of Debaryomyces sp. with nano-Fe3O4 under hypersaline conditions. Int. Biodeterior. Biodegradation **123**, 37–45 (2017). https://doi.org/10.1016/j.ibiod.2017.05.029
34. K. Rajendran, S. Sen, *Environmental Nanotechnology, Monitoring & Management* (2018). https://doi.org/10.1016/j.enmm.2018.01.001
35. A.K. Rathoure, Dioxins: source, origin and toxicity assessment. Biodiversity Int. J. **2**(4), 310–314 (2018). https://doi.org/10.15406/bij.2018.02.00079
36. Q. Zhao, X. Li, S. Xiao, W. Peng, W. Fan, Integrated remediation of sulfate reducing bacteria and nano zero valent iron on cadmium contaminated sediments. J. Hazard. Mater. **406**, 124680 (2021). https://doi.org/10.1016/j.jhazmat.2020.124680
37. A.O. Nyabola, P.G. Kareru, E.S. Madivoli, S.I. Wanakai, E.G. Maina, Formation of Silver Nanoparticles via Aspilia pluriseta extracts their antimicrobial and catalytic activity. J. Inorg. Organomet. Polym Mater. **30**(9), 3493–3501 (2020). https://doi.org/10.1007/s10904-020-01497-7
38. C. Jayaseelan, R. Ramkumar, A.A. Rahuman, P. Perumal, Green synthesis of gold nanoparticles using seed aqueous extract of Abelmoschus esculentus and its antifungal activity. Ind. Crops Prod. **45**, 423–429 (2013). https://doi.org/10.1016/j.indcrop.2012.12.019
39. D. Philip, C. Unni, Extracellular biosynthesis of gold and silver nanoparticles using Krishna tulsi (Ocimum sanctum) leaf. Physica E: Low-Dimensional Syst. Nanostrut. **43**(7), 1318–1322 (2011). https://doi.org/10.1016/j.physe.2010.10.006
40. E.J. Espinosa-Ortiz, M. Shakya, R. Jain, E.R. Rene, E.D. van Hullebusch, P.N.L. Lens, Sorption of zinc onto elemental selenium nanoparticles immobilized in Phanerochaete chrysosporium pellets. Environ. Sci. Pollut. Res. **23**(21), 21619–21630 (2016). https://doi.org/10.1007/s11356-016-7333-6
41. Y. Nangia, N. Wangoo, N. Goyal, G. Shekhawat, C.R. Suri, A novel bacterial isolate Stenotrophomonas maltophilia as living factory for synthesis of gold nanoparticles. Microbial Cell Factories **8**(1), 1–7 (2009). https://doi.org/10.1186/1475-2859-8-39
42. G. Jagathesan, P. Rajiv, Biosynthesis and characterization of iron oxide nanoparticles using Eichhornia crassipes leaf extract and assessing their antibacterial activity. Biocatalysis Agri. Biotech. **13**(December 2017), 90–94 (2018). https://doi.org/10.1016/j.bcab.2017.11.014

43. Y. Pang, G.M. Zeng, L. Tang, Y. Zhang, Y.Y. Liu, X.X. Lei, M.S. Wu, Z. Li, C. Liu, Cr(VI) reduction by Pseudomonas aeruginosa immobilized in a polyvinyl alcohol/sodium alginate matrix containing multi-walled carbon nanotubes. Biores. Technol. **102**(22), 10733–10736 (2011). https://doi.org/10.1016/j.biortech.2011.08.078
44. E. Benassai, M. Del Bubba, C. Ancillotti, I. Colzi, C. Gonnelli, N. Calisi, M.C. Salvatici, E. Casalone, S. Ristori, Green and cost-effective synthesis of copper nanoparticles by extracts of non-edible and waste plant materials from Vaccinium species: Characterization and antimicrobial activity. Mat. Sci. Eng. C, **119**, 111453 (2021). https://doi.org/10.1016/j.msec.2020.111453
45. H. Horváthová, K. Lászlová, K. Dercová, Bioremediation vs. nanoremediation: degradation of polychlorinated biphenyls (PCBS) using integrated remediation approaches. Water, Air, Soil Pollut. **230**(8) (2019). https://doi.org/10.1007/s11270-019-4259-x
46. J. Xu, J. Sun, Y. Wang, J. Sheng, F. Wang, M. Sun, Application of iron magnetic nanoparticles in protein immobilization. Molecules **19**(8), 11465–11486 (2014). https://doi.org/10.3390/molecules190811465
47. X. Liu, L. Yang, H. Zhao, W. Wang,Pyrolytic production of zerovalent iron nanoparticles supported on rice husk- derived biochar: simple, in situ synthesis and use for remediation of Cr(VI)-polluted soils. Sci. Total Environ. **708**(xxxx), 134479 (2020). https://doi.org/10.1016/j.scitotenv.2019.134479
48. X. Wang, Z. Gai, B. Yu, J. Feng, C. Xu, Y. Yuan, Z. Lin, P. Xu, Degradation of carbazole by microbial cells immobilized in magnetic gellan gum gel beads. Appl. Environ. Microbiol. **73**(20), 6421–6428 (2007). https://doi.org/10.1128/AEM.01051-07
49. C. Jayaseelan, A.A. Rahuman, A.V. Kirthi, S. Marimuthu, T. Santhoshkumar, A. Bagavan, K. Gaurav, L. Karthik, K.V.B. Rao, Novel microbial route to synthesize ZnO nanoparticles using Aeromonas hydrophila and their activity against pathogenic bacteria and fungi. Spectrochimica Acta—Part A: Molecular Biomole. Spect. **90**, 78–84 (2012). https://doi.org/10.1016/j.saa.2012.01.006
50. J.T. Nurmi, P.G. Tratnyek, J.E. Amonette, K. Pecher, C. Wang, J.C. Linehan, D.W. Matson, R.L.E.E. Penn, M.D. Driessen, Characterization and properties of metallic iron nanoparticles : Spectroscopy, electrochemistry, and Kinetics, 1221–1230 (2005)
51. M.W. Amer, A.M. Awwad, Green synthesis of copper nanoparticles by Citrus limon fruits extract, characterization and antibacterial activity. Chem. Int. **7**(1), 1–8 (2021)
52. M. Jamzad, M. Kamari Bidkorpeh, Green synthesis of iron oxide nanoparticles by the aqueous extract of Laurus nobilis L. leaves and evaluation of the antimicrobial activity. J. Nanostruct. Chem. **10**(3), 193–201 (2020). https://doi.org/10.1007/s40097-020-00341-1
53. K. Araya-Castro, T.C. Chao, B. Durán-Vinet, C. Cisternas, G. Ciudad, O. Rubilar, Green synthesis of copper oxide nanoparticles using protein fractions from an aqueous extract of brown algae macrocystis pyrifera. Processes **9**(1), 1–10 (2021). https://doi.org/10.3390/pr9010078
54. M.A. Shamsuzzaman, H. Khanam, R.N. Aljawfi, Biological synthesis of ZnO nanoparticles using C. albicans and studying their catalytic performance in the synthesis of steroidal pyrazolines. Arab. J. Chem. **10**, S1530–S1536 (2020). https://doi.org/10.1016/j.arabjc.2013.05.004
55. H. Khatoon, J.P.N. Rai, Augmentation of Atrazine biodegradation by two Bacilli immobilized on α-Fe 2 O 3 magnetic nanoparticles OPEN. Sci. Rep. (2018). https://doi.org/10.1038/s41598-018-36296-1
56. M.K. Rajesh, K.S. Muralikrishna, S.S. Nair, B. Krishna Kumar, T.M. Subrahmanya, .K.P. Sonu, K. Subaharan, H. Sweta, T.S. Keshava Prasad, N. Chandran, K.B. Hebbar, A. Karun, Coconut inflorescence sap mediated synthesis of silver nanoparticles and its diverse antimicrobial properties. BioRxiv, 1–30 (2019). https://doi.org/10.1101/775940
57. O.M. Darwesh, I.A. Matter, M.F. Eida, Development of peroxidase enzyme immobilized magnetic nanoparticles for bioremediation of textile wastewater dye. J. Environ. Chem. Eng. **7**(1), 102805 (2019). https://doi.org/10.1016/j.jece.2018.11.049

58. C. Xiao, H. Li, Y. Zhao, X. Zhang, X. Wang, Green synthesis of iron nanoparticle by tea extract (polyphenols) and its selective removal of cationic dyes. J. Environ. Manage. **275**(August), 111262 (2020). https://doi.org/10.1016/j.jenvman.2020.111262
59. X. Zhang, L. Fan, Y. Cui, T. Cui, S. Chen, G. Ma, W. Hou, L. Wang, Green synthesis of gold nanoparticles using longan polysaccharide and their reduction of 4-nitrophenol and biological applications. Nano **15**(1) (2020). https://doi.org/10.1142/S1793292020500022
60. J. Sharma, Nanoremediation. Int. J. Life Sci. Technol. **12**(1), 1–6 (2019)
61. W. Yan, H.L. Lien, B.E. Koel, W.X. Zhang, Iron nanoparticles for environmental clean-up: recent developments and future outlook. Environ. Sci. Process. Impacts. **15**(1), 63–77 (2013)
62. C. Fajardo, S. Sánchez-fortún, G. Costa, M. Nande, P. Botías, J. García-cantalejo, G. Mengs, M. Martín, Science of the total environment evaluation of nanoremediation strategy in a Pb, Zn and Cd contaminated soil. Sci. Total Environ. **706**, 136041 (2020). https://doi.org/10.1016/j.scitotenv.2019.136041
63. P. Cao, K. Qiu, X. Zou, M. Lian, P. Liu, L. Niu, L. Yu, X. Li, Z. Zhang, Mercapto propyltrimethoxysilane- and ferrous sulfate-modified nano-silica for immobilization of lead and cadmium as well as arsenic in heavy metal- contaminated soil. Environ. Pollut. **266**, 115152 (2020). https://doi.org/10.1016/j.envpol.2020.115152
64. E. Akhayere, E.A. Essien, D. Kavaz, Effective and reusable nano-silica synthesized from barley and wheat grass for the removal of nickel from agricultural wastewater. Environ. Sci. Pollut. Res. **26**(25), 25802–25813 (2019). https://doi.org/10.1007/s11356-019-05759-x
65. T. Kathiraven, A. Sundaramanickam, N. Shanmugam, T. Balasubramanian, Green synthesis of silver nanoparticles using marine algae Caulerpa racemosa and their antibacterial activity against some human pathogens. Applied Nanoscience (Switzerland) **5**(4), 499–504 (2015). https://doi.org/10.1007/s13204-014-0341-2
66. H. Dong, Z. Jiang, C. Zhang, J. Deng, J., Hou, K., Cheng, Y., Zhang, L., G. Zeng, Removal of tetracycline by Fe/Ni bimetallic nanoparticles in aqueous solution. J. Colloid Inter. Science (Vol. 513) (2018). https://doi.org/10.1016/j.jcis.2017.11.021
67. M. Gil-díaz, J. Alonso, E. Rodríguez-valdés, J.R. Gallego, M.C. Lobo, Science of the Total Environment Comparing different commercial zero valent iron nanoparticles to immobilize As and Hg in brown field soil. Sci. Total Environ. (2017). https://doi.org/10.1016/j.scitotenv.2017.02.011
68. V. Bokare, K. Murugesan, J. Kim, E. Kim, Y. Chang, Science of the Total Environment Integrated hybrid treatment for the remediation of. Sci. Total Environ. **435–436**, 563–566 (2012). https://doi.org/10.1016/j.scitotenv.2012.07.079
69. W. Yan, H.L. Lien, B.E. Koel, W.X. Zhang, Iron nanoparticles for environmental clean-up: Recent developments and future outlook. Environmental Sci.: Processes Impact. **15**(1), 63–77 (2013). https://doi.org/10.1039/c2em30691c
70. A.D. Dwivedi, K. Gopal, Biosynthesis of silver and gold nanoparticles using Chenopodium album leaf extract. Colloids Surf., A **369**(1–3), 27–33 (2010). https://doi.org/10.1016/j.colsurfa.2010.07.020
71. S.A. Ansari, Q. Husain, Potential applications of enzymes immobilized on/in nano materials: A review. Biotechnology Adv. **30**(3), pp 512–523. Elsevier. https://doi.org/10.1016/j.biotechadv.2011.09.005
72. F.F. Yan, C. Wu, Y.Y. Cheng, Y.R. He, W.W. Li, H.Q. Yu, Carbon nanotubes promote Cr(VI) reduction by alginate-immobilized Shewanella oneidensis MR-1. Biochem. Eng. J. **77**, 183–189 (2013). https://doi.org/10.1016/j.bej.2013.06.009
73. N. Beheshtkhoo, M.A.J. Kouhbanani, A. Savardashtaki, A.M. Amani, S. Taghizadeh, Green synthesis of iron oxide nanoparticles by aqueous leaf extract of Daphne mezereum as a novel dye removing material. Appl. Phys. A Mater. Sci. Process. **124**(5), 0 (2018). https://doi.org/10.1007/s00339-018-1782-3
74. Q. Husain, Magnetic nanoparticles as a tool for the immobilization/stabilization of hydrolases and their applications: An overview. Biointerface Res. Appl. Chem. **6**(6), (2016)
75. K.S. Iliger, T.A. Sofi, N.A. Bhat, F.A. Ahanger, J.C. Sekhar, A.Z. Elhendi, A.A. Al-Huqail, F. Khan, Copper nanoparticles: Green synthesis and managing fruit rot disease of chilli caused

by Colletotrichum capsici. Saudi J. Biological Sciences **28**(2), 1477–1486 (2021). https://doi.org/10.1016/j.sjbs.2020.12.003
76. A. Tao, P. Sinsermsuksakul, P. Yang, Polyhedral silver nanocrystals with distinct scattering signatures. Angewandte Chemie - International Edition **45**(28), 4597–4601 (2006). https://doi.org/10.1002/anie.200601277
77. J. Qu, X. Yuan, X. Wang, P. Shao, Zinc accumulation and synthesis of ZnO nanoparticles using Physalis alkekengi L. Environ. Pollut. **159**(7), 1783–1788 (2011). https://doi.org/10.1016/j.envpol.2011.04.016
78. P. Srinivasan, T. Selvankumar, B.A. Paray, M.U. Rehman, S. Kamala-Kannan, M. Govarthanan, W. Kim, K. Selvam, Chlorpyrifos degradation efficiency of Bacillus sp. laccase immobilized on iron magnetic nanoparticles. 3 Biotech **10**(8), 1–11 (2020). https://doi.org/10.1007/s13205-020-02363-6
79. E. Bestawy, B.F. El-Shatby, A.S. Eltaweil, Integration between bacterial consortium and magnetite (Fe_3O_4) nanoparticles for the treatment of oily industrial wastewater. World J. Microbiology Biotechnology **36**(9) (2021). https://doi.org/10.1007/s11274-020-02915-1
80. V. Kumar, R. Chandra, Bioremediation of Melanoidins containing distillery waste for environmental safety. Bioremediation of Industrial Waste for Environmental Safety: Vol. I (2020). https://doi.org/10.1007/978-981-13-3426-9_20
81. D. Kratochvil, B. Volesky, Advances in the biosorption of heavy metals. Trends Biotechnol. **16**(7), 291–300 (1998). https://doi.org/10.1016/S0167-7799(98)01218-9
82. P. Chelkar, M. Shetty, E.J.E. Packiyam, P.R. Bhat, K. Jayadev, Decolorization of dye congo red by Aspergillus niger silver nanoparticles. J. Microbiology Biotech. Res. **4**(3), 373–383 (2014)
83. D. Huang, C. Wang, P. Xu, G. Zeng, B. Lu, International Biodeterioration & Biodegradation A coupled photocatalytic-biological process for phenol degradation in the Phanerochaete chrysosporium -oxalate-Fe 3 O 4 system. Int. Biodeterior. Biodegradation **97**, 115–123 (2015). https://doi.org/10.1016/j.ibiod.2014.11.001
84. K.V.G. Ravikumar, D. Kumar, G. Kumar, P. Mrudula, C. Natarajan, A. Mukherjee, Enhanced Cr(VI) Removal by Nanozerovalent Iron-Immobilized Alginate Beads in the Presence of a Biofilm in a Continuous-Flow Reactor. Ind. Eng. Chem. Res. **55**(20), 5973–5982 (2016). https://doi.org/10.1021/acs.iecr.6b01006
85. V. Bokare, K. Murugesan, Y.M. Kim, J.R. Jeon, E.J. Kim, Y.S. Chang, Degradation of triclosan by an integrated nano-bio redox process. Biores. Technol. **101**(16), 6354–6360 (2010). https://doi.org/10.1016/j.biortech.2010.03.062
86. D.L. Huang, C. Wang, P. Xu, G.M. Zeng, B.A. Lu, N.J. Li, C. Huang, C. Lai, M.H. Zhao, J.J. Xu, X.Y. Luo, A coupled photocatalytic-biological process for phenol degradation in the Phanerochaete chrysosporium-oxalate-Fe_3O_4 system. Int. Biodeterior. Biodegradation **97**, 115–123 (2015). https://doi.org/10.1016/j.ibiod.2014.11.001
87. W. De Windt, P. Aelterman, W. Verstraete, Bioreductive deposition of palladium (0) nanoparticles on Shewanella oneidensis with catalytic activity towards reductive dechlorination of polychlorinated biphenyls. Environ. Microbiol. **7**(3), 314–325 (2005). https://doi.org/10.1111/j.1462-2920.2004.00696.x
88. S. Argulwar, S.V. Sudakaran, M. Pulimi, N. Chandrasekaran, A. Mukherjee, Nano-bio sequential removal of hexavalent chromium using polymer-nZVI composite film and sulfate reducing bacteria under anaerobic condition. Environmental Tech. Inno. **9**, 122–133 (2018). https://doi.org/10.1016/j.eti.2017.11.006
89. J.C. Koenig, H.K. Boparai, M.J. Lee, D.M. O'Carroll, R.J. Barnes, M.J. Manefield, Particles and enzymes: Combining nanoscale zero valent iron and organochlorine respiring bacteria for the detoxification of chloroethane mixtures. J. Hazard. Mater. **308**, 106–112 (2016). https://doi.org/10.1016/j.jhazmat.2015.12.036
90. K.N. Thakkar, S.S. Mhatre, R.Y. Parikh, Biological synthesis of metallic nanoparticles. Nanomedicine: Nanotech. Biol. Med. **6**(2), 257–262. (2010) https://doi.org/10.1016/j.nano.2009.07.002

91. M. Sadat, M.A. Khalilzadeh, M. Mohseni, Biocatalysis and Agricultural Biotechnology Green synthesis of Ag nanoparticles from pomegranate seeds extract and synthesis of Ag-Starch nanocomposite and characterization of mechanical properties of the films. Biocatal. Agric. Biotechnol. **25**(March), 101569 (2020). https://doi.org/10.1016/j.bcab.2020.101569
92. F. Liang, J. Fan, Y. Guo, M. Fan, J. Wang, H. Yang, Reduction of nitrite by ultrasound-dispersed nanoscale zero-valent iron particles. Ind. Eng. Chem. Res. **47**(22), 8550–8554 (2008). https://doi.org/10.1021/ie8003946
93. G. Pei, Y. Zhu, J. Wen, Y. Pei, H. Li, Vinegar residue supported nanoscale zero-valent iron: Remediation of hexavalent chromium in soil. Environmental Pollut. **256**(xxxx), 113407 (2020). https://doi.org/10.1016/j.envpol.2019.113407
94. P. Xu, G. Ming, D. Lian, C. Ling, S. Hu, M. Hua, Science of the Total Environment Use of iron oxide nanomaterials in wastewater treatment: A review. Sci. Total Environ. **424**, 1–10 (2012). https://doi.org/10.1016/j.scitotenv.2012.02.023
95. Z. Xiu, J. Ming, Z. Hui, T. Li, S. Long, S. Mahendra, G.V. Lowry, P. Alvarez, Effects of nano-scale zero-valent iron particles on a mixed culture dechlorinating trichloroethylene. Bioresource Tech. **101**(4), 1141–1146 (2010). https://doi.org/10.1016/j.biortech.2009.09.057
96. R. Dinesh, M. Anandaraj, V. Srinivasan, S. Hamza, Geoderma engineered nanoparticles in the soil and their potential implications to microbial activity. Geoderma. **173–174**, 19–27 (2012). https://doi.org/10.1016/j.geoderma.2011.12.018
97. E.S. Murgueitio Herrera, Synthesis, characterization and application of iron nanoparticles, in the removal of HTPs in soils and waters of the province of Francisco de Orellana-Ecuador (2018)
98. H. Shu, M. Chang, H. Yu, W. Chen, Reduction of an azo dye Acid Black 24 solution using synthesized nanoscale zerovalent iron particles. **314**, 89–97 (2007). https://doi.org/10.1016/j.jcis.2007.04.071
99. R. Singh, N. Manickam, M.K.R. Mudiam, R.C. Murthy, V. Misra, An integrated (nano-bio) technique for degradation of γ-HCH contaminated soil. J. Hazard. Mater. **258–259**, 35–41 (2013). https://doi.org/10.1016/j.jhazmat.2013.04.016
100. C.C. Azubuike, C.B. Chikere, G.C. Okpokwasili, Bioremediation techniques–classification based on site of application: principles, advantages, limitations and prospects. World J. Microbiol. Biotechnol. **32**(11), 1–18 (2016). https://doi.org/10.1007/s11274-016-2137-x
101. N. Biotechnology, D. Agency, Nanotechnology: Review on emerging techniques in remediating water soil pollutions. **24**, 933–941 (2020)
102. X. Cao, A. Alabresm, Y.P. Chen, A.W. Decho, J. Lead, Improved metal remediation using a combined bacterial and nanoscience approach. Science Total Environ. **704**, 135378 (2020). https://doi.org/10.1016/j.scitotenv.2019.135378
103. A.K. Chauhan, N. Kataria, V.K. Garg, Green fabrication of ZnO nanoparticles using Eucalyptus spp. leaves extract and their application in wastewater remediation. Chemosphere **247**, 125803 (2020). https://doi.org/10.1016/j.chemosphere.2019.125803
104. I. Chung, A.A. Rahuman, S. Marimuthu, A.V. Kirthi, K. Anbarasan, P. Padmini, G. Rajakumar, Green synthesis of copper nanoparticles using eclipta prostrata leaves extract and their antioxidant and cytotoxic activities. Exp. Ther. Med. **14**(1), 18–24 (2017). https://doi.org/10.3892/etm.2017.4466
105. R.W. Gillham, *Advances in Groundwater Pollution Control and Remediation*, ed. M.M. Aral, 249–274. © 1996 Kluwer Academic Publishers. 249–250
106. S.P. Goutam, G. Saxena, D. Roy, A.K. Yadav, R.N. Bharagava, Green synthesis of nanoparticles and their applications in water and wastewater treatment. Bioremediation Indust. Waste Environ. Safety (Issue Dm) (2020). https://doi.org/10.1007/978-981-13-1891-7_16
107. P. Govindrao, N.W. Ghule, A. Haque, M.G. Kalaskar, Journal of Drug Delivery Science and Technology Metal nanoparticles synthesis : An overview on methods of preparation, advantages and disadvantages, and applications. J. Drug Delivery Sci. Tech. **53**(June), 101174 (2019). https://doi.org/10.1016/j.jddst.2019.101174
108. S.J. Huang, M. Liao, D.H. Chen, Direct binding and characterization of lipase onto magnetic nanoparticles. Biotechnology Prog. **19**(3), 1095–1100 (2003). https://doi.org/10.1021/bp025587v

109. M.I. Husseiny, M.A. El-Aziz, Y. Badr, M.A. Mahmoud, Biosynthesis of gold nanoparticles using Pseudomonas aeruginosa. Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy **67**(3–4), 1003–1006 (2007). https://doi.org/10.1016/j.saa.2006.09.028
110. J.H. Jo, P. Singh, Y.J. Kim, C. Wang, R. Mathiyalagan, C.G. Jin, D.C. Yang, Pseudomonas deceptionensis DC5-mediated synthesis of extracellular silver nanoparticles. Artificial Cells, Nanomedicine Biotech. **44**(6), 1576–1581 (2016). https://doi.org/10.3109/21691401.2015.1068792
111. A. Karthick, B. Roy, P. Chattopadhyay, Comparison of zero-valent iron and iron oxide nanoparticle stabilized alkyl polyglucoside phosphate foams for remediation of diesel-contaminated soils. J. Environ. Manage. **240**(March), 93–107 (2019). https://doi.org/10.1016/j.jenvman.2019.03.088
112. L. Karthik, G. Kumar, A.V. Kirthi, A.A. Rahuman, K.V. Bhaskara Rao, Streptomyces sp. LK3 mediated synthesis of silver nanoparticles and its biomedical application. Bioprocess Biosyst. Eng. 37(2), 261–267 (2014). https://doi.org/10.1007/s00449-013-0994-3
113. Y. Kim, K. Murugesan, Y. Chang, E. Kim, Y. Chang, Degradation of polybrominated diphenyl ethers by a sequential treatment with nanoscale zero valent iron and aerobic biodegradation, June, 216–224 (2011). https://doi.org/10.1002/jctb.2699
114. S. Nayak, S.P. Sajankila, C.V. Rao, Green synthesis of gold nanoparticles from banana pith extract and its evaluation of antibacterial activity and catalytic reduction of Malachite green dye. J. Microbiol. Biotech. Food Sci. **7**(6), 641–645 (2018). https://doi.org/10.15414/jmbfs.2018.7.6.641-645
115. S. Pai, S.M. Kini, M.K. Narasimhan, A. Pugazhendhi, R. Selvaraj, Structural characterization and adsorptive ability of green synthesized Fe3O4 nanoparticles to remove Acid blue 113 dye. Surfaces Interf. **23**, 100947 (2020). https://doi.org/10.1016/j.surfin.2021.100947
116. K.M. Rajesh, B. Ajitha, Y.A.K. Reddy, Y. Suneetha, P.S. Reddy, Assisted green synthesis of copper nanoparticles using Syzygium aromaticum bud extract: Physical, optical and antimicrobial properties. Optik **154**, 593–600 (2018). https://doi.org/10.1016/j.ijleo.2017.10.074
117. R. Seif El-Nasr, S.M. Abdelbasir, A.H. Kamel, S.S.M. Hassan, Environmentally friendly synthesis of copper nanoparticles from waste printed circuit boards. Sep. Purif. Tech. **230**(June), 115860 (2019). https://doi.org/10.1016/j.seppur.2019.115860
118. B. Sharma, D.D. Purkayastha, S. Hazra, M. Thajamanbi, C.R. Bhattacharjee, N.N. Ghosh, J. Rout, Biosynthesis of fluorescent gold nanoparticles using an edible freshwater red alga, Lemanea fluviatilis (L.) C.Ag. and antioxidant activity of biomatrix loaded nanoparticles. Bioprocess Biosyst. Eng. **37**(12), 2559–2565 (2014). https://doi.org/10.1007/s00449-014-1233-2
119. A. Sherry Davis, P. Prakash, K. Thamaraiselvi, Nanobioremediation technologies for sustainable environment. Environ. Sci. Eng. (Subseries: Environmental Science), 9783319484389, 13–33 (2017). https://doi.org/10.1007/978-3-319-48439-6_2
120. R. Singh, M. Behera, S. Kumar, Nano-bioremediation: an innovative remediation technology for treatment and management of contaminated sites bioremediation of industrial waste for environmental safety, 165–182 (2020). https://doi.org/10.1007/978-981-13-3426-9_7
121. C. Sun, S. Kr Karn, A. Almeida, L. Yang, S. He, L. Zhong, J. Duan, Y. Feng, B. Yang, Bioremediation of wastewater by iron oxide-biochar nanocomposites loaded with photosynthetic bacteria. Front. Microbiol **8**, 823 (2017). https://doi.org/10.3389/fmicb.2017.00823
122. P. Yuan, M. Fan, D. Yang, H. He, D. Liu, A. Yuan, J.X. Zhu, T.H. Chen, Montmorillonite-supported magnetite nanoparticles for the removal of hexavalent chromium [Cr(VI)] from aqueous solutions. J. Hazardous Mat. **166**(2–3), 821–829 (2009). https://doi.org/10.1016/j.jhazmat.2008.11.083
123. E. Zare, S. Pourseyedi, M. Khatami, E. Darezereshki, Simple biosynthesis of zinc oxide nanoparticles using nature's source, and it's in vitro bio-activity. J. Mol. Struct. **1146**, 96–103 (2017). https://doi.org/10.1016/j.molstruc.2017.05.118
124. F. Zhu, S. Ma, T. Liu, X. Deng, Green synthesis of nano zero-valent iron/Cu by green tea to remove hexavalent chromium from groundwater. J. Clean. Prod. **174**, 184–190 (2018). https://doi.org/10.1016/j.jclepro.2017.10.302

Effect of Hydrogen Sulfide on Microbial Methane Oxidation in Biochar-Amended Soil

Jyoti K. Chetri and Krishna R. Reddy

1 Introduction

Municipal solid waste landfills are source to odiferous compounds such as hydrogen sulfide (H_2S) apart from greenhouse gases like methane (CH_4) and carbon dioxide (CO_2). Hydrogen sulfide is a major odor causing component of landfill gas (LFG). Hydrogen sulfide is a colorless gas with characteristic smell of rotten egg at very low concentrations [1]. Hydrogen sulfide has very low odor threshold (0.01–1.5 ppm). At higher concentrations, H_2S exposure can cause detrimental health effects. Apart from health effects, H_2S sulfide causes corrosion of equipment and infrastructure [2]. Odor pollution is the one of the biggest concerns of landfill operators as it affects the quality of life of people residing around landfill.

In the recent years, bio-based cover systems have been explored extensively to mitigate landfill CH_4 emissions [3–5]. Landfill cover soils are enriched in CH_4 oxidizing microorganisms called methanotrophs due to their continuous exposure to methane emanating from the waste. Methanotrophs oxidize CH_4 in the presence of oxygen and release CO_2 and water [6]. Organic amendment to landfill cover soil helps to enhance the microbial CH_4 oxidation efficiency by creating favorable environment for microbial growth and sustenance. More recently, biochar-based biocovers have gained prominence owing to the unique characteristics of biochar such as high moisture retention, high intrinsic porosity and gas adsorption [6]. Biochar-amended soil has shown promising potential to mitigate landfill CH_4, however, the effect of other trace gases such as H_2S on the CH_4 oxidation potential is not well understood. The optimal pH for methanotrophic methane oxidation is found to be in the range of 7–7.6

J. K. Chetri (✉) · K. R. Reddy
University of Illinois at Chicago, Chicago, IL 60607, USA
e-mail: jkc4@uic.edu

K. R. Reddy
e-mail: kreddy@uic.edu

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_3

in the landfill cover soil [7]. Studies in the past have reported an inhibitory effect of H_2S on the methanotrophic CH_4 oxidation in landfill cover soil [8]. However, the effect of H_2S on CH_4 oxidation in biochar-amended soil is not known.

In this study, a biogeochemical cover consisting of biochar-amended soil overlying steel slag was evaluated for its potential to mitigate CH_4, CO_2 and H_2S significantly through large-scale column test. Biochar-amended soil can mitigate CH_4 through microbial CH_4 oxidation and steel slag can mitigate CO_2 and H_2S through geochemical reactions with the minerals and oxides present in the steel slag. The main aim of this study is to investigate: (1) effect of H_2S on the microbial CH_4 oxidation in the biochar-amended soil; and (2) effect of steel slag on the microbial community in the biochar-amended soil.

2 Materials and Methods

2.1 Materials

The simulated biogeochemical cover profile consisted of a sand gas distribution layer (GDL), a 10% by weight biochar-amended soil layer, basic oxygen furnace (BOF) still slag layer and a topsoil layer. Ottawa (20/40) sand (US Silica, IL, USA) was used for the GDL. Landfill cover soil and topsoil were obtained from Zion landfill, Zion, IL, USA. Pinewood biochar was obtained from commercial vendor (Chip Energy, Goodfield, IL, USA). BOF slag was obtained from Indiana Harbor East Steel Mill, East Chicago, IN, USA.

2.2 Methods

Material characterization. The cover materials were characterized for their physical, chemical and geotechnical properties which are summarized in Table 1. The hydraulic conductivity of 10% biochar-amended soil was determined by preparing cylindrical sample at similar density placed in the test column using flexible wall permeameter as per ASTM D5084.

Column setup. The cover profile was set up in a plexiglass column 100 mm height and 18.25 mm diameter. A 10 cm thick dry sand layer was loosely placed at the bottom of the column as GDL. A 45 cm thick 10% by weight biochar-amended soil layer was placed over the GDL to serve as a CH_4 capture layer or biologic layer. Prior to placing in the column, the air-dried pulverized landfill cover soil was mixed with 10% by weight of biochar. The soil biochar mixture was adjusted to 15% (by weight) of moisture content. About 15% moisture content was chosen based on the previous studies which showed optimum moisture for CH_4 oxidation to be in the similar range

[9]. The layer was placed in 5 cm lifts with light compaction with a tamping rod (3.1 kg). The bulk density of the biochar-amended soil layer was 1.38 g/cm^3. Over the biochar-amended soil layer, a 30 cm thick layer of BOF slag adjusted to moisture content of 10% was added in 5 cm lifts with light compaction. The placement density of BOF slag was 1.80 g/cm^3. A 5 cm thick topsoil layer adjusted to moisture content of 15% was added above the BOF slag layer at a bulk density of 1.56 g/cm^3. Each layer was separated with a 6 oz (~170 g) needle punched geotextile fabric (EPI, The Liner Company, Traverse City, MI).

A synthetic LFG made of 48.25% CH_4, 50% CO_2 and 1.75% H_2S was passed through the bottom of the column into the GDL. The inflow rate was controlled with the flowmeter. Atmospheric air after passing through a water column was supplied into the top of the column. The gas sampling ports were provided along the depth of the column at an interval of 10 cm in the bottom 50 cm and 5 cm interval in the top 50 cm of the column. A sampling port was provided at the top cap of the column to monitor the headspace gas concentration. The inflow gas flux varied from 50 to 150 $gCH_4\ m^{-2}day^{-1}$ during the column operation. The gas samples were withdrawn from the sampling ports at regular intervals (2−3 times a week) and analyzed using a gas chromatograph equipped with thermal conductivity detector (TCD) and flame ionization detector/flame photometric detector (FID/FPD) for the detection of CH_4, CO_2, H_2S and O_2.

Table 1 Properties of biogeochemical cover components

Properties	ASTM method	Sand	Landfill cover soil	BOF slag	Topsoil
Specific gravity	D854	2.66	2.65	3.34	2.59
Organic content (%)	D2974	0.3	4.9	1.94	3.6
Grain size distribution					
Gravel (%)		0.0	0.0	0	0.2
Sand (%)		100	35.4	86.4	18.1
Fines (%)	D6913/6	0.0	64.6	13.6	81.7
D_{50} (mm)	913M	0.6	0.023	0.82	0.018
C_c		0.91	–	29.17	–
C_u		1.36	–	0.72	–
Hydraulic conductivity (cm/s) @dry density		1.4×10^{-2}@1.6 g cm^{-3}	ND	2.6×10^{-3}@1.7 g cm^{-3}	1.8×10^{-7}@1.30 g cm^{-3}
pH	D4972	6.7	8.0	12.4	7.7
Carbonate content ($CaCo_3$, %)	D4373	2.15	13.60	3.79	3.67

Column operation. The simulated cover profile was pre-acclimated with 1000 ppm CH_4, 99.99% N_2 under low CH_4 flux (0.2 $gCH_4\ m^{-2}\ day^{-1}$) during Phase I to allow microbes to adjust to the column conditions. The gas flow was switched to 48.25% CH_4, 50% CO_2 and 1.75% H_2S at flux rate of 50 $gCH_4\ m^{-2}\ day^{-1}$ after 17 days in Phase II when the biochar-amended soil layer showed consistently high production of CO_2 and consumption of CH_4. Phase II was operated for 25 days until quasi-static flow conditions were achieved within the columns. Following Phase II, the gas flow rate was increased to 150 $gCH_4\ m^{-2}\ day^{-1}$ in Phase III and operated for 58 days. During Phase III, rainfall event was simulated on day 20th of Phase III by adding 340 mL of water to the top of the column to simulate ½ inch rainfall. In Phase IV, the gas flux was lowered to 50 $gCH_4\ m^{-2}\ day^{-1}$ to analyze if the CH_4 oxidation conditions could be restored to Phase II level.

Column exhumation. Column experiment was terminated after 176 days of LFG exposure under different flux rates. The column samples were exhumed from various depths. The biochar-amended soil was exhumed from various depths and analyzed for moisture content, pH, organic content, carbonate content and carbon/sulfur content. The samples were also analyzed for microbial characterization using 16S rRNA gene amplicon sequencing following procedures explained in Chetri et al. [5]. The exhumed biochar-amended soil samples were also subjected to batch testing following procedures explained in Chetri et al. [5] to evaluate the CH_4 oxidation rates of the biochar-amended soils at various depths.

3 Results and Discussions

3.1 Gas Concentration Profiles

The quasi-steady state average gas concentration profiles of CH_4, CO_2 and O_2 along the depth of the column during Phase II to Phase IV are shown in Fig. 1a–c, respectively. H_2S is not shown as it was not detected in the gas sampling ports and was completely absorbed in the lowermost part of the biochar-amended soil layer. Figure 1a shows average concentrations of CH_4 along the depth of the column. Biochar-amended soil showed significant reduction of CH_4 concentration during Phase II and Phase IV (Fig. 1a) due to CH_4 oxidation, whereas CH_4 removal efficiency reduced during Phase III (high flux) which could be attributed to the lower retention time under high CH_4 flux rate. Studies in the past also had similar observation [4].

In contrary, the CO_2 concentrations remained higher than the CH_4 concentration throughout Phase II to Phase IV in the biochar-amended soil layer (Figure 1b) which is due to the production of CO_2 during CH_4 oxidation. During Phase II, BOF slag layer overlying biochar-amended soil layer sequestered all the CO_2 resulting in zero emissions into the headspace. During Phase III, the CO_2 removal efficiency in the BOF slag layer reduced which could be attributed to the high flux rate. The CO_2 removal efficiency of the BOF slag reduced gradually and in Phase IV, high amount

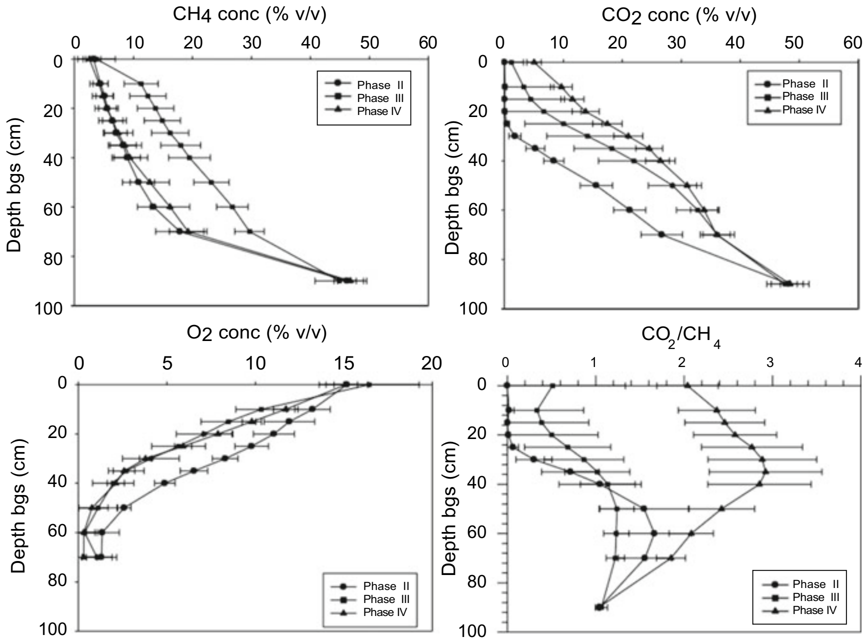


Fig. 1 Average quasi-static gas concentration profiles along the depth of the column: **a** CH_4, **b** CO_2 and **c** O_2; and **d** average CO_2/CH_4 ration along the depth during Phase II (50 gCH_4 m^{-2} day^{-1}), III (150 gCH_4 m^{-2} day^{-1}) and IV (50 gCH_4 m^{-2} day^{-1}). The columns were preincubated for 17 days with 1000 ppm CH_4 gas balanced in nitrogen for acclimation as Phase I

of CO_2 was released into the headspace. It shows that the BOF slag underwent breakthrough in Phase III due to reaction of the readily available calcium minerals such as lime (CaO) and portlandite [Ca(OH)2] with CO_2 [10]. Overall, the BOF slag showed CO_2 sequestration for an extended period suggesting high CO_2 removal capacity of the slag. Figure 1c shows concentration of O_2 along the depth. The O_2 penetrated the deeper layers affirming aeration of the biochar-amended soil layer. However, the O_2 concentrations in the biochar-amended soil layers were significantly reduced which could be attributed to the high microbial CH_4 oxidation rates. Figure 1d shows average ratio of CO_2/CH_4 along the depth during Phase II to IV. The inlet CO_2/CH_4 ratio was 1.04. The ratios within the biochar-amended soil layer remained greater than the inlet ratio which is a confirmation that CH_4 oxidation was occurring within the system. The CO_2/CH_4 ratios were significantly higher in the biochar-amended soil layer during Phase II and Phase IV, whereas it was significantly lower during Phase III which again affirms that the CH_4 oxidation efficiency reduces under high gas flux rates. The CO_2/CH_4 ratio became zero in the BOF slag layer during Phase II which is attributed to the complete sequestration of CO_2 in the BOF slag layer. The CO_2/CH_4 ratio gradually increased in Phase III and was highest in Phase IV which is attributed to the reduction in the CO_2 sequestration capacity of the BOF slag.

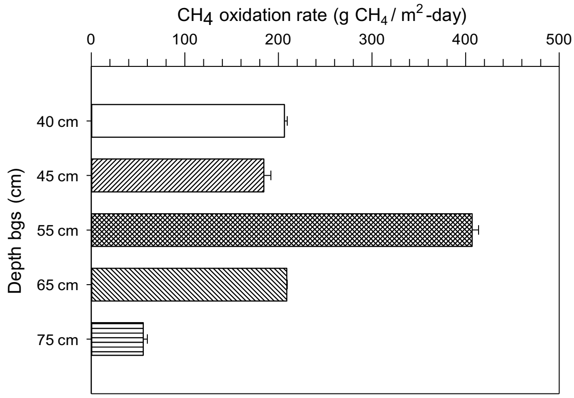


Fig. 2 Methane oxidation rates of the column exhumed biochar-amended soil at select depths

3.2 Methane Oxidation Rates

Methane oxidation rates along the depth of the biochar-amended soil layer quantified based on the batch incubation experiments are shown in Figure 2. The CH_4 oxidationrates were in the range of 180–400 gCH_4 m^{-2} day^{-1}. The average CH_4 oxidation rate was 200 gCH_4 m^{-2} day^{-1} which is in the range reported by previous studies [11]. The maximum CH_4 oxidation rate (400 gCH_4 m^{-2} day^{-1}) was obtained at 55 cm bgs (or 20 cm below top of biochar-amended soil layer) which is consistent with observation reported by past studies [6, 11, 12] and could be attributed to the optimum combination of CH_4 and O_2 at the middle of the layer. The CH_4 oxidation rate at the bottommost part of the biochar-amended layer (75 cm bgs) was 7.4 times lower than the maximum CH_4 oxidation and 3.6 times lower than that of the average oxidation. H_2S was completely absorbed at this depth which could be the reason for significantly lower CH_4 oxidation rate. Lee et al. (2015) reported an inhibitory effect of H_2S on CH_4 oxidation. However, it is interesting to note that the effect of H_2S was only observed at the bottommost part of the column, while the upper strata was able to remove CH_4 significantly.

3.3 Microbial Community Distribution

Microbial community distribution at various depths of biochar-amended soil layer is shown in Fig. 3. The microbial community was dominated with methylotrophs accounting for 35–50% of the total bacterial sequences. Around 98% of the methylotrophs were methanotrophs at all the depths. This shows that the biochar-amended soil created favorable environment for the methanotrophic growth despite exposure to H_2S. The relative abundance of methylotrophs is positively correlated with the methane oxidation rates. The lowest relative abundance of methylotrophs was

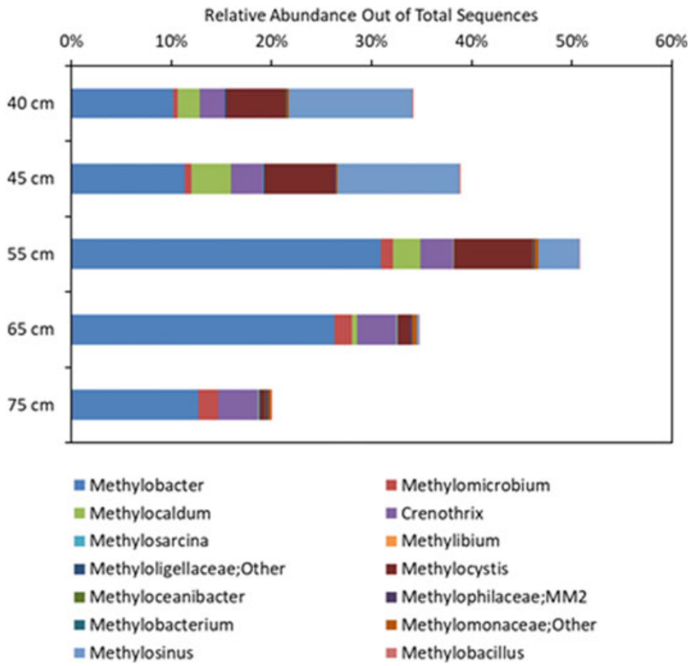


Fig. 3 Relative abundance of methylotrophs put of total 16S rRNA bacterial sequences in biochar-amended soil layer

observed at the bottommost part (75 cm bgs) which is consistent with the CH_4 oxidation rates. Major methanotrophic groups detected in the both the column samples included both Type I such as *Methylobacter*, *Methylomicrobium*, *Crenothrix*, *Methylocaldum*, *Methylosarcina* and Type II such as *Methylocystis* and *Methylosinus*. Apart from methylotrophic communities, some known sulfur oxidizing bacterial (SOB) communities such as *Thiobacillus* were detected, however, their abundance was $< 1\%$. Trace sulfur/sulfate reducing bacteria (SRB) ($<1\%$) such as *Desulfosporosinus*, *Desulfotomaculum*, *Desulfatitalea* and *Desulfocapsa* [13–15] was found in the biochar-amended soil mainly in the bottom 65–75 cm depth. The presence of trace amount of SOB and SRB signals that H_2S was not removed through biologic activity but rather through abiotic reaction mechanisms.

3.4 Terminal Material Properties

A slight increase in the moisture content from the initial 15% was observed along the depth of the biochar-amended soil layer. It could be due to the water produced during CH_4 oxidation process. Biochar-amended soil did not undergo any drying which is normally encountered in landfill cover soils (Table 2).

Table 2 Properties of the biochar-amended soil exhumed from the column

Depth (cm)	MC (%)	OC (%)	pH	Sulfur (%)
40	16.7	11.6	7.6	
45	17.6	12.1	7.7	0.114
55	17.0	11.2	7.7	0.1132
65	16.3	12.4	7.5	0.1049
75	15.1	7.5	7.25	0.6604

Note MC = Moisture content; OC = Organic content

The organic content remained nearly similar to the initial value of 13% except at the bottommost part (75 cm bgs). The lowest organic content at the bottommost part could be due to heterogeneity in the sample or could be associated with the H_2S removal at this depth which needs to be investigated further. The pH of the biochar-amended soil remained near neutral. Studies in the past have shown reduction of pH of the soil due to the oxidation of H_2S [2, 16] which was not observed in this study. This further suggests that the removal mechanism of H_2S was other than biodegradation. The sulfur content was highest at 75 cm bgs which is consistent with the H_2S removal. It means H_2S was absorbed in the bottommost part minimizing exposure of H_2S in upper layers.

4 Conclusion

Large-scale column test was performed simulating biogeochemical cover profile which consisted of 10% biochar-amended soil overlain by BOF steel slag. The cover profile was exposed to synthetic LFG comprising of 48.25 % CH_4, 50% CO_2 and 1.75% H_2S under varying CH_4 flux of 50–150 $gCH_4\ m^{-2}\ day^{-1}$. The biogeochemical cover showed significant potential to remove CH_4, CO_2 and H_2S. Biochar-amended soil showed significant CH_4 oxidation potential. Maximum CH_4 oxidation rate was observed at the middle of the biochar-amended soil layer. The lowest CH_4 oxidation rate was observed at the bottommost part of the biochar-amended soil layer, where most of the H_2S was observed signaling the inhibitory effect of H_2S on the CH_4 oxidation. The relative abundance of methylotrophs ranged from 30 to 50% with highest at the middle of the biochar-amended layer consistent with the CH_4 oxidation rate. The lowest methylotrophic relative abundance was observed at the bottommost part (75 cm bgs) consistent with the CH_4 oxidation rate. The bottommost part of biochar-amended soil layer which showed complete removal of H_2S also showed significantly higher sulfur content which suggests that sulfur precipitation was one of the H_2S removal mechanisms. Although biochar-amended soil was exposed to H_2S, it was dominated with methane oxidizing methanotrophs. It suggests that biochar amendment helps to reduce the harmful effects of H_2S in methane oxidation.

References

1. OSHA (Occupational Safety and Health Administration). Homepage, https://www.osha.gov/hydrogen-sulfide, last accessed 2021/9/24
2. H. Duan, L.C.C. Koe, R. Yan, Treatment of H_2S using a horizontal biotrickling filter based on biological activated carbon: reactor setup and performance evaluation. Appl. Microbiol. Biotech. **67**(1), 143–149 (2005)
3. B.Y. Sadasivam, K.R. Reddy, Landfill methane oxidation in soil and bio-based cover systems: a review. Rev. Environ. Sci. and Bio/Tech. **13**(1), 79–107 (2014)
4. E.N. Yargicoglu, K.R. Reddy, Biochar-amended soil cover for microbial methane oxidation: Effect of biochar amendment ratio and cover profile. J. Geotech. Geoenviron. Eng. **144**(3), 04017123 (2018)
5. J.K. Chetri, K.R. Reddy, J.S. Green, Methane oxidation and microbial community dynamics in activated biochar amended landfill soil cover. J. Environ. Eng. (2021) (under review)
6. E.N. Yargicoglu, K.R. Reddy, Microbial abundance and activity in biochar-amended landfill cover soils: evidence from large-scale column and field experiments. J. Environ. Eng. **143**(9), 04017058 (2017)
7. K.R. Reddy, R.K. Rai, S.J. Green, J.K. Chetri, Effect of pH on methane oxidation and community composition in landfill cover soil. J. Environ. Eng. **146**(6), 04020037 (2020)
8. E.H. Lee, K.E. Moon, T.G. Kim, S.D. Lee, K.S. Cho, Inhibitory effects of sulfur compounds on methane oxidation by a methane-oxidizing consortium. J. Biosci. Bioeng. **120**(6), 670–676 (2015)
9. J.K. Chetri, K.R. Reddy, in *Climate-resilient biogeochemical cover for waste containment systems*. Proceedings of Geo-Extreme, ASCE, Savannah, Georgia (accepted) (2021)
10. J.K. Chetri, K.R. Reddy, D.G. Grubb, Carbon-dioxide and hydrogen-sulfide removal from simulated landfill gas using steel slag. J. Environ. Eng. **146**(12), 04020139 (2020)
11. E.N. Yargicoglu, K.R. Reddy, Effects of biochar and wood pellets amendments added to landfill cover soil on microbial methane oxidation: A laboratory column study. J. Environ. Manag. **193**, 19–31 (2017)
12. A. De Visscher, D. Thomas, P. Boeckx, O. Van Cleemput, Methane oxidation in simulated landfill cover soil environments. Environ. Sci. Tech. **33**(11), 1854–1859 (1999)
13. S. Ramamoorthy, H. Sass, H. Langner, P. Schumann, R.M. Kroppenstedt, S. Spring, J. Overmann, R.F. Rosenzweig, Desulfosporosinus lacus sp. nov., a sulfate-reducing bacterium isolated from pristine freshwater lake sediments. Int. J. Syst. Evol. Microbiol. **56**(12), 2729–2736 (2006)
14. F. Widdel, F. Back, The genus Desulfotomaculum. The prokaryotes **4**, 787–794 (2006)
15. Y. Higashioka, H. Kojima, M. Watanabe, M. Fukui, Desulfatitalea tepidiphila gen. nov., sp. nov., a sulfate-reducing bacterium isolated from tidal flat sediment. Int. J. Syst. Evol. Microbiol. **63**(Pt_2), 761–765 (2013)
16. H. Duan, R. Yan, L.C.C. Koe, X. Wang, Combined effect of adsorption and biodegradation of biological activated carbon on H_2S biotrickling filtration. Chemosphere **66**(9), 1684–1691 (2007)

Effects of Open Dumping of Municipal Solid Waste on Surrounding Soil Characteristics: A Review

Vishal Pastapure, Davinder Singh, and Sanjeev Kumar

Terminology

MSW	Municipal solid waste
TPD	Tones per day
SEM	Scanning electron microscopy
EDS	Energy-dispersive X-ray spectroscopy
COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
NHn-N	Ammoniacal nitrogen
MDD	Maximum dry density
OMC	Optimum moisture content
RDF	Refuse-derived fuel
LL	Liquid limit
Φ	Angle of internal friction
HM	Heavy metals
Cl	Chlorine
Cd	Cadmium
Cr	Chromium
Mn	Manganese
Zn	Zinc
Fe	Iron
Ni	Nickel
Pb	Lead
C	Cohesion
Gs	Specific gravity

V. Pastapure (✉) · D. Singh · S. Kumar
Dr B. R. Ambedkar National Institute of Technology, Jalandhar 144011, India
e-mail: vishalravinderp@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_4

PL Plastic limit
PI Plasticity index

1 Introduction

Open dumping of MSW at landfill sites is the most common practice in most of the countries. In developing countries like India, there is an increase in generation of MSW due to rapid growth in industrialization. The per capita generation of MSW in India is 100–500 g in small and large towns, respectively, and among this waste, only, 13–20% of content is recyclable [1]. As of 2020, the urban area of India has generated 147,613 tons of MSW. Only, 75–80% of the total MSW gets collected in which more than 80% of waste is dumped in dump sites without any scientific consideration, which will lead to public health and environmental degradation [2]. The increase in MSW generation is around 5% annually [3–5].The per capita generation of MSW in upcoming years has been estimated as shown in Table 1.

Due to inadequate data on volume of generation, collection, transportation, and disposal of solid waste, there is no proper management of MSW. For the existing system in India, the efficiency of management of MSW is less than 40% [6]. It is a common practice to dispose of MSW in low-lying areas without taking any measures or maintaining any operational controls, which is the major cause of soil and groundwater contamination [7]. Due to chemical, biological, and physical changes in MSW, a by-product will be formed known as leachate, which is absorbed into soil strata and aquifers. Transportation of heavy metals into humans and animals is shown in Fig. 1. Leachate can contain a significant amount of organic matter, metals, and salts [8–10]. Due to attribution between leachate chemicals and soil particles, the effect of leachate on altering soil characteristics decreases with increase in depth [11]. It has been reported that leachate causes an increase in biological activity and loss of vegetation due to heavy metal contamination thus destroying further ecology of the region [12]. The open dumping sites or landfills which are not properly designed or constructed become a point of source for soil, ground, and surface waters. This paper presents a review on geotechnical properties of soil contaminated by open dumping. The geochemical analysis in these studies was done by energy-dispersive X-ray spectroscopy (EDS) and scanning electron microscopy

Table 1 India's estimated waste generation rate for the projected years (CPCB, 2000)

No	Year	Per capita waste generated (Kg/d)	Waste generated (TPD)
1	2011	0.356	127,458.10
2	2021	0.406	177,281.07
3	2031	0.463	239,240 0.00
4	2041	0.529	313,839.90

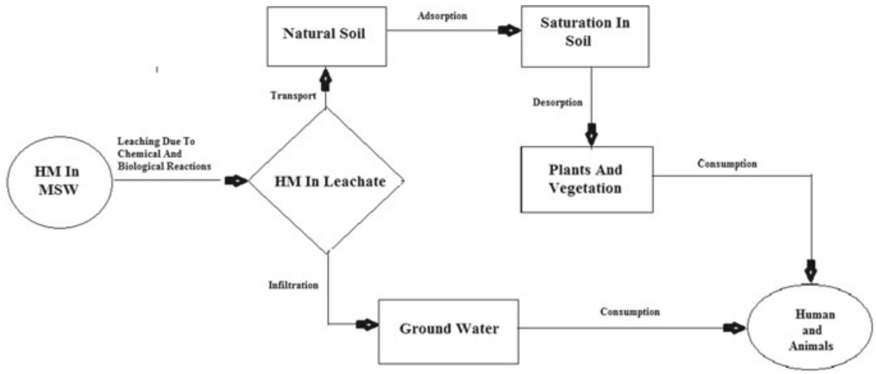


Fig. 1 Flowchart for transportation of heavy metals in to animals and humans [28]

(SEM) to get the idea of element composition. The leachate characteristics such as organic matter (BOD), inorganic matter (COD), and heavy metals are also the reason for change in soil properties. The mechanical properties of contaminated soil were also altered to support sustainable construction and destroy ecological balance in the area.

2 MSW Composition

The constituents in MSW vary with location due change in local area economy, standards of residents, and availability of commodities. The materials like paper, glass, plastic, metals, and organic waste are common compositions of MSW [5, 13, 14]. The MSW contains hazardous waste like batteries, pesticides, and medical waste, and the organic waste includes vegetable, fruits, and food waste. The biomedical waste should never be incorporated into MSW as in guidance with biomedical waste management and handling rules 1998 and revised in 2003 [15, 16]. The MSW management site numbers are presented in Table 2. The typical constituents in MSW in urban areas are by weight 41% organic waste, 40% inert waste, and remaining 19% is recyclable waste.

3 Leachate Characteristics

When the water percolates through any solid waste dumping site, it will carry the by-products formed by chemical and biological activity the leachate will be formed. Due to its higher concentrations in toxic and metallic constituents, it causes all types of nuisances in the area. In absence of barriers, this leachate makes its way toward soil, subsurface, and surface waters [17]. The heavy metals (Cl, Cd, Cr, Cu, Fe,

Table 2 MSW management sites in India (Census 2011)

Parameters	Data
Population density	382/person/km^2
Door to door collection	18 states
Waste segregation at sources	5 states
Untechnical sites constructed numbers Compost (vermicomposting) facilities	1285 numbers
At dump site	95
Operating pipe composting sites	7000
Operating RDFs sites	12
Biogas plants in operation	645
Energy generation plants	11 (only 6 are operational)

Mn, Ni, Pb, Zn, etc.) carried in to surrounding soil. The COD, BOD5, ammoniacal nitrogen (NHn- N), and chlorides values are more in pre-monsoon than in post-monsoon [18–20]. Table 3 represents the constituents of leachate from different dump locations. Leachate can be found in dump sites as biodegradable–dissolvable, non-biodegradable–dissolvable, and non-biodegradable–non-dissolvable leachate [21].

4 Change in Soil Characteristics

When the organic matter from MSW open dump site or the formed leachate travels/infiltrates through near-by soil, its properties start to change [3]. The variation in geotechnical properties is found to greater with variation in leachate characteristics [12]. The physiochemical analysis on contaminated soils shows increased organic matter which in turn reducing specific gravity of soil [26]. Soil samples collected at different depth on the basis of level of infiltration of leachate. Heavy metal contamination from leachate is also observed at site where open dumping is practiced for more than 10 years [26]. Data on soil properties and its parameters are given in Table 4. Test on other engineering properties such as swell index, compressibility, and consolidation settlement indicates increment in values for contaminated soil compared to virgin one [27].

5 Conclusion

The dumping of MSW without any precautionary measures is hazardous to the surrounding environment as well as soil. At shallow depths, the properties of soil are altered more in the deeper layer which shows a direct relationship with leachate

Table 3 Characteristic data on leachate produced by MSW dump sites (All values in ppm)

COD	BOD5	NH-N	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	pH	Author	Comments
13,1650.5	3385 1	143 2.0	0.2 1	1.0 7	1.0 6	67.5	10.2	0.74	0.95	4.21	7.21		At 0.5 m depth
7932.4	1326.5	1553.1	–	–	0.26	0.18	18	0.56	0.42	0.72	7.56	[18]	After 10 years
16,160	20,880	–	–	–	2.92	–	–	–	0.14	9.8	6.56		Pre-monsoon
7093	2428	204	–	–	0.65	–	–	–	0.03	3.9	6.56	[19]	Post-monsoon
18,184	–	–	0	0.32	0.35	13.2	0.59	1.02	0.46	4.22	7.42		Hyderabad
14,490	–	–	0.12	0.97	1.56	49.4	0.52	2.36	1.56	2.34	8.25	[22]	Delhi Ghazipur
16,240	–	2824	0.54	–	3.11	–	42.5	–	0.43	8.99	–		Pre-Monsoon
7650	–	2055	0.02	–	0.88	–	37	–	0.28	4.52	–	[20]	Post-Monsoon
–	3250	1038	4820	0.05	–	–	0.58	–	0.18	–	7.2	[23]	
–	4150	1320	–	0.09	–	–	–	0.08	0.05	0.01	–	[24]	
8400	2250	2200	0.01	0.99	–	0.63	–	0.5	0.1	1.32	8.3	[25]	Runoff leachate

Table 4 Test data collected on contaminated soil

S. no	Test	Data	Comment	Refs
1	Index properties	Gs = 2, Cu = 6.6, Cc = 6, LL = 23.4, PL = 19, PI = 5	At 0.5 m depth	
	Mechanical properties	OMC = 12%, MDD = 1.78 g/cm^3,Φ = 35.79^0, C = 1.67 kPa, CBR = 12.34%, k = 3.4 × 10^{-3} cm/s	At 0.5 m depth	[3]
2	Bulk density	Lower = 0.5 and upper = 1.5 g/cm^3	–	[28]
3	Compaction test	MDD = 1.54 g/cm^3, OMC = 29%	–	
	UCS test	Max cohesion and friction Angle—5 kPa and 38^0	–	[6]
4	Index properties	GS = 2.38, LL = 30%, PL = 15%	Max of 6 samples	[27]
	Compaction and strength Parameters	MDD = 19.5KN/m^3, OMC = 16.66%, C = 75KN/m^2, φ = 30.27^0, K = 3.15 × 10^{-5} m/s		

percolation. The review on the constituents of leachate from recent studies confirms the following statements:

- The constituents of MSW also directly influenced leachate properties which in turn influenced changes in characteristics of affected soil.
- Due to the increase in the organic fraction in soil, Parameters such as MDD and specific gravity have been decreased. The reduced internal angle and cohesion values also reduced soil shear strength.
- In geochemical analysis, it has been observed that apart from higher organic matter contamination, there is heavy metal contamination in upper layers of soil near the dumpsite.
- The loss of vegetation has been observed when there are higher fractions of heavy metals are present. At lower concentrations, these heavy metals are making their way into living beings through plants. Plants observe heavy metals along with necessary nutrition from the soil.
- Due to the increase in biological activity in the soil, the pathogen population is also increased. This disturbs the present ecological balance in soil which further leads to environmental and human health hazards.

References

1. Research Studies Comparative | Ministry of Statistics and Program Implementation | Government of India. http://mospi.nic.in/research-studies-comparative. Last accessed 2021/09/25
2. S. Singh, Solid waste management in Urban India: Imperatives for improvement (2020)
3. A. Sharma, A.K. Gupta, R. Ganguly, Impact of open dumping of municipal solid waste on soil properties in mountainous region. J. Rock Mech. Geotech. Eng. **10**, 725–739 (2018). https://doi.org/10.1016/J.JRMGE.2017.12.009
4. D. Singh, A. Kumar, Factors affecting properties of MSWI bottom ash employing cement and fiber for geotechnical applications. Environ. Dev. Sustain. **22**, 6891–6905 (2020). https://doi.org/10.1007/S10668-019-00519-W
5. S. Kumar, S. Deswal, Comparative assessment of Kurukshetra City waste dumping sites using RIAM analysis: A case study. Lect. Notes Civ. Eng. **154**, 31–38 (2022). https://doi.org/10.1007/978-981-16-1993-9_4
6. P. Alam, D. Singh, S. Kumar, Incinerated municipal solid waste bottom ash bricks: A sustainable and cost-efficient building material. Mater. Today Proc. (2021). https://doi.org/10.1016/J.MATPR.2021.07.346
7. S. Nayak, B.M. Sunil, S. Shrihari, Hydraulic and compaction characteristics of leachate-contaminated lateritic soil. Eng. Geol. **94**, 137–144 (2007). https://doi.org/10.1016/J.ENGGEO.2007.05.002
8. S. Renou, J.G. Givaudan, S. Poulain, F. Dirassouyan, P. Moulin, Landfill leachate treatment: Review and opportunity. J. Hazard. Mater. **150**, 468–493 (2008). https://doi.org/10.1016/J.JHAZMAT.2007.09.077
9. S.Q. Aziz, H.A. Aziz, M.S. Yusoff, M.J.K. Bashir, M. Umar, Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study. J. Environ. Manag. **91**, 2608–2614 (2010). https://doi.org/10.1016/J.JENVMAN.2010.07.042
10. S.Q. Aziz, Y.I. Maulood, Contamination valuation of soil and groundwater source at anaerobic municipal solid waste landfill site. Environ. Monit. Assess. **187**, 1–11 (2015). https://doi.org/10.1007/S10661-015-4971-Y
11. H. Nanda, R.S.-P. of Indian, Undefined: Impact of municipal solid waste disposal on geotechnical properties of soil.gndec.ac.in (2011)
12. S.M. Ali, A. Pervaiz, B. Afzal, N. Hamid, A. Yasmin, Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. J. King Saud Univ. Sci. **26**, 59–65 (2014). https://doi.org/10.1016/J.JKSUS.2013.08.003
13. V. Sridevi, M. Modi, M.V.V.C. Lakshmi, L. Kesavarao, M. Tech, A Review on integrated solid waste management
14. S. Kumar, D. Singh, Municipal solid waste incineration bottom ash: a competent raw material with new possibilities. Innov. Infrastruct. Solut. **6** (2021). https://doi.org/10.1007/S41062-021-00567-0
15. B. Bhalla, M.S. Saini, M.K. Jha, Effect of age and seasonal variations on leachate characteristics of municipal solid waste landfill. IJRET Int. J. Res. Eng. Technol., 2321–7308
16. V. Mathur, Scope of recycling municipal solid waste in Delhi and National Capital Region (NCR). Integr. Rev. J. Manag. **5** (2012)
17. Z. Youcai, Summary. Pollut. Control Technol. Leachate from Munic. Solid Waste. **xxiii** (2018). https://doi.org/10.1016/B978-0-12-815813-5.00012-7
18. M. Vaccari, T. Tudor, G. Vinti, Characteristics of leachate from landfills and dumpsites in Asia, Africa and Latin America: an overview. Waste Manag. **95**, 416–431 (2019). https://doi.org/10.1016/J.WASMAN.2019.06.032
19. S. Mor, P. Negi, R. Khaiwal, Assessment of groundwater pollution by landfills in India using leachate pollution index and estimation of error. Environ. Nanotechnology, Monit. Manag. **10**, 467–476 (2018). https://doi.org/10.1016/J.ENMM.2018.09.002
20. P. Negi, S. Mor, K. Ravindra, Impact of landfill leachate on the groundwater quality in three cities of North India and health risk assessment. Environ. Dev. Sustain. **222**(22), 1455–1474 (2018). https://doi.org/10.1007/S10668-018-0257-1

21. T. Tesseme, S. Chakma, Trend analysis of long-term MSW leachate characteristics. Adv. Waste Manag., 143–153 (2019). https://doi.org/10.1007/978-981-13-0215-2_10
22. M. Somani, M. Datta, S.K. Gupta, T.R. Sreekrishnan, G.V. Ramana, Comprehensive assessment of the leachate quality and its pollution potential from six municipal waste dumpsites of India. Bioresour. Technol. Reports. **6**, 198–206 (2019). https://doi.org/10.1016/J.BITEB.2019.03.003
23. S.K.M. Cumar, B. Nagaraja, Environmental impact of leachate characteristics on water quality. Environ. Monit. Assess. **1781**(178), 499–505 (2010). https://doi.org/10.1007/S10661-010-1708-9
24. A. Giannis, G. Makripodis, F. Simantiraki, M. Somara, E. Gidarakos, Monitoring operational and leachate characteristics of an aerobic simulated landfill bioreactor. Waste Manag. **28**, 1346–1354 (2008). https://doi.org/10.1016/J.WASMAN.2007.06.024
25. T. Prechthai, P. Parkpian, C. Visvanathan, Assessment of heavy metal contamination and its mobilization from municipal solid waste open dumping site. J. Hazard. Mater. **156**, 86–94 (2008). https://doi.org/10.1016/J.JHAZMAT.2007.11.119
26. S. Kanmani, R. Gandhimathi, Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. Appl. Water Sci. **31**(3), 193–205 (2012). https://doi.org/10.1007/S13201-012-0072-Z
27. E.R. Sujatha, R. Gurucharan, C. Ramprasad, V. Sornakumar, Impact of municipal solid waste dumping on the geotechnical properties of soil and ground water in Ariyamangalam, Trichy, India. Electron. J. Geotech. Eng. **18**, 2119–2132 (2013)
28. M. Singh, M. Verma, R.N. Kumar, Effects of open dumping of MSW on metal contamination of soil, plants, and earthworms in Ranchi, Jharkhand, India. Environ. Monit. Assess. **1903**(190), 1–12 (2018). https://doi.org/10.1007/S10661-018-6492-Y

Analysis of Landfill Leachate and Contaminated Groundwater: A Review

Shweta Ranjan, Davinder Singh, and Sanjeev Kumar

1 Introduction

Landfills are the dumping site for municipal solid wastes, industrial and hazardous waste. Landfill waste poses several challenges to our environment through leachate, toxins, greenhouse gases, and other harmful products. Leachate is formed by extracting soluble, insoluble, and suspended materials by liquid passing through any matter. The breakdown of organic waste generates landfill leachate, and chemicals thus produced are mixed with percolating water. Rainfall on the landfill is one of the significant causes of leachate formation. Groundwater entering the landfill also contributes toward leachate formation. Thus, toxic leachate is produced by chemical reactions of decomposed landfill components picked up by the liquid. Chemicals including Methane, Carbon Dioxide, Alcohol, Organic Acids, Aldehydes, etc., are usually found in leachate. Different types of toxic materials produced in the decomposition of landfill wastes seep into the soil then groundwater, resulting in groundwater contamination. Not only groundwater but soil quality and other environmental factors will degrade.

Landfills pose several environmental problems, including vegetation damage, dust, greenhouse gases, other air emissions, etc. However, this review will solely focus on the leachate and groundwater contamination in the present study. Landfill leachate compositions depend on the age of the landfill itself and the variety of wastes present in it. It contains both dissolved and suspended materials. Landfill leachate is generally toxic, thus possessing a significant threat to the surrounding environment and ecosystems. Dissolved organic matter (DOM) in leachate can change the fate of heavy metals in their stability, transport behavior, and bioavailability. It can also affect microbial activity, decrease the effluent quality of the coagulation process, cause

S. Ranjan (✉) · D. Singh · S. Kumar
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar 144011, Punjab, India
e-mail: shwetaranjan9798@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_5

membrane fouling and interact with organic contaminants [1]. Water is essential for life to exist. From industries to agriculture and home, water is used everywhere. It is a vital re- source of a nation as economic development and prosperity depend on it. Leaching would have a severe consequence on this very resource of the country. The mechanism of leaching of metals is essential to study as metals migrating will contaminate the groundwater and soil and its surrounding. Leachate with a high level of landfill-derived nitrates and phosphate, subsequently contaminating both the soil and groundwater and growth of waste generation leads to increased contamination level of groundwater and soil. So monitoring and assessment of potential risks of lateral and vertical percolation from landfills for contaminating soil and groundwater resources are needed [2]. Modern landfills are well-engineered, have facilities for safe, solid waste disposal. Wastes disposed of in these modern landfills prevent the environment from contamination. In environmentally sensitive areas, landfills are not built. A monitoring system is used on-site to monitor their environmental impact. Besides detecting signs of groundwater contamination and landfill gas, these monitoring systems also provide additional safeguards.

2 Landfill and Landfill Leachate

2.1 Landfill Overview

Landfill sites are used for the management of waste materials that are no longer in use. All the waste has not the same landfill. Wastes are deposited in different landfills based on their nature. Non-hazardous domestic waste and hazardous industrial waste materials are considered in municipal solid waste (MSW) and industrial landfills, respectively. Construction demolition, incinerator ash, and refuse are part of the inert waste landfill. Completely unknown types of waste are considered in the abandoned landfill.

Management of waste recycling, reuse can be helpful in the reduction of waste from the landfill. These wastes are managed carefully to preserve the environment and living beings. The municipal solid waste generation rate depends upon affluence, season, and education. Location for the public landfill is selected by the local government and for private landfill, it will choose the prospective selected site and approach the government. The term landfill refers to the act of disposing of waste by compression and embankment filling at suitable locations. Landfilling is easy, adjustable, and cost-effective compared to other disposal methods. Studies comparing different waste management (WM) methods (landfilling, burning, composting, etc.) show that sanitary waste disposal-open dumping—is the best available option [3] (Fig. 1).

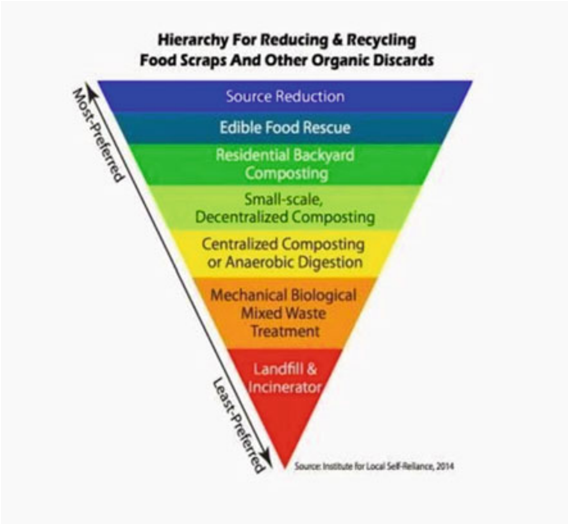


Fig. 1 Hierarchy of methods for managing waste generated

2.2 Characteristic of Leachate

Typically landfill leachate is identified by the parameters like biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), suspended solids, heavy metals, pH, and ammonia (NH_4^+-N). The oxidation state of organic carbon and the biodegradability of organic compounds are measured by the ratios of COD/TOC and BOD_5/COD. Landfill leachate qualities are affected by different parameters such as landfill age, operational conditions, waste type, climate, and hydrogeology. The properties of landfills show variations due to the differences in moisture content, refuse composition, precipitation, and temperature [4]. Electrical conductivity, total nitrogen, and pH are higher in winter compared to summer. COD and DOC concentrations are lower in summer due to higher temperatures. The heavy metal concentrations, volatile suspended solids, total suspended solids, and oxidation–reduction potential shows no remarkable seasonal variation [5]. Landfill age can affect the properties and configuration of leachate. Landfill leachate can be divided into three groups based on their ages. Leachate age less than 5 years belongs to young leachate, 5–10 years old is medium, and above than ten years is considered old leachate (shown in Fig. 2). Generally, a young landfill having less pH value, low molecular weight, and high level of (BOD_5/COD) biodegradability index.

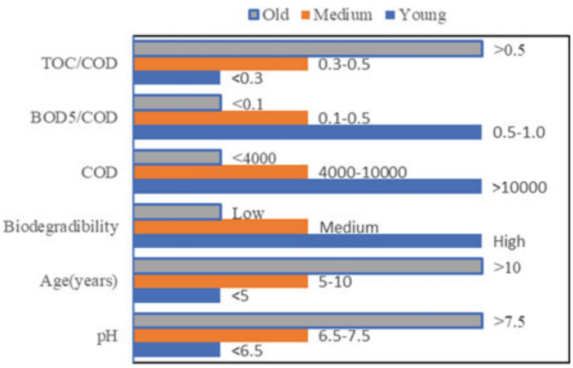


Fig. 2 Characteristic parameters of landfill leachates of different ages [1, 6]

2.3 Impact of Landfill Leachate on Environment and Human Health

Municipal solid waste disposal all over the world, landfills are the primary option. Generally, the landfill sites are very old and not adequately designed, resulting in contamination of soil surface and groundwater due to toxic leachate. The regulatory authorities are facing challenges to manage the enormously increasing level of toxic leachate. It is necessary to treat the maximum limits of the contamination before disposal into the environment, so they made specific regulation that helps to protect the environment. For the management of leachate, there are different phases, for example, (i) monitoring of leachate information (ii) identification of hazards (iii) treatment of toxic leachate. After accomplishing these phases, waste can be disposed of in the environment. There are three ways to control contamination risk on the environment: remove the hazards' source, remove the hazards' receptors, and handle the pathways between the source and receptor.

3 Sampling and Analysis

Landfill leachate and groundwater samples are collected from the landfill site and the nearby area. These samples are collected carefully in a clean bottle or polythene and transported to the laboratory for further analysis. The sample is stored at 4°C and examined within 24 h for better results [7, 8]. Different techniques are available for the study of heavy metals, physicochemical and microbiological. To assess the physicochemical parameters, standard methods and internationally accepted methods are used. Some of the parameters such as total dissolved solids (TDS), electrical conductivity (EC), pH, and temperature can be measured directly on the site by using a multiparameter detector instrument. The NO_3^- content find out by using the method of phenoldisulfonic acid. After filtration, the groundwater sample is acidified using HNO3 (having pH < 2) for heavy metal analysis. The concentrations of heavy metals like Cd, Co, As, Cr, Fe, Mo, Cu, Ni, Pb, Zn, and Mn are analyzed.

Except for pH, TDS, EC (mS/cm) all parameters are in mg/l.

To assess the heavy metals in landfill leachate and groundwater samples, ICP-Perkin Elmer Model can be used [2]. Physiochemical characteristics of landfill leachate in various regions are compared with Municipal Solid Waste (2000) and United Nations Environment Program (UNEP 2005) data in Table 1. Parameters of groundwater by the World Health Organization (WHO) and allowable limit of drinking water as per the Bureau of Indian Standards (BIS-10,500:2012) are compared with Tamil Nadu, Varanasi, Himachal Pradesh (Solan) in Table 2.

Table 1 Physiochemical characteristics of landfill leachate in different regions

Parameters	Tamil Nadu [9]	Solan (H.P) [7]	Varanasi (U.P) [10]	Municipal solid waste managementand handling (2000)	MSW in developing countries, UNEP (2005)
pH	6.9	7.41	8.8	5.5–10	5.5–9
BOD	17,552	2300	1335	30	20–40,000
COD	25,102	7150	8332	250	500–60,000
TDS	25,514	1968	2322	2100	0–42,300
Fe	63.41	0.210	1.77	_	3–2100
Zn	2.10	0.084	5.40	5.0	0.03–120
Pb	1.10	0.035	0.33	0.1	8–1020
Ni	0.38	0.017	_	3.0	_

Table 2 Parameters of groundwater quality compared with WHO and BIS Standards

Parameter	Tamil Nadu [9]	Varanasi [10]		Solan (H.P) [7]		WHO (2011)	BIS (10500:2012)
		Pre-monsoon	Post-monsoon	Surface water	Ground water		
pH	7.63	6.9	7.6	8.28	7.41	6.5–9.2	6.5–8.5
TDS	862.27	723	1006	389	242	500	500
EC (mS/cm)	1463.48	1.32	1.49	_	_	0.3	NM
Na^+	142.37	137.0	137.4	_	_	200	NM
Ca	84.74	24.23	57.00	_	_	150	75
Mg	55.72	26.7	2.33	_	_	200	30
$SO4^-$	81.74	_	1.06	_	_	400	400
Flouride	0.80	0.51	0.24	_	_	1.5	1.0
BOD	_	3.11	1.57	6.2	Nil	_	_
COD	_	67.8	93.52	20	Nil	_	_

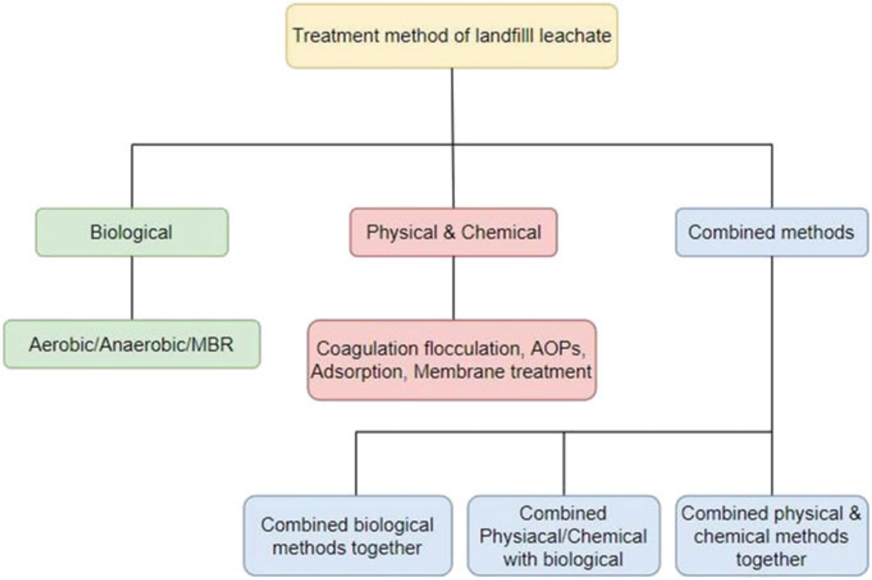


Fig. 3 Various methods for landfill leachate treatment

4 Treatment Techniques

4.1 Leachate Treatment

Landfill leachates are treated using various techniques categorized as physicochemical, biological methods, and combined methods (Fig. 3).

4.1.1 Physicochemical Treatments

Physicochemical treatment divides into several parts: adsorption, coagulation-flocculation, advanced oxidation processes, membrane treatment chemical precipitation. In adsorption, the pollutants are stick to the surface of the adsorbent [11]. In coagulation-flocculation chemical, reagents are used to destabilize and to increase the size of the suspended particles. A large number of small particles aggregate to form flocs. These solids can then be separated from the liquid by physical separation. Physical separation usually includes sedimentation, decantation, and filtration [12, 13]. Most often, organic materials are removed from wastewater through oxidation with hydroxyl radicals. NH_4^+-N and heavy metals negatively affect the landfill leachate in the biological process and are eliminated by pre-treatment strategy in the chemical precipitation method. Chemical precipitation is widely employed for landfill leachate treatment due to its high potential, simplicity, and low cost [14].

4.1.2 Biological Treatment

Biological treatment methods are commonly used for landfill leachate due to their cost-effectiveness. It eliminates the organic compound from the landfill leachate but is not able to eradicate the non-biodegradable organics and heavy metals. It is mainly used due to its low environmental impacts and economic costs. Biological processes are distinguished into two groups, (1) aerobic biological process (with oxygen) (2) anaerobic biological process (without oxygen). For the elimination of contamination from landfill leachates, microorganisms and bacteria are used in this process. During this process, the microbial metabolism of living cells increases at this stage; such metabolic conditions can eliminate the leachate parameters [15]. The impact of biological treatment primarily depends on the composition of landfill leachate and its types. So usually, young landfill leachates are selected for biological treatments due to their biodegradability.

4.1.3 Combined Treatment

By combining techniques, for instance, physical/chemical treatment with biological treatment, efficiency of metal removal can be enhanced. Due to the low demand for biodegradability and high concentrations of ammonia and chemical oxygen demand combined technique proved to be efficient in studies done earlier. In these techniques, removal efficiency can be increased while keeping energy consumption low [16]. Various physical/chemical combined methods include AOPs combined with the membrane, AOPs combined with coagulation, AOPs combined with adsorption, and membrane filtration with coagulation or adsorption. Biological treatments are often integrated with adsorption, AOP, coagulation, membrane methods in hybrid physical/chemical and biological processes.

5 Conclusion

The properties of leachate BOD, COD, and ratios of BOD/COD are essential to assess the selection of treatment techniques for landfill leachate. Even if landfill leachates have the same COD value, their chemical compositions differ significantly, leading to significant differences in their treatment performance. Thus, it is important to acknowledge the structural properties of leachate dissolved organic matter and the changes made during treatment to select the most appropriate and economically feasible treatment method. These toxic landfill leachates pose a threat badly to the environment and living beings. After the proper treatment of the landfill, leachate can be disposed of in the environment. Analysis of the groundwater gives information about the impact of pollutants on groundwater quality. Water quality index results show groundwater quality has moderately changed from good to medium over time and the water near the landfill area was quietly threatened. Studying the future effects of open dumping landfill sites on groundwater could be extremely helpful in protecting it from becoming a toxic water source surrounding the outlet.

References

1. C. Teng, K. Zhou, C. Peng, W. Chen, Characterization and treatment of landfill leachate: A review. Water Res. **203**, 117525 (2021). https://doi.org/10.1016/j.watres.2021.117525
2. A.G. Alghamdi, A.A. Aly, H.M. Ibrahim, Assessing the environmental impacts of municipal solid waste landfill leachate on groundwater and soil contamination in western Saudi Arabia. Arab. J. Geosci. **14** (2021). https://doi.org/10.1007/s12517-021-06583-9
3. M.D. Vaverková, Landfill impacts on the environment—review. Geosci. **9**, 1–16 (2019). https://doi.org/10.3390/geosciences9100431
4. A.M. Costa, R.G. Alfaia, S.M. de Campos, Landfill leachate treatment in Brazil—an overview. J. Environ. Manage. **232**, 110–116 (2019). https://doi.org/10.1016/j.jenvman.2018.11.006
5. J. Zhao, X.Q. Lu, J.H. Luo, J.Y. Liu, Y.F. Xu, A.H. Zhao, F. Liu, J. Tai, G.R. Qian, B. Peng, Characterization of fresh leachate from a refuse transfer station under different seasons. Int. Biodeterior. Biodegrad. **85**, 631–637 (2013). https://doi.org/10.1016/j.ibiod.2013.05.012
6. S. Renou, J.G. Givaudan, S. Poulain, F. Dirassouyan, P. Moulin, Landfill leachate treatment: Review and opportunity. J. Hazard. Mater. **150**, 468–493 (2008). https://doi.org/10.1016/j.jhazmat.2007.09.077
7. D. Sharma, R. Ganguly, Parametric analysis of Leachate and water resources around municipal solid waste landfill area in Solan. MATEC Web Conf **57** (2016). https://doi.org/10.1051/matecconf/20165703011
8. S. Kumar, D. Singh, Municipal solid waste incineration bottom ash: a competent raw material with new possibilities. Innov. Infrastruct. Solut. **64**(6), 1–15 (2021). https://doi.org/10.1007/S41062-021-00567-0
9. R. Nagarajan, S. Thirumalaisamy, E. Lakshumanan, Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. J. Environ. Heal. Sci. Eng. **9**, 1–12 (2012)
10. S. Mishra, D. Tiwary, A. Ohri, A.K. Agnihotri, Impact of Municipal Solid Waste Landfill leachate on groundwater quality in Varanasi, India. Groundw. Sustain. Dev. **9**, 100230 (2019). https://doi.org/10.1016/j.gsd.2019.100230
11. I.K. Erabee, A. Ahsan, B. Jose, M.M.A. Aziz, A.W.M. Ng, S. Idrus, N.N.N. Daud, Adsorptive treatment of landfill Leachate using activated carbon modified with three different methods. KSCE J. Civ. Eng. **22**, 1083–1095 (2018). https://doi.org/10.1007/s12205-017-1430-z
12. M. Moradi, F. Ghanbari, Application of response surface method for coagulation process in leachate treatment as pretreatment for Fenton process: Biodegradability improvement. J. Water Process Eng. **4**, 67–73 (2014). https://doi.org/10.1016/j.jwpe.2014.09.002
13. P. Alam, D. Singh, S. Kumar, Incinerated municipal solid waste bottom ash bricks: A sustainable and cost-efficient building material. Mater. Today Proc. (2021). https://doi.org/10.1016/J.MATPR.2021.07.346
14. W. Li, X. Ding, M. Liu, Y. Guo, L. Liu, Optimization of process parameters for mature landfill leachate pretreatment using MAP precipitation. Front. Environ. Sci. Eng. China. **6**, 892–900 (2012). https://doi.org/10.1007/s11783-012-0440-9
15. A.Ž Gotvajn, T. Tišler, J. Zagorc-Končan, Comparison of different treatment strategies for industrial landfill leachate. J. Hazard. Mater. **162**, 1446–1456 (2009). https://doi.org/10.1016/j.jhazmat.2008.06.037
16. A. Mojiri, J.L. Zhou, H. Ratnaweera, A. Ohashi, N. Ozaki, T. Kindaichi, H. Asakura, Treatment of landfill leachate with different techniques: an overview. J. Water Reuse Desalin. **11**, 66–96 (2021). https://doi.org/10.2166/wrd.2020.079

The Potential of *Chrysopogon Zizanioides (L.) Nash* in Remediation of Heavy Metal-Contaminated Land—A Review

Pawan Kumar and V. P. Singh

1 Introduction

One of the major environmental problems facing the world today is the environmental contamination by toxic chemicals which is a result of industrialization, urbanization, and extensive use of pesticides in agricultural production. Phytoremediation a group of technologies that utilize green plants and its associated microbes for removing contaminants from soil/sediment and water (Fig. 1). It is becoming popular due to its reduced remediation cost when compared to other conventional remediation techniques and methods. The collaboration of vetiver grass (VG) and its associated microorganisms in phytoremediation process is an important tool for its effective force to remove the environmental contaminants. Vetiver is a fast-growing perennial, tussock grass belonging to the family Poaceae and native to India. The VG is widely cultivated in tropical and sub-tropical reasons of the world, and it was first used for soil restoration purposes in Fiji during 1950. The vetiver, *Chrysopogon zizanioides (L.) Roberty*, formerly known as *Vetiver zizanioides (L.) Nash*, was first developed by the World Bank for soil and water conservation in India in the mid-1980s [1]. The vetiver grass has a well-developed root system which is useful for environmental restoration.

The stiff and erect shoots of VG form a dense funnel and umbrella-shaped structure with its leaves angled between 45° and 135° from horizontal (Fig. 2). According to the moving position of the sun, this structure provides longer exposure of sunlight interception on each and every leaf. The vetiver had been grown and used to prevent soil erosion, landslides, and to treat the contaminated environment since early 1990

P. Kumar (✉) · V. P. Singh
Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad, Prayagraj 211004, India
e-mail: rce1652@mnnit.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_6

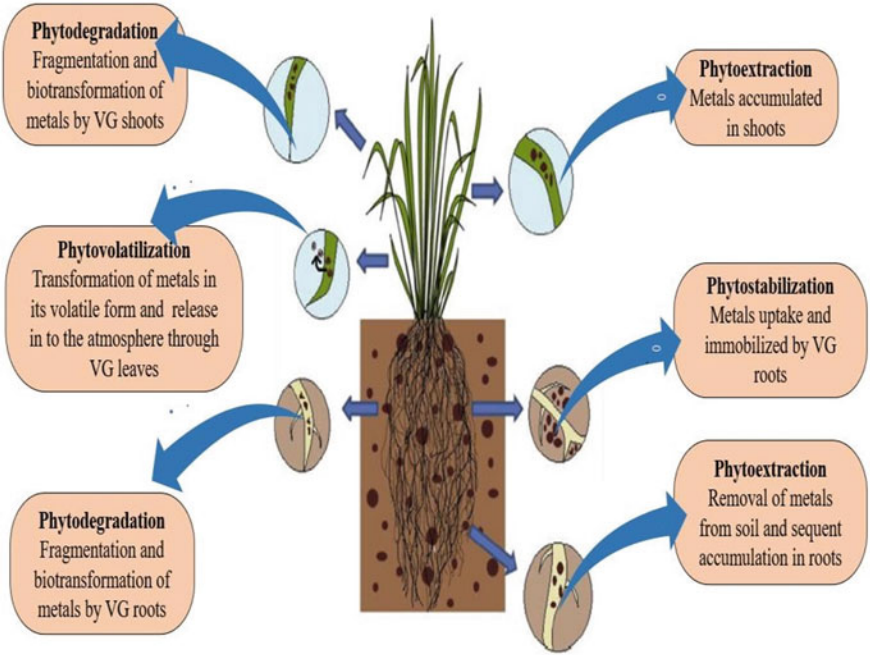


Fig. 1 Phytoremediation strategies of vetiver

[2]. Vetiver system prevents soil erosion, preserves rain water, stabilizes earth, beautifies landscapes, purifies wastewater, remediates contaminated soils, keeps away pests, and stabilizes slope due to its enhanced root structures. It has advanced characteristics for remediation of soil and water, i.e., resistant to high level of pollution, produces huge biomass due to high C4 photosynthetic efficiency, fast-growing plants with strong, deep, and complex root system [3]. The vetiver grows very fast and is capable of reaching down up to 3–4 m within first year of plantation [4]. The fine structured root of VG reinforces the soil mass and makes them very difficult to be dislodged under high water flow velocity (Fig. 2). When planted together, the stiff and erect stem forms dense hedges, which stand up with relative deep-water flows, reduce the velocity of flow, and trap the soil and sediments. The vetiver grass has a unique characteristics of a xerophytes which makes it suitable to survive under long flooding and drought conditions [5].

In Malaysia, China, and Madagascar, it is being utilized in stabilization of steep slope for protection of infrastructure. It is capable of withstanding extremely adverse environmental conditions in Australia (15–30 S) (Table 1). The accumulation of heavy metals in the root and shoot of VG neither affects its growth nor makes it toxic for its further utilization. Its unique morphological behavior and mycorrhizal association, within its root, enables it to withstand with the high toxic metal concentration in the soil.

Fig. 2 Dense and funnel-shaped structure of shoot and massive structured fine root of vetiver [6]

Table 1 Adaptability range of vetiver plant in Australian Environment [7]

Adverse soil condition		Heavy metals concentration		Climatic conditions	
Conditions	Value	Conditions	Value (mg/kg)	Conditions	Value
Acidity (pH)	3.3–9.5	As	100 - 250	Annual rainfall (cm)	45–400
Aluminum	68–87%	Cd	20	Winter temperature	−11 °C
Magnesium	2400 mg/kg	Cr	200–600	Summer temperature	45 °C
Manganese	>578 mg/kg	Cu	35–50	Drought	1.25 years
Salinity	17.5–47.5 mS cm^{-1}	Pb	>1500	Palatability	Dairy cows, cattle, horse, rabbits, sheep kangaroo
Sodium exchange rate	48%	Zn	>750	Nutritional value	N = 1.10%; P = 0.17%; K = 2.20%
		Ni	50–100		

Phytoremediation of contaminated soil and water through VG concentrates mainly on two processes: phytostabilization, where roots of plants immobilize the heavy metals in the soil, and phytoextraction, where roots of plants translocate metals from contaminated soil to their above ground harvestable parts. The vetiver system (VS) is a universal remedy and a proven technological solution for several environmental problems like soil and water conservation, treatment waste water effluents, contaminated soil remediation, stabilization of embankment and fly ash ponds, controlling the flood flow, and mitigation of various other types of pollution. During 1998, the VS has provided a very effective protection against high cyclonic situation in many Central American countries due to El-Nino effects. VG is a non-aggressive plant; it flowers but produces no seeds; therefore, it has to be established by crown splitting. It can be easily killed either by spraying glyphosate or uprooting and drying out. Due to its eligibility for the sustainable mitigation of environmental contaminations, it is found as the best living material that nature has provided to earth for restoring its natural environment. The objective of this study is to review the potential of vetiver grass in remediation of contaminated lands.

2 Literature Screening Process

Data were collected from the Web of Science, Google Scholar, Science Direct, Scopus, etc., including science citation index data, journals, proceedings, book chapters, research articles, covering the period 1991–2020. Total number of research papers found, on the basis of keyword ‘vetiver’, were 370. To select the major journals, we started with International Journal of Phytoremediation and International Vetiver Conference (International Vetiver Network), which has been regarded as the core field in the phytoremediation through vetiver. After that the data were collected from other journals which had published ‘the potentials of vetiver grass against contamination’ related articles from several journals. Various different keyword had been used to search the literatures, i.e., *Vetiveria zizanioides (L.) Nash*/Vetiver grass/phytoremediation of contaminated soil/metal uptake/sustainability/socioeconomic consideration. The screening of these literatures has been achieved by reviewing the images, graphs, and tables present in those literatures.

2.1 Selection of Plant Growth Media

The vetiver grass had been selected for remediation of contaminated soil, water, and sediments. The medium was either contaminated by industrial activity or by artificially considering different concentration of salts of heavy metals (Table 2). Some researchers had considered soil contaminated by effluent of mine tailings for study the growth and remediation potential of VG. Hydroponic treatment with green house experiment had been also used for the study of VG potential. Various types of soil, i.e., sandy soil, sandy loamy soil, silty soil, clay loam, laterite soil etc., had been used by various researchers to study the growth and behavior of vetiver under phytoremediation strategy.

Table 2 Heavy metal salts used for artificial soil contamination in phytoremediation study by vetiver grass

S. No.	Metals	Metal salt	Chemical formula	References
1	Cd	Cadmium nitrate Cadmium chloride	$Cd(NO_3)_2.4H_2O$ $CdCl_2.5H_2O$	[8–12]
2	Cr	Potassium dichromate Chromium chloride Potassium chromate Chromium sulfate Chromium (III) nitrate non-hydrate	$K_2Cr_2O_7$ $CrCl_3$ K_2CrO_4 $Cr_2(SO_4)_3.2H_2O$ $Cr_2(NO_3)_3$	[13–17]
3	Cu	Copper chloride Copper carbonate Copper acetate mono-hydrate Copper sulfate Ferrous sulfate Ferric chloride Fe-EDDHA	$CuCl_2).2H_2O$ $CuCO_3$ $Cu(C_2H_3O)_2.H_2O$ $CuSO_4.5H_2O$ FeSO4 FeCl3 Fe-EDDHA	[8, 9, 16, 18]
4	Mn	Manganese chloride Manganese sulfate	$MnCl_2.4H_2O$ $MnSO_4.H_2O$	[8, 11, 19]
5	Pb	Lead carbonate basic, (Resp.) Lead hydroxides Lead sulfide Lead chloride Lead nitrate Lead carbonate	$(PbCO_3)_2$ $Pb(OH)_2$ PbS $PbCl_2$ $Pb(NO_3)_2$ $PbCO_3$	[8, 9, 20] [11, 12, 21] [16, 18, 22–25]
6	Zn	Triuranium octoxide Zinc carbonate Zinc chloride Zinc oxide Zinc sulfide Zinc sulfate	U_3O_8 $ZnCO_3$ $ZnCl_2$ ZnO ZnS $ZnSO_4.7H_2O$	[8, 9, 12] [16, 18, 19]

3 Soil, Water, and Sediment Contamination Procedure

The vetiver is xerophytes (drought tolerant) as well as hydrophytes (wetland plants). The media used for the study was contaminated either by industrial effluents of or by artificially in the laboratory scale by selecting the range of concentration of contaminants. In the laboratory scale, two types of study have been done on the basis of soil contamination a) artificially contaminated soil for study b) soil contaminated by industrial activities obtained for study. Various contaminants that have been used to contaminate the soil naturally or artificially and will be used in phytoremediation studies by using vetiver in laboratory/field studies using vetiver-assisted bioremediation include heavy metals, radioactive elements, pesticides and herbicides, chlorinated solvents, petroleum hydrocarbon (BTEX), polychlorinated biphenyls, polynuclear aromatic hydrocarbons (PAHs), and explosives. Several heavy metals salt that had been utilized by various researchers as a representative of heavy metals, to contaminate the soil artificially for the study of phytoremediation process through VG. Some researchers have also used the chelating agents, i.e., EDTA with (NH4)2SO4 and (NH4NO3) in the laboratory scale study, to increase the bioavailability of contaminants within the soil and water. Table 3 shows the list of heavy metals with their respective salts and their concentration used to contaminate the soil artificially for the study of the potential of VG in phytoremediation.

Table 3 Heavy metals, their salts and amount used

S. No.	Heavy metals	Metal salt used	Concentration (mg/kg)	References
1	Arsenic (As)	$Na_2HAsSO_4.7H_2O$	10, 40, 70, and 110	[26]
2	Boron (B) and Lead (Pb)	H_3BO_4 and $Pb(NO_3)_2$	0, 45, 90, 180 kg/ha	[24]
3	Cadmium (Cd)	$Cd(NO_3)_2{\cdot}4H_2O$	0, 10, 20, and 40	[10]
4	Chromium (Cr)	$K_2Cr_2O_7$	5, 10, 30, and 70	[13]
5	Chromium (Cr)	$CrCl_3.6H_2O$ and K_2CrO_4	0, 100, 500	[27]
6	Chromium (Cr)	K_2CrO_4	0, 1.25, 2.5, 5.0, 10.0	[15]
7	Chromium (Cr) Chromium (Cr)	$Cr_2(SO_4)_3.2H_2O$ and $K_2Cr_2O_7$ $CrCl_3$	250 and 100 resp. 623	[14]
8	Copper (Cu) Lead (Pb) Zinc (Zn) Cadmium (Cd)	$CuCl_2$, $PbCl_2$, $ZnCl_2$ $CdCl_2$,	190 621 653 10, 30, 60	[16]
9	Copper (Cu) Lead (Pb) Zinc (Zn) Copper (Cu)	$CuCl_2$, $Pb(NO_3)_2$ $ZnCl_2$ $Cu(C_2H_3O)_2H_2O$	50, 70, 100 100, 300, 700 300, 400, 500 0, 100, 400, 1600	[9]
10	Lead (Pb) Zinc (Zn)	$Pb(NO_3)_2$, and ZnO	0, 500, 2000, 8000 0, 400, 1600, 6400	[18]
11	Lead (Pb) and Calcium (Ca)	$Pb(NO_3)_2$ and $CaCO_3$	4000 0, 2000, 4000, 6000	[21]
12	Lead (Pb)	$Pb(NO_3)_2$	50, 200, 400, 800	[19]
13	Lead (Pb)	$Pb(NO_3)_2$	0, 500, 2500, 5000	[23]
14	Lead (Pb)	$Pb(NO_3)_2$	5, 7, 9, 11	[22]

Table 4 Concentration ranges and guidelines of some toxic metals for soil/sediments [28]

S. No.	Toxic metal	Soil/sediments (mg/kg)	Guidelines (mg/kg)
1	Arsenic (As)	0.1–102	19
2	Cadmium (Cd)	0.10–345	78
3	Chromium (Cr)	0.05–3950	–
4	Copper (Cu)	0.03–550	3100
5	Nickle (Ni)	–	1600
6	Manganese (Mn)	–	11,000
7	Mercury (Hg)	<0.01–1800	23
8	Lead (Pb)	1.00–69,000	400
9	Selenium (Se)	0.15–5000	390
10	Zinc (Zn)	150.0–5000	1500

4 Methodology for Research Work

Based on the previous literatures, it is observed that following methodologies have been adapted by various researchers such as (a) laboratory study (Pot scale, batch scale), (b) Pot scale study under greenhouse effect, (c) hydroponic study, (d) field scale study, had been conducted to study the growth and decontamination potential of vetiver. The soil is said be contaminated if it had foreign particles within it above certain limit set by standards of regulating authority based on previous research data (Table 4).

After going through the previous published research articles on vetiver grass, few literatures were selected for detailed discussion which includes 23 articles under laboratory scale study, 13 articles under greenhouse study, 11 articles under field scale study, and 7 articles under hydroponic scale study.

5 Discussion

The VS is an effective technological solution for environment protection demonstrated over the world. Due to its unique morphological and physiological characteristics, it is cost-effective, environment friendly, and practical bioremediation tool for the protection of soil, water, and tolerant to highly contaminated soil. The chemical formula of VG composed by its ultimate analysis is CH1.57O0.91N0.012 [29]. To obtain fast growth of VG system, it should be planted during the late winter season of February and March. The VG planted in clayey soil was the tallest and had the largest number of sprouts per plant, which may be due to the high water holding capacity and soil fertility [30].

5.1 Vetiver with Heavy Metals

Two main species of VG *(Chrysopogon zizanioides* and *Chrysopogon nemoralis)* which showed similar trends in their ability to remediate contaminated soil by heavy metals. The absorbing potential of VG for heavy metals has been studied in laboratory field and greenhouse scale doing wide range of experiments. Naturally and artificially contaminated soils have been used to investigate the potential of VG to deal with several heavy metals [31]. The combination of VG system with oil production had improved the profitability of phytoremediation of Pb contaminated soil [32]. The VG is able to extract and store the heavy metals in its roots, so the toxic heavy metals cannot enter into the food chain, which is a good attribute for phytoremediation technique [33]. For the pot experiments, when vetiver plants were grown mature, the heavy metals concentration in the shoot were decreased, may be due to dilution effects, while the heavy metals concentration in the root was increased. The reason behind this phenomenon is the spatial limitation of pot on root growth and the restricted translocation of metals from roots to aerial parts, as a result the accumulation of metals in the roots increased. The vetiver under phytoextraction experiments showed that it can be considered as a hyperaccumulator plant for Pb and Zn, but it can accumulate very low concentrations of Cr and Cu in its root and shoot. VG can grow and develop in the sandy soil and clay with Cd concentrations from 10 to 60 ppm, Zn concentrations from 300 to 500 ppm, Cu concentrations from 50 to 100 ppm, and Pb concentrations from 100 to 700 ppm. In the four heavy metals tested (Cd, Cu, Pb, and Zn), uptake and transport of Zn from root to shoot in VG is the highest, whereas the ability of absorption and translocation of Cu and Pb in medium and low, especially for Cd is very low [9]. The root of the VG acts as a barrier against arsenic translocation, with a maximum accumulation of arsenic in the roots (494.50 ppm) that was almost seven times higher than in the shoots (71.92 ppm) and nearly sixteen times higher than in the leaves (30.05 ppm). Among the various others heavy metals analyzed in vetiver plant tissues, the chromium and zinc had the highest accumulation in the shoots, with values above 5–30 ppm for chromium and 100–400 ppm for zinc [34].

5.2 Accumulation of Metal Within Vetiver Grass

The number of heavy metals absorbed by VG was evaluated by two important parameters, translocation factor and bioaccumulation factor. The translocation factor is defined as a ratio of metals stored in shoot to the metals stored in the roots. The bioaccumulation factor is considered as the ratio of metals stored in root or shoot to metals amount in soil. From the previous literature, it has been found that that vetiver can accumulate the heavy metals within its fine structured roots (maximum) and can also transfer them to shoots and leaves (less than its root). The absorption of chromium was found higher in its roots, when chromium was treated with 5–10 mg

Cr/kg of soil, whereas chromium accumulates in the leaves of vetiver when it was planted 30–70 mg Cr/kg of soil. On the basis of the amount distributed over root and shoot of VG, the metals can be categorized in 3 groups: (a) low proportion of absorbed metals translocated to shoot such as As, Cd, Cr, and Hg (1–6%), (b) a moderate proportion translocated to the shoots of Cu, Ni, and Se (16–45%), and (c) Pb and Zn were almost evenly distributed between shoot and root (>45%) [31]. The accumulation of Fe by the vetiver roots was found nearly 3377.09 mg/kg, which is three times higher than the sprouts having 1037.49 mg/kg and almost nine times higher than absorbed by the leaves 362.77 mg/kg. The metabolism and productivity of VG did not found to be affected by the accumulation of metals in plant tissues, which makes VG to tolerate and adapt the heavy metal-induced stress.

6 Concluding Remarks

Being native to India, *Chrysopogon zizanioides (L.) Roberty* syn. *Vetiveria zizanioides (L.) Nash* is a perennial and tussock grass of the Poaceae family (subfamily Panicoideae). The VS has been used in more than 100 countries of Asia, Africa, Oceania, and Central America, for soil and water conservation, stabilization of infrastructure, pollution mitigation, wastewater treatment, sediment control, prevention of storm damage, and other environmental rehabilitation with other several applications through bioremediation process. The phytoremediation potential of VG for of heavy metals and organic wastes is superior to other plant species due to its high biomass production, rapid growth rate, high survival rate, and high accumulation potential. It can produce huge amount of biomass and highly tolerate to adverse climatic conditions such as drought, flood, submergence and high temperature variation, highly acidic, alkaline, saline and sodic soils with high levels of aluminum and manganese, and a wide range of toxic metals with the maximum concentration such as arsenic (959 mg/kg), boron (180 mg/kg), cadmium (60 mg/kg), copper (3291 mg/kg), chromium (2290 mg/kg), lead (10750 mg/kg), and zinc (2472 mg/kg). 6 cm root length of VG was observed as optimal root length that could help to grow fast and accumulate large amount of cadmium within its tissues. The remediation ability of plants for heavy metals contaminated soils can be analyzed by TF and BF. The uptake and accumulation of heavy metals, such as As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn, were found higher in roots, and some amounts have been translocated in shoot. Its efficiency of uptake and accumulation of metals within its roots and shoot can be increased with the addition of chelators. The accumulation of metals (Fe, Mn, Zn, Cr, and Cu) in plant tissues does not reflect any major adverse effect on plant metabolism and its productivity. The VG with its roots together constitutes a carbon sink of more than 1,00,000 kg/hectare/day, reducing the global warming. Due to its ability of extraction, translocation, and confinement of the major toxic metals and organic waste within its roots and shoots, the VG is considered as an excellent and ideal candidate for the bioremediation of contaminated soil and water with metals and organic wastes.

6.1 Application of Vetiver System

The VS is a very efficient, esthetically looking pleasant and cost-effective methods for treating contaminated soil, sediments and wastewater effluent, and leachate of domestic and industrial sources. The paste of roots and shoots of vetiver grass had been used for medicinal purposes for long time by several Indian tribes. It is used for stabilization of coal fly ash due to its fine root structures. Its shoots, due to least storage of heavy metals in leaves tissues from fly ash, can be safely grazed by animals. The vetiver has been proved as a practical and environment friendly tool for restoration of dumpsites of fly ash. Holocellulose (cellulose plus hemicellulose) has been found in its compositions is 44.66% by weight and lignin 33.07%; therefore, it can be beneficial to extract activated carbon from the VG due to sufficient amount of lignin present. Due to its complex and fine structured root system, vetiver is used for slope stability in rural areas and oil production. It provides green and beautiful esthetical looks along the highway embankments used for stability of slopes.

7 Future Research Possibilities

The phytoremediation of contaminated soil and water is a sustainable and eco-friendly techniques with its least application cost and low maintenance. The safe disposal of post-remediation biomass is an emerging topic for research in the field of phytoremediation. There are several possibilities for research to be worked on the fate of heavy metals absorbed by vetiver grass after phytoremediation project. The assessment of health risk analysis for utilization of ash containing heavy metals in the construction industries such as brick works and as a fill material beneath the flyover bridges. The biomass of vetiver grass can be used as fuel due to presence of lignin and cellulose. The utilization of post-remediated biomass as a compressed pallet in the thermal power plant for energy production can be studied due to higher calorific value of vetiver grass (40% of benzoic acid). There are several research possibilities on post-remediated contaminated biomass such as production of activated carbon and accumulated metals in the plant biomass can be regain through the phytomining or metal recovery processes.

References

1. J.F. Veldkamp, A revision of Chrysopogon Trin. including Vetiveria Bory (Poaceae) in Thailand and Malesia with notes on some other species from Africa and Australia, Austrobaileya, vol. 5, no. 3 (1999), pp. 503–533
2. C. Ghosh, S. Bhattacharya, Landslides and erosion control measures by vetiver system, in disaster risk governance in India and cross cutting issues, disaster risk reduction (2018), pp. 387–413

3. M. Mucciarelli, C.M. Bertea, M. Cozzo, S. Scannerini, M. Gallino, Vetiveria zizanioides as a tool for environmental engineering, in *Proceedings plant biotechnology as a tool for the exploitation of mountain lands acta horticulture*, vol. 457 (1998), pp. 261–269. https://doi.org/10.17660/actahortic.1998.457.33
4. P. Truong, The global impact of vetiver grass technology on the environment, in *Proceedings of the second international conference on vetiver. Office of the royal development projects board* (2000), pp. 48–61
5. J.C. Greenfield, Vetiver grass: an essential grass for the conservation of the planet earth (Infin. Publ., 2002)
6. P. Truong, Effects of shading on vetiver growth: a photo essay (1993). Available www.vetiver.org
7. P.N.V Truong, Vetiver grass technology for mine tailing rehabilitation, in *First Asia-Pacific Conference on Ground and Water Bio-engineering* (Manila, 1999), pp. 1–8
8. N. Roongtanakiat, P. Chairoj, Uptake potential of some heavy metals by vetiver grass. Kasetsart J., Nat. Sci. **35**(1), 46–50 (2001)
9. V. Van Minh, N. Van Khanh, L. Van Khoa, Potential of using vetiver grass to remediate soil contaminated with heavy metals. VNU J. Sci. Earth Sci. **27**, 146–150 (2011)
10. X. Chen, Y. Liu, G. Zeng, G. Duan, X. Hu, M. Zou, The optimal root length for vetiveria zizanioides when transplanted to Cd polluted soil. Int. J. Phytoremediation, 37–41 (2014)
11. F. Gravand, A. Rahnavard, G.M. Pour, Investigation of vetiver grass capability in phytoremediation of contaminated soils with heavy metals (Pb, Cd, Mn, and Ni). Soil Sediment. Contam. An Int. J. 1–24 (2020)
12. R. Wasino, S. Likitlersuang, D. Janjaroen, The performance of vetivers (Chrysopogon zizaniodes and Chrysopogon nemoralis) on heavy metals phytoremediation: laboratory investigation. Int. J. Phytoremediation **21**(7), 624–633 (2019)
13. F.F. Masinire, D.O. Adenuga, S.M. Tichapondwa, E.M.N. Chirwa, Remediation of chromium (VI) containing wastewater using chrysopogon zizanioides (Vetiver Grass). Chem. Eng. Trans. **79**, 385–390 (2020)
14. A.K. Shanker, V. Ravichandran, G. Pathmanabhan, Phytoaccumulation of chromium by some multipurpose-tree seedlings. Agrofor. Syst. **64**, 83–87 (2005)
15. G.S. Dheri, M.S. Brar, S.S. Malhi, Comparative Phytoremediation of chromium—contaminated soils by fenugreek, spinach, and raya. Commun. Soil Sci. Plant Anal. **38**(11–12), 1655–1672 (2007)
16. R. Antiochia, L. Campanella, P. Ghezzi, K. Movassaghi, The use of vetiver for remediation of heavy metal soil contamination. Anal. Bioanal. Chem. **388**(4), 947–956 (2007)
17. A.K. Nayak, S.S. Panda, A. Basu, N.K. Dhal, Enhancement of toxic Cr (VI), Fe, and other heavy metals phytoremediation by the synergistic combination of native Bacillus cereus strain and Vetiveria zizanioides L. Int J Phytoremediation **20**(7), 682–691 (2018)
18. L.T. Danh et al., Economic incentive for applying vetiver grass to remediate lead, copper and economic incentive for applying vetiver grass to remediate lead, copper and zinc contaminated soils. Int. J. Phytoremediation **13**(1), 47–60 (2011)
19. M. Bahraminia, M. Zarei, A. Ronaghi, R. Ghasemi-Fasaei, Effectiveness of Arbuscular mycorrhizal fungi in phytoremediation of lead-contaminated soil by vetiver grass. Int. J. Phytoremediation **6514**, 1–33 (2015)
20. P.C. Badger, Ethanol from cellulose: a general review, in *Trends in New Crops and New Uses*, ed. by J. Janick, A. Whipkey (ASHS Press, Alexandria, VA, 2002), pp. 17–21
21. L.T. Danh, P. Truong, R. Mammucari, A. Biology, Effect of Calcium on growth performance and essential oil of vetiver grass (Chrysopogon zizanioides) grown on lead contaminated soils. Int. J. Phytoremediation **13**(1), 37–41 (2011)
22. S. Chantachon, M. Kruatrachue, P. Pokethitiyook, S. Upatham, S. Tantanasarit, V. Soonthornsarathool, Phytoextraction and accumulation of lead from contaminated soil by vetiver grass: laboratory and simulated field study. Water. Air. Soil Pollut. **154**(1–4), 37–55 (2004)
23. Y. Chen, Z. Shen, X. Li, The use of vetiver grass (Vetiveria zizanioides) in the phytoremediation of soils contaminated with heavy metals. Appl. Geochem. **19**(10), 1553–1565 (2004)

24. I. Angin, M. Turan, Q.M. Ketterings, A. Cakici, Humic acid addition enhances b and Pb phytoextraction by vetiver grass (Vetiveria zizanioides (L.) Nash). Water. Air. Soil Pollut. **188**(1–4), 335–343 (2008)
25. S.S. Andra et al., Induction of lead-binding phytochelatins in vetiver grass [Vetiveria zizanioides (L.)]. J. Environ. Qual. **38**(3), 868–877 (2009)
26. M.M. Taleei, N. Karbalaei Ghomi, S.A. Jozi, Arsenic Removal of contaminated soils by phytoremediation of vetiver grass, chara algae and water hyacinth. Bull. Environ. Contam. Toxicol. **102**(1), 134–139 (2019)
27. H. Shahandeh, L.R. Hossner, Plant screening for chromium phytoremediation. Int. J. Phytoremediation **2**(1), 31–51 (2000)
28. R.G. Riley, J.M. Zachara, F.J. Wobber, Chemical and selection on DOE lands of contaminant subsurface tures for science research, in *US-DOE* (Office of Energy Research Subsurface Science Program Washington, D.C., 1992), pp. 1–80
29. L.S. Thakur, A.K. Varma, P. Mondal, Analysis of thermal behavior and pyrolytic characteristics of vetiver grass after phytoremediation through thermogravimetric analysis. J. Therm. Anal. Calorim. **131**(3), 3053–3064 (2018)
30. N. Dudai, E. Putievsky, D. Chaimovitch, M. Ben-Hur, Growth management of vetiver (Vetiveria zizanioides) under mediterranean conditions. J. Environ. Manage. **81**(1), 63–71 (2006)
31. L.T. Danh, P. Truong, R. Mammucari, T. Tran, N. Foster, Vetiver grass, vetiveria zizanioides: a choice plant for phytoremediation of heavy metals and organic wastes. Int. J. Phytoremediation **11**(8), 664–691 (2009)
32. L.T. Danh, P. Truong, R. Mammucari, N. Foster, Extraction of vetiver essential oil by ethanol-modified supercritical carbon dioxide. Chem. Eng. J. **165**(1), 26–34 (2010)
33. F.A. Melato, N.S. Mokgalaka, R.I. Mccrindle, Adaptation and detoxification mechanisms of Vetiver grass (Chrysopogon zizanioides) growing on gold mine tailings. Int. J. Phytoremediation 6514, 1–46 (2015)
34. E. Meyer et al., Arbuscular mycorrhizal fungi in the growth and extraction of trace elements by Chrysopogon zizanioides (vetiver) in a substrate containing coal mine wastes. Int. J. Phytoremediation **19**(2), 113–120 (2017)

Performance Evolution and Analytical Approach of Air Pollution Control System in Al Foundry

Anas Khan, Shaurya Kumar Singh, Davinder Singh, and Tarun Kumar

1 Introduction

A significant issue has been air contamination from squander vapour, exhaust and deposits created in the foundry. Consistently our globe handles around 2.5 billion tons of crude and non-mineral products. This prompts the arrival of 200 just as 250 million tons of compressed canned products and 250 million tons of sulphur dioxide just as a critical extent of other dangerous organization blends [1]. A sweeping methodology to battling contamination is expected; solid advances should be taken to lessen the amount of toxin delivered at each conceivable area. The reuse of waste gas and the improvement of a maintainable waste administration framework may add to an economical future. The presentation begins with an outline of the organization's distinctive cycle types, a portrayal of spreads and a conversation of advancements used to direct surges from foundries, particularly those engaged with optional aluminium reusing and projecting.

A. Khan (✉) · S. K. Singh · T. Kumar
Department of Civil Engineering, Greater Noida Institute of Technology, Greater Noida, Uttar Pradesh 201310, India
e-mail: khan.anas86@gmail.com

D. Singh
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology Jalandhar, Punjab 144011, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_7

1.1 Objective of the Air Pollution Control System for Secondary Al Recycling and Casting Process

- Exhaust emissions may be cleaned using a variety of methods. This system consists of a burner, cooling towers, bag house filters, an aluminium melting crucible furnace, a chimney linked to a suction blower, and extremely effective wet scrubbers.
- This system is responsible for the regulation of critical parameters such as NO_2, SO_2, CO and suspended particle counts. The remaining gas is now totally dry and particle-free and is ready to leave the chimney through the flue.
- This sector offers a tremendous amount of room for growth and technical progress. Combustion analysis and fuel efficiency improvements, as well as the installation of this pollution control system, would substantially boost this industry's competitiveness.

Pollution control systems are a need in the modern day. Air pollutants are produced both naturally (through volcanic eruptions and wildfires) and artificially (by mobile and permanent sources). Portable sources are those that move, like airplane, trains and vehicles, while fixed sources are those that are set up, for example, power plants, businesses and different offices. Critical sources radiate no less than 11 tons of a solitary air poison or possibly 26 tons of a blend of air harms, while district sources discharge under 11 tons of a solitary tainting or under 26 tons of a mix of defilements. At the point when pollutions from compact or fixed sources arrive at adequately high focuses, they can detrimentally affect the air, the overall environment, and human life, like expanding the normal worldwide temperature, diminishing air detectable quality, corrupting air quality and weakening human prosperity. The Natural Assurance Office (EPA) endorsed the Spotless Air Act (CAA), which forced limitations on both the sources and beneficiaries of air contamination to alleviate their hostile consequences for the air, the environment and human existence.

The EPA regulates three kinds of pollutants: criterion air pollutants, air toxics and greenhouse gases.

Criteria air poisons are an assortment of six significant sorts of air contamination—particulate matter (PM), photochemical oxidants (e.g. ozone), carbon monoxide, sulphur oxide, nitrogen oxide and lead—that can adversely affect human well-being and government help, the climate and environment and close by structures.

- The expression "air toxics" alludes to an assortment of more than 180 air poisons, including regular artificial materials, unstable natural mixtures (VOCs), metals and metal combinations, for example, empowers, solvents, mercury, arsenic, asbestos and benzene, that can have inconvenient well-being and environmental impacts regardless, when present in higher fixations and delivered by less sources than model toxins.
- Ozone depleting substances (GHGs) are gases like carbon dioxide, chlorofluorocarbons (CFCs), methane and ozone that antagonistically impact human well-being and add to the strengthening of earth's ecological impact and ensuing effect

on the worldwide climate. In total, the guidelines overseeing these different sorts of air poisons direct a portion of the variables that enterprises should consider staying agreeable with EPA principles, for example, carrying out the vital and appropriate air contamination control gear and frameworks and keeping away from government repercussions.

Industrial Applications of Air Pollution Control Equipment

- Nuclear power plants
- Metallurgical facilities
- Refineries of petroleum and natural gas
- Mills de papier
- Coating and printing establishments
- Manufacturing of chemicals
- Manufacturing of rubber and plastic
- Refineries of petroleum and natural gas
- Controlling Methods In foundries for Air Emission.

For foundry particles, there are two principle gathering strategies: wet and dry. Wet scrubbers are accessible in low-and high-energy arrangements. Bughouses, mechanical authorities and electrostatic precipitators are generally instances of dry gathering. Furthermore, cremation or max engine thrust might be expected to decrease natural compound emanations. Exceptional consideration ought to be given to air toxics, which requires cautious choice of the discharge control method.

Scrubbers—Scrubbers, sometimes referred to as gas scrubbers, are devices that purify air emissions. Their technique enables them to halt the subsequent polluting release, which is as damaging to the atmosphere as sulphur spewed by ships. Scrubbers, who are shaped like cylindrical tanks, collect this gas and use liquid to neutralize the contaminants' components. Depending on the pollutants to be treated, the liquid may be water, a chemical reagent, or a combination of the two.

Nitrogen derivatives may be absorbed in an acidic environment, while sulphur derivatives can be eliminated in an alkaline or oxidising environment. There are also certain pollutants that are very water soluble and do not need the use of chemical reagents during the washing procedure.

However, the outcome of liquid-gas interaction is always the same: separation of contaminating molecules. This results in the production of a non-toxic, clean gas that may be released into the atmosphere.

Wet Scrubbers are based upon the inertia based impaction of particles and direct throw or interception of those particles which are employed in the wet-type collector to capture and accumulate the particles. These might be utilized alone or in mix. Free researchers set up the contact power theory, which contends that the assortment effectiveness of an all-around planned wet scrubber is a component of the energy utilized noticeable all around to-water contact measure and isn't dependent on the authority plan.

On this reason, it is sensible to expect comparable execution from very much planned authorities working at or close to a similar pressing factor drop. All wet

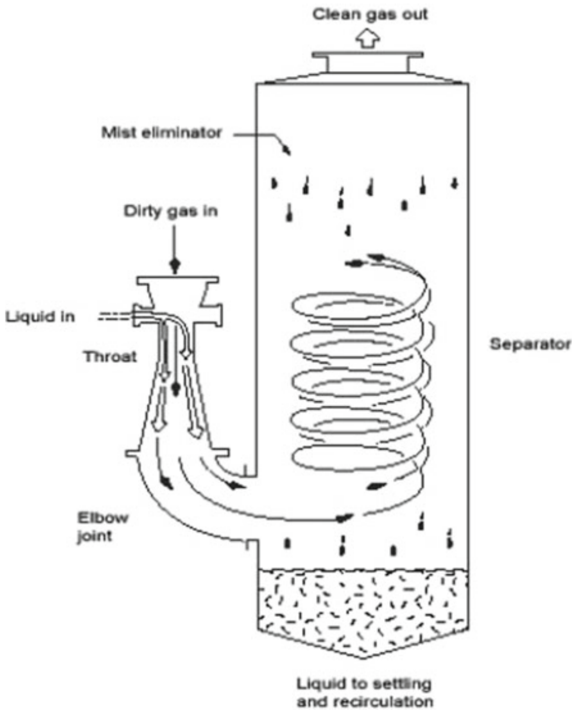


Fig. 1 Wet scrubber

authorities have a fragmentary proficiency trademark, which implies that their cleaning viability shifts as indicated by the molecule size being gathered. Overall, gatherers working at extremely low pressing factor misfortune recuperate simply medium to coarse particles.

More prominent energy input is needed for high-effectiveness assortment of minuscule particles, which is reflected in expanded authority pressure misfortune. Alongside molecule matter, gas scrubbers might be used to lessen smells, dangerous, and sulphur dioxide outflows. Acids, bases or oxidizing specialists may should be added to the cleaning arrangements in this example. This stream should be discarded as per metal embellishment and projecting gushing guidelines (Fig. 1).

2 Methodology

Various methods exist for cleaning exhaust gases from optional aluminium reusing and projecting cycles. This framework is involved a burner, cooling towers, pack house channels, an aluminium dissolving cauldron heater, a stack associated with a pull blower, and profoundly effective wet scrubbers. We need to recommend that this is a productive methodology for decreasing air discharges in foundries and adding to the making of a perfect climate.

This framework is answerable for checking and controlling key boundaries like NO_2, SO_2, CO and suspended molecule matter. We will show the variation of NOx, SOx and SPM by trend line equation as shown in Figs. 2, 3 and 4 and calculate the stimulated model and from stimulated model we will show the standard deviation in graph as shown in Figs. 5, 6 and 7.

The exertion might be cantered around receiving this methodology that is advantageous for limiting, treating and discarding air discharges.

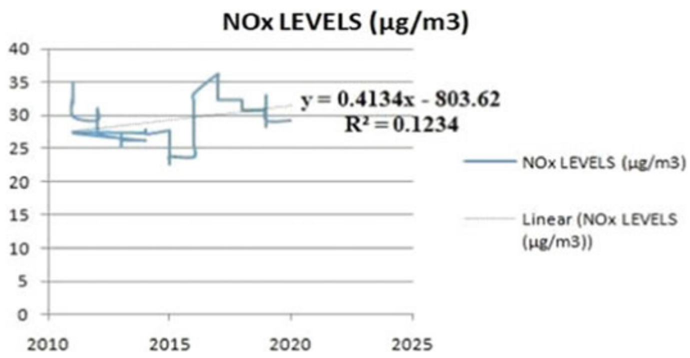


Fig. 2 Trend of individual values of oxides of nitrogen

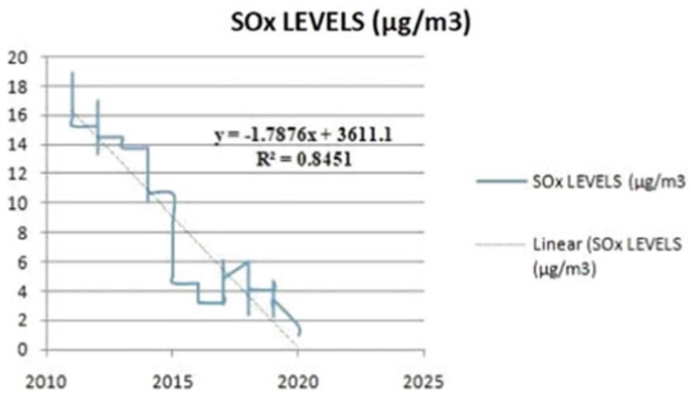


Fig. 3 Trend of individual values of oxides of sulphur

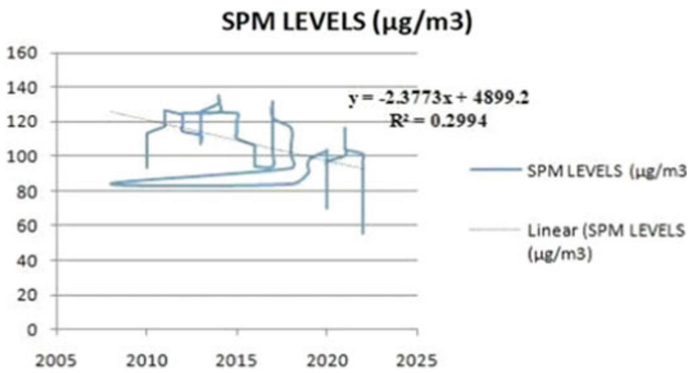


Fig. 4 Trend of Individual values of suspended particulate matter

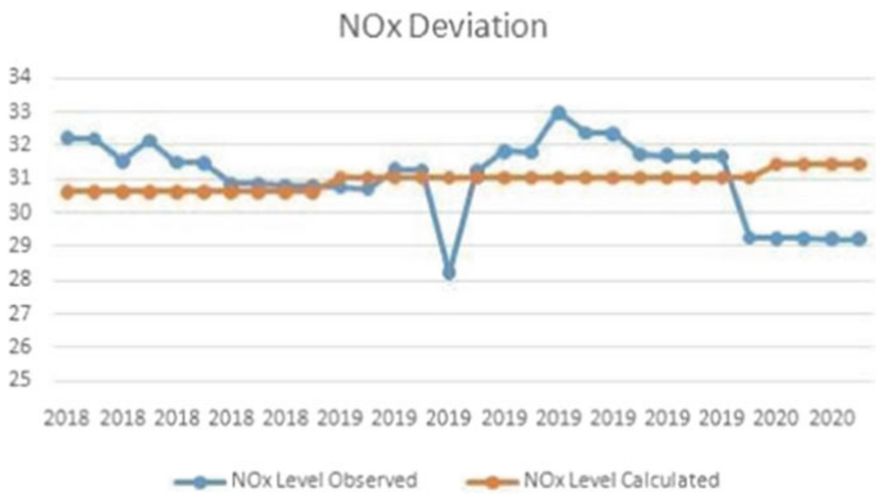


Fig. 5 Standard deviation of oxides of nitrogen

3 Result and Discussion

Individually, three graphs are plotted which include SOx, NOx and SPM with the trend line equation and linear line (dotted line). From the previous research data, i.e. observed value. Thus, calculated value are obtained by taking in consideration the 75% previous research data, that is observed data and from remaining 25% data having both x and y values from observed data (previous data) are obtained and from 25% data graphs are plotted of SOx, NOx and SPM, respectively. So, from 25% data we will get the stimulated model and from stimulated model the standard deviation of SOx, NOx and SPM will obtained and analysed.

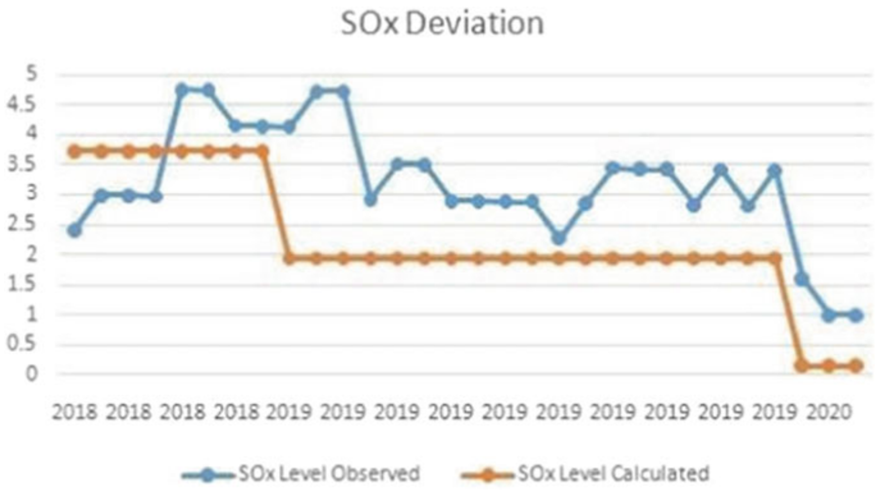


Fig. 6 Standard deviation of oxides of sulphur

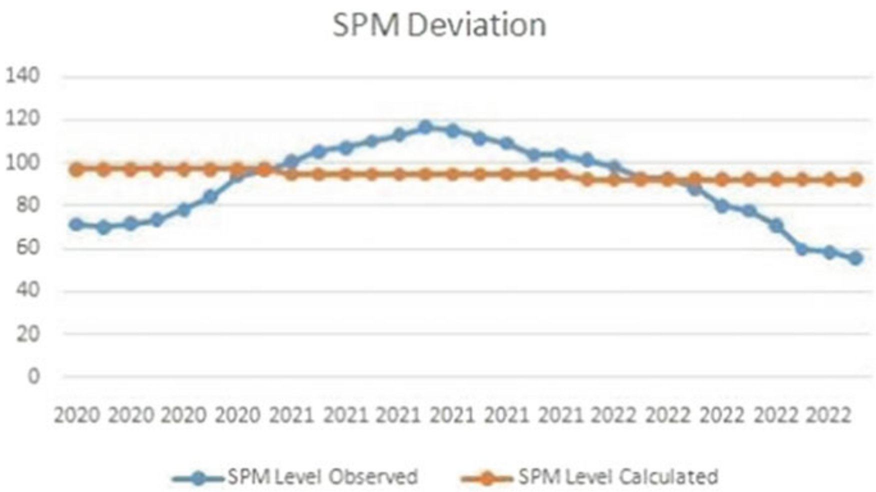


Fig. 7 Standard deviation of suspended particulate matter

Hence, standard deviation of NOx, SOx and SPM is secure between the 75% observed value (i.e. previous research data) and 25% calculated value. Proceeds both observed value and calculated value in account separate graph of NOx, SOx and SPM is plotted.

4 Conclusions

Al recycling and casting may be carried out without causing harm to the environment. This envisions the future of the aluminium scrap recycling and casting sectors being indigenous via structured and scientific metal scrapping and collecting facilities spread throughout India, reducing India's reliance on scrap imports. Additionally, remelting facilities create high-quality goods for a variety of industries. This will improve the Al sector's resource efficiency.

Disciplined worker conduct is also critical for meeting environmental, health, and safety requirements. Continuous education and training of employees and workers is therefore necessary for the establishment and maintenance of these standards. Environmental, health and safety controls that are satisfactory can only be accomplished via the proper operation and maintenance of production and pollution control facilities. The environment should be checked on a frequent basis to verify that control mechanisms are operating efficiently.

Environmental control technologies have been created and are accessible. It is just a matter of selecting the appropriate technology for the particular circumstances. Pollution control facilities should be incorporated into manufacturing plants. Environmental impact assessment is critical for making the final choice between various plant locations and facility designs. Top management should have a strong policy in place to safeguard the environment and the health and safety of employees. This policy should be integrated into the activities of the entire workforce, with adequate resource allocation and periodic monitoring.

Reference

1. G.S. Patange, et al, Investigation of air emission control system in Indian foundry. Int. J. Eng. Res. Technol. (IJERT) vol. 2 (2013)

Recovery Techniques and LCA Involved with Municipal Solid Waste Bottom Ash Treatment: A Review

Pravez Alam, Sanjeev Kumar, Davinder Singh, and Tarun Kumar

1 Introduction

Effective management of the daily production of municipal solid waste (MSW) is an urgent environmental issue. Various factors are responsible for the rapid increase of daily MSW in both urban and rural areas at a global level out of which improved lifestyle and increased population is the important ones. The World Bank study predicts a massive production of 6.1 MT/day by the year 2025 (The World Bank, 2019). Waste generation of such a huge number requires effective implementation of scientific technologies at both the point of generation and final disposal. Landfilling being the popular option of waste disposal has certain limitations, whereas the incineration of MSW comes with its environmental drawbacks. The wastes to energy generation (WTE) plants are the new popular means to meet the energy demand while dealing with MSW at the one end [1, 2]. These plants are designed and operated scientifically, and hence, the economic output compensates for the environmental setbacks. The concept of circular economy promotes the addition of final residues from these facilities to work with the production of essentials.

Studies suggest applications of bottom ash (BA) and fly ash (FA) in a variety of civil engineering applications. Many countries in Europe are already allowing BA usage as unbound construction aggregates as a replacement of natural aggregates in the subbase layers [3]. Further, applications include replacement in a definite amount in mortar, concrete, and building blocks productions [4, 5]. Since the composition of the residues depends directly on the type of the raw feed, the residue hence requires proper monitoring and examination for further applications. The chemical

P. Alam (✉) · S. Kumar · D. Singh
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India
e-mail: parvezalamce@gmail.com; praveza.ce.21@nitj.ac.in

T. Kumar
Greater Noida Institute of Technology, Greater Noida, Uttar Pradesh, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_8

Table 1 Chemical composition of MSW BA from recent studies

Components (wt.%)	[8]	[9]	[10]	[11]	[12]	[13]	[14]
Fe_2O_3	4.93	12.13	2.93	1.25	14.4	10.02	5.29
SiO_2	55.37	39.73	34.5	11.83	37.2	32.75	54.43
Al_2O_3	9.20	9.09	4.38	7.28	11.7	8.57	10.11
CaO	19.39	14.69	5.26	48.1	18.7	29.06	18.71
K_2O	0.43	0.91	0.88	3.65	1.2	1.24	0.52
MgO	0.41	2.10	1.52	2.07	2.6	1.75	0.53
P_2O_5	0.07	–	3.09	0.34	1.6	4.77	0.09
SO_3	1.53	–	5.04	6.76	0.9	3.01	1.67
Na_2O	0.24	1.77	1.63	4.05	–	–	0.28
TiO_2	–	–	1.12	0.34	1.3	1.57	–

compositions of MSW BA are from different studies are shown in Table 1. The concentrations of certain elements can be controlled using pre-treatment to avoid contamination due to certain traces of heavy metals. Due to the highly porous nature and poor particle distribution of BA, the applications are limited in the construction sector. This is the reason behind direct dumping into landfills [6, 7].

The paper gives a comprehensive outlook on different treatment options available for BA pre-treatment and their mechanisms. The common issue of leaching of heavy metals due to BA disposal in landfills is discussed in detail. The paper highlights metal and energy recovery options available due to the implementation of BA in industrial use. Studies related to life cycle assessments (LCAs) are also reviewed to establish the impact of BA use on the environment and its components. It also highlights the importance of a circular economy where BA has the potential to fulfill the requirement of the present century while serving the environment and economic benefits.

2 Leaching Mechanism

The heavy metal present in MSWI bottom ashes is very high compared to other combustion residues, posing more difficult tasks which require attention. When the majority of MSWI BA are disposed of at the designated sites, these water-soluble ions are likely to separate and join the environment. To minimize the effect, an immediate and viable process is needed to combat and prevent various toxic metals from being leached [15]. In previous years, incinerated ash has been disposed of without any treatment to landfill, which poses a significant danger because wind can move particles easily. Due to rain, soluble elements and compounds may leach that can affect the environment. For example, particles of such unstable ash will eventually reach the food chain through an underground water system. Generally, certain elements like Ca, Fe, Si, and Al, which appear in the ashes, typically causing toxic metal leaching. Various chemical reagents were used to extract metals from ash which, when dumped in the sites, would eventually reduce metal concentrations from the ashes. For example, sulfuric acid, nitric acid, and hydrochloric acid can be leached to toxic metal in a strongly acidic environment [16].

Geochemical process and hydrological factors are two main factors on which the leaching of MSWI BA depends. The geochemical process specifies a concentration range, while weathering/aging, pH, bulk material, particle size, and liquid-to-solid ratio and are included in hydrological factors. Liquid-to-solid ratio and pH are the two dominant factors influencing metal mobility. The solubility of metals varies between different metal species and changes in the pH are affected. The leaching behavior of trace elements therefore highly depends on pH. For metal, leaching is important in determining the correct liquid-to-solid ratio. The leaching process increases with a high liquid-to-solid ratio [17].

3 Pre-treatment Techniques for MSWI Bottom Ash

The purpose of separation procedures is to increase the quality of bottom ashes and also increasing their application. The separation process involves the separation of soluble salts, heavy metals, and other compounds through physical, chemical, or biological processes. The most common separating methods are washing, leaching, and electro-osmosis.

3.1 Separation Processes

Washing. This is a common pre-treatment method in which soluble salts are removed by water. Soluble substances such as Cl^-, K^+, and Na^+ can be effectively removed by washing [18]. The extraction efficiency of Ca and Pb increased with an increase in liquid–solid ratio, and it goes to 78.25% and 78%, respectively, when the ratio of liquid–solid is 100. However, the extraction efficiency of Cr, Cu, Zn, and Cd was unaffected by an increase in the liquid–solid ratio. Silicates and metal sulfides are the primary elements after washing [18]. The washing process is simple to use; the cost is low, and dust and soluble substances on the surface can be removed easily [19].

Leaching. Some other solvent solutions can be used for further extraction of heavy metals. Heavy metals like Pb, Cu, Al, and Zn can be recovered by the leaching process. The leaching agents are classified as the alkaline leaching agent, acid leaching agent, and biological leaching agent. The leaching effect is dependent on leaching agents, heavy metals, pH, liquid–solid ratios, temperature, and time. HCl, HNO_3, H_2SO_4, and other inorganic acids are the acid leaching agents [20]. The extraction efficiency of acid leaching is high and also has a good leaching effect, but it is costly. In comparison to the acid leaching agent, the alkaline leaching agent is more effective for specific metal elements like Pb and Zn [21]. Bioleaching is more environmentally friendly in comparison to chemical leaching and was originally used to extract heavy metals from minerals.

Electrodialysis. Electrodialysis is based on the reduction/oxidation reaction at the electrode–electrolyte interface [22]. In this process, oxygen is produced by the oxidation reaction of the anode, and metal and hydrogen are produced by the reduction reaction of the cathode. Temperature, pH, mixing condition, and current density are the influence factor. The inert metal is precipitated first and then active metal during the metal precipitation process. In order to increase solution conductivity and improve metal leakage performance, alkaline agents, acidic agents, and complexing agents can be added to the solution. The metal efficiency can also be increased by selective ion exchange [23].

3.2 Solidification and Stabilization Technology

The solidification and stabilization procedure refers to the employment of an additive or a binder to chemically and/or physically immobilize hazardous waste content [24]. The purpose of stabilization is to reduce the solubility and toxicity of contaminants. Binders, such as cement, are typically employed to encapsulate waste material in order to immobilize contaminants and minimize leachability. The disadvantage of this procedure is that it is not ideal for treating soluble salts, and long-term leaching will be an environmental issue [25]. The majority of solidification techniques are conceived to increase physical strength and material durability simultaneously. The technology for solidification/stabilizations primarily involves cement solidification, melting solidification, and chemical stabilization.

Cement Solidification Technology. This involves mixing the water and cement with the BA to occur the hydration reaction and to form a calcium silicate hydrate product with low toxicity to the leaching of heavy metal and good stability in the long term [26]. Heavy metals can react to cement through sedimentation, ion exchange, adsorption, passivation, and other forms during the hydration phase of cement. The cement–ash mix showed a behavior close to that of compacted clay. For hazardous waste treatment, cement solidification technology is most commonly used worldwide. The advantages of this technology are low treatment cost, simple technology and equipment, a wide source of materials, and high strength [27].

Melt Curing Technology. MSWI bottom ash is melted by heating to 1400 °C and then cooled into slag. Following melt treatment, BA will decrease in volume by 1/3–1/2, with most dioxins decomposed [28]. A totally amorphous, homogenous vitreous body is the final product of the melt. The melting temperature and volatilization can reduce by adding MgO, SiO_2, CaF_2, coke, borax, and other auxiliary materials to ash. Slag may also be rendered into construction materials or used for the utilization of ash as a source of raw materials for ceramics, glass, and other industries [29].

Chemical Stabilization. Chemical stabilization is a method of chemical reactions to make toxic and hazardous compounds to low toxicity [30]. Organic curing agents and inorganic curing agents may be categorized into chemical agents. Na_2S, NaOH ferrous salt, and phosphate are inorganic curing agents, while EDTA and its sodium salt, polyamines, and derivatives are organic curing agents [31]. When the heavy metals are solidified in BA with an inorganic curing agent, however, it can help secondary heavy metal leaching, which exceeds the standard for the leaching of the treated residues. The long-term safety standards for hazardous waste disposal are difficult to fulfill [32]. The method of chemical stabilization has the benefits of being harmless, less or no compatible, and less expensive than other treatment and stabilization methods.

3.3 Thermal Treatment

By evaporating at a high temperature, heavy metals can be removed, or stable oxides can be formed. This approach works well with Ca, Cr, Pb, and Zn. High temperatures can also cause dioxins to degrade. Heat treatment is commonly done at temperatures between 1300 and 1400 °C [33]. Heat treatment waste gas contains heavy metal contaminants, which must be handled individually [34]. Thermal separation and thermal curing are two methods of heat treatment. The separation of heavy metals by evaporation at high temperatures is referred to as thermal separation. Thermal solidification is the process by which heavy metals are immobilized in materials through the production of stable products. The porosity of the products after heat treatment is lower, and their strength is higher when compared to those before heat treatment. In addition to the above methods of treatment, new processes are being developed too. For example, a recent small-scale study has been carried out in the CT Fluapur method, combining with a gas reactant which also used as a heat source, such as HCl from acid scrubber in an incinerator [35], which indicates that metal species like Pb, Cd, Zn, and Cu have almost been removed completely.

4 Recovery

4.1 Metal

Due to mineralogical chemical composition and origin, recovery of BA for secondary materials could be difficult due to its contamination with metals and organic contaminants. Fe is the most prevalent metal in BA that may be easily separated from other metals by means of a magnet. A number of studies have shown that up to 80% of

Fe can be recovered successfully. The recovery of ferrous metal is influenced by a number of different factors. On the other hand, Zn and Cu have a significant monetary value and are therefore valuable heavy metals to recover [36].

The treatment associated with metal recovery is categorized into three types, i.e., wet processing of wet BA, dry processing of wet BA, and dry processing of dry BA. The decision between dry and wet BA treatment is determined by the ash discharge system. The BA is quenched by contact with water using a wet extraction system and then delivered to a bunker using a ram discharger or a chain transport system [37].

Metal recovery treatment trains can be approached in two ways, without any aim of using the mineral component in building or with the aim to use the mineral component in the construction industry. These objectives guide the entire BA treatment process, from the discharge system to crushing and aging. Because BA can be used as a subbase layer in pavement construction when discharged wet and aged, crushing must be confined to large oversized particles over 40 mm. Instead, if the mineral component of BA dry discharge will not be used, it has various advantages and increases metal recovery from fine particles.

4.2 Energy

Paper, cardboard, glass, wood, rubber, plastic, biological waste, and textiles are the most common materials found in MSW. As a result, the energy-yielding components of MSW account for approximately 82% of the overall volume of MSW [38]. In contrast to hydrocarbons, MSW has a low calorific value and a high concentration of hazardous gases. As a result, MSW cannot be used as a substitute for hydrocarbons. It is critical to conduct research on converting MSW into energy as part of a composite fuel employing high-potential industrial technologies. The ignition and combustion of composite fuel liquid can be improved by adding fine MSW particles, which also delivers an equivalent quantity of energy during burning [38].

Tan et al., investigated and assessed the framework of three assessments for waste-to-energy technologies analysis (energy, economic, and environmental (3E)) for Malaysian municipal solid waste (MSW) management [39] (Fig 1). When the production of power and heat was evaluated, the 3E assessment revealed that incineration was the optimal technology choice. Anaerobic digestion was determined to be more advantageous when considering simply electricity production. The money from MSW electricity generation might be raised due to electricity sales additionally; a coal-based power plant can achieve significant CO_2 avoidance [40]. Figure 2 shows the waste-to-energy analysis in general.

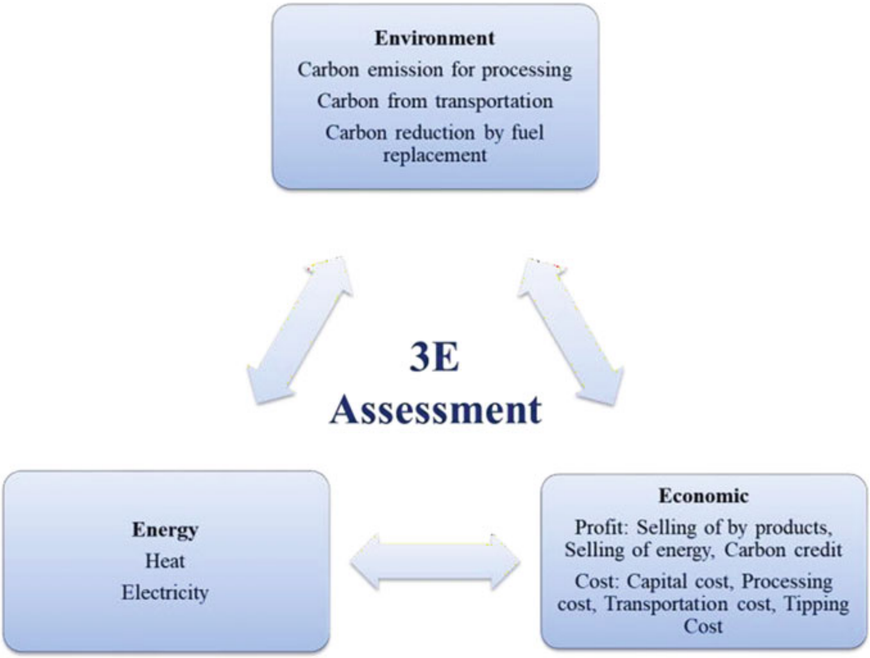


Fig. 1 3E assessment framework for waste-to-energy technologies

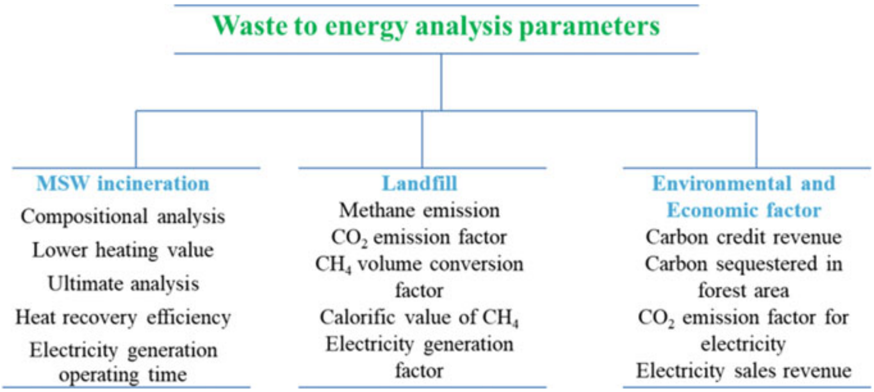


Fig. 2 Waste-to-energy analysis parameters

5 Life Cycle Assessment

Life cycle assessment is a comprehensive approach that can be used to analyze waste management systems and discover environmental advantages as well as important components of those systems [41]. Through the software tool, a life cycle assessment provides insight into the benefits associated with MSW BA utilization by potentially substituting the production and disposal of raw materials. For example, the fate and movement of pollutants, as well as the important components which contribute to such transport, might be modeled, allowing for predictions based on various scenarios. Given a set of boundary circumstances, the data could also imply other aspects, such as ecotoxicity and leaching emissions.

Regardless of the type of leaching data, the consequences of pollutant leaching from BA should not be ignored in life cycle assessment analyses of waste management systems where waste-to-energy systems or more generally benefits from energy recovery play a key role [42]. A life cycle assessment was used to determine whether landfill disposal or using the material as aggregate in roadways was superior to using BA as a concrete aggregate due to metal leaching during the recycling phase of the demolished concrete [43]. Dabo et al., studied the use of BA for road and parking lot building, with a focus on the long-term evolution of leachate chemistry and mineralogical transformation of the BA in a trial setup in northern France during 10 years [44]. Batch tests on core samples drilled after 10 years and geochemical modeling support the data interpretation. Heavy metals and pH concentrations in leaching reduced considerably during the first 2 years, then progressively decrease over the next 10 years, eventually reaching a set of lowest values. The concentration of SO^{2-} shows a slightly increasing tendency with time, with maximum concentration peaks occurring at 3 months. In terms of ash evolution, the actual pH of the paved material has not decreased considerably from its initial value of 12.3 for the fresh BA although it is significantly higher than the leachate at approximately 8 after 10 years. This is due to the lack of carbonation and gas exchange caused by the lack of air and water.

6 Conclusions

Since the BA generated from MSW incineration plants has a variety of components, the applications of BA are not limited to a certain area. With the recent studies regarding the impact of leachate generated by BA disposal and resource recovery, the following comments can be made.

- Incineration is not a new concept for solid waste management and disposal. When combined with waste to energy, the economic viability of incineration suggests a potential for a better and sustainable future.
- The by-products obtained after the incineration can be a threat to the environment; hence, treatment is recommended before disposal or further reuse. Thus, the understanding of the true nature of BA and its components is necessary.

- The employment of BA for specific applications can be made only if it exhibits certain physiochemical properties. Thus, specific standards for BA reuse are required to be followed at a global level.
- Technological advancements can be employed for a resource recovery to achieve maximum economic benefits. These advancements also make sure that the impact of incineration has minimal impact on the environment and its sub-components.
- To avoid leaching, solidification/stabilization of BA is recommended where ash the pre-treatment techniques like separation, thermal treatment, and chemical treatments are also the other viable options to follow.
- Using BA as a raw material for ceramic production avoids the high probability of leaching. The other applications like landfill covering material, cement concrete aggregated, or highway engineering material are also economical yet require control on leaching.

References

1. P.N. Ashani, M. Shafiei, K. Karimi, Biobutanol production from municipal solid waste:technical and economic analysis. Bioresour. Technol. **308** (2020). https://doi.org/10.1016/j.biortech.2020.123267
2. N. Wang, D. Chen, U. Arena, P. He, Hot char-catalytic reforming of volatiles from MSW pyrolysis. Appl. Energy. **191**, 111–124 (2017). https://doi.org/10.1016/j.apenergy.2017.01.051
3. D. Blasenbauer, F. Huber, J. Lederer, M.J. Quina, D. Blanc-Biscarat, A. Bogush, E. Bontempi, J. Blondeau, J.M. Chimenos, H. Dahlbo, J. Fagerqvist, J. Giro-Paloma, O. Hjelmar, J. Hyks, J. Keaney, M. Lupsea-Toader, C.J. O'Caollai, K. Orupõld, T. Pająk, F.G. Simon, L. Svecova, M. Šyc, R. Ulvang, K. Vaajasaari, J. Van Caneghem, A. van Zomeren, S. Vasarevičius, K. Wégner, J. Fellner, Legal situation and current practice of waste incineration bottom ash utilisation in Europe. Waste Manag. **102**, 868–883 (2020). https://doi.org/10.1016/J.WASMAN.2019.11.031
4. C.J. Lynn, G.S. Ghataora, R.K. Dhir OBE, Municipal incinerated bottom ash (MIBA)characteristics and potential for use in road pavements. Int. J. Pavement Res. Technol. **10**, 185–201 (2017). https://doi.org/10.1016/j.ijprt.2016.12.003
5. D. Singh, T. Kumar, B.E. James, M. Hanifa, Utilization of MSWI ash for geotechnical applications: a review. Lect. Notes Civ. Eng. **31**, 229–236 (2019). https://doi.org/10.1007/978-981-13-7010-6_22
6. J. Hykš, O. Hjelmar, Utilisation of incineration bottom ash (IBA) from waste incineration-prospects and limits (2018)
7. S. Kumar, D. Singh, Municipal solid waste incineration bottom ash: a competent raw material with new possibilities. Innov. Infrastruct. Solut. **6** (2021). https://doi.org/10.1007/S41062-021-00567-0
8. D. Singh, A. Kumar, Mechanical characteristics of municipal solid waste incineration bottom ash treated with cement and fiber. Innov. Infrastruct. Solut. **4**, 1–7 (2019). https://doi.org/10.1007/s41062-019-0247-7
9. N. Saikia, G. Mertens, K. Van Balen, J. Elsen, T. Van Gerven, C. Vandecasteele, Pre- treatment of municipal solid waste incineration (MSWI) bottom ash for utilisation in cement mortar. Constr. Build. Mater. **96**, 76–85 (2015). https://doi.org/10.1016/j.conbuildmat.2015.07.185
10. B.K. Biswal, Z. Chen, E.H. Yang, Hydrothermal process reduced Pseudomonas aeruginosa PAO1-driven bioleaching of heavy metals in a novel aerated concrete synthesized using municipal solid waste incineration bottom ash. Chem. Eng. J. **360**, 1082–1091 (2019). https://doi.org/10.1016/j.cej.2018.10.155

11. K. Yan, H. Sun, F. Gao, D. Ge, L. You, Assessment and mechanism analysis of municipal solid waste incineration bottom ash as aggregate in cement stabilized macadam. J. Clean. Prod. **244**, 118750 (2020). https://doi.org/10.1016/j.jclepro.2019.118750
12. Q. Alam, A. Lazaro, K. Schollbach, H.J.H. Brouwers, Chemical speciation, distribution and leaching behavior of chlorides from municipal solid waste incineration bottom ash. Chemosphere **241** (2020). https://doi.org/10.1016/j.chemosphere.2019.124985
13. Y. Song, B. Li, E.-H. Yang, Y. Liu, Z. Chen, Gas generation from incinerator bottom ash: potential aerating agent for lightweight concrete production. J. Mater. Civ. Eng. **28**, 04016030 (2016). https://doi.org/10.1061/(ASCE)MT.1943-5533.0001524
14. P. Alam, D. Singh, S. Kumar, Incinerated municipal solid waste bottom ash bricks: a sustainable and cost-efficient building material. Mater. Today Proc. (2021). https://doi.org/10.1016/J.MATPR.2021.07.346
15. X. Gao, B. Yuan, Q.L. Yu, H.J.H. Brouwers, Characterization and application of municipal solid waste incineration (MSWI) bottom ash and waste granite powder in alkali activated slag. J. Clean. Prod. **164**, 410–419 (2017). https://doi.org/10.1016/j.jclepro.2017.06.218
16. K. Komonweeraket, B. Cetin, C.H. Benson, A.H. Aydilek, T.B. Edil, Leaching characteristics of toxic constituents from coal fly ash mixed soils under the influence of pH. Waste Manag. **38**, 174–184 (2015). https://doi.org/10.1016/j.wasman.2014.11.018
17. M.A. Al-Ghouti, M. Khan, M.S. Nasser, K. Al-Saad, O.E. Heng, Recent advances and applications of municipal solid wastes bottom and fly ashes: Insights into sustainable management and conservation of resources. Environ. Technol. Innov. **21**, 101267 (2021). https://doi.org/10.1016/j.eti.2020.101267
18. K.Y. Chiang, Y.H. Hu, Water washing effects on metals emission reduction during municipal solid waste incinerator (MSWI) fly ash melting process. Waste Manag. **30**, 831–838 (2010). https://doi.org/10.1016/j.wasman.2009.12.009
19. Y. Xu, Y. Fu, W. Xia, D. Zhang, D. An, G. Qian, Municipal solid waste incineration (MSWI) fly ash washing pretreatment by biochemical effluent of landfill leachate: a potential substitute for water. Environ. Technol. (United Kingdom) **39**, 1949–1954 (2018). https://doi.org/10.1080/09593330.2017.1345985
20. G. Cornelis, T. Van Gerven, C. Vandecasteele, Antimony leaching from uncarbonated and carbonated MSWI bottom ash. J. Hazard. Mater. **137**, 1284–1292 (2006). https://doi.org/10.1016/j.jhazmat.2006.04.048
21. W. Li, Y. Sun, Y. Huang, T. Shimaoka, H. Wang, Y. Wang, L. Ma, D. Zhang, Evaluation of chemical speciation and environmental risk levels of heavy metals during varied acid corrosion conditions for raw and solidified/stabilized MSWI fly ash. Waste Manag. **87**, 407–416 (2019). https://doi.org/10.1016/j.wasman.2019.02.033
22. P.E. Jensen, G.M. Kirkelund, K.B. Pedersen, C. Dias-Ferreira, L.M. Ottosen, Electrodialytic upgrading of three different municipal solid waste incineration residue types with focus on Cr, Pb, Zn, Mn, Mo, Sb, Se, V, Cl and SO4. Electrochim. Acta. **181**, 167–178 (2015). https://doi.org/10.1016/j.electacta.2015.06.012
23. A.J. Pedersen, L.M. Ottosen, A. Villumsen, Electrodialytic removal of heavy metals from different fly ashes: influence of heavy metal speciation in the ashes. J. Hazard. Mater. **100**, 65–78 (2003). https://doi.org/10.1016/S0304-3894(03)00064-5
24. C.C. Wiles, Municipal solid waste combustion ash: state-of-the-knowledge. J. Hazard. Mater. **47**, 325–344 (1996). https://doi.org/10.1016/0304-3894(95)00120-4
25. N. Alba, E. Vázquez, S. Gassó, J.M. Baldasano, Stabilization/solidification of MSW incineration residues from facilities with different air pollution control systems. Durability of matrices versus carbonation. Waste Manag. **21**, 313–323 (2001). https://doi.org/10.1016/S0956-053X(00)00082-9
26. B. Du, J. Li, W. Fang, Y. Liu, S. Yu, Y. Li, J. Liu, Characterization of naturally aged cement-solidified MSWI fly ash. Waste Manag. **80**, 101–111 (2018). https://doi.org/10.1016/j.wasman.2018.08.053
27. K. Yin, A. Ahamed, G. Lisak, Environmental perspectives of recycling various combustion ashes in cement production—a review (2018). https://doi.org/10.1016/j.wasman.2018.06.012

28. H. Harada, M. Takaoka, K. Oshita, N. Takeda, T. Matsumoto, Ash-melting process utilizing thermite reaction between chromium electroplating sludge and aluminum dross. Environ. Eng. Sci. **22**, 716–724 (2005). https://doi.org/10.1089/ees.2005.22.716
29. Y. Yue, J. Zhang, F. Sun, S. Wu, Y. Pan, J. Zhou, G. Qian, Heavy metal leaching and distribution in glass products from the co-melting treatment of electroplating sludge and MSWI fly ash. J. Environ. Manage. **232**, 226–235 (2019). https://doi.org/10.1016/j.jenvman.2018.11.053
30. L. Benassi, M. Pasquali, A. Zanoletti, R. Dalipi, L. Borgese, L.E. Depero, I. Vassura, M.J. Quina, E. Bontempi, Chemical stabilization of municipal solid waste incineration fly ash without any commercial chemicals: first pilot-plant scaling up. ACS Sustain. Chem. Eng. **4**, 5561–5569 (2016). https://doi.org/10.1021/acssuschemeng.6b01294
31. W.J. Huang, J.S. Lo, Synthesis and efficiency of a new chemical fixation agent for stabilizing MSWI fly ash. J. Hazard. Mater. **112**, 79–86 (2004). https://doi.org/10.1016/j.jhazmat.2004.04.006
32. W. Ma, D. Chen, M. Pan, T. Gu, L. Zhong, G. Chen, B. Yan, Z. Cheng, Performance of chemical chelating agent stabilization and cement solidification on heavy metals in MSWI fly ash: a comparative study. J. Environ. Manage. **247**, 169–177 (2019). https://doi.org/10.1016/j.jenvman.2019.06.089
33. F. Huber, D. Blasenbauer, O. Mallow, J. Lederer, F. Winter, J. Fellner, Thermal co-treatment of combustible hazardous waste and waste incineration fly ash in a rotary kiln. Waste Manag. **58**, 181–190 (2016). https://doi.org/10.1016/j.wasman.2016.09.013
34. F. Huber, H. Herzel, C. Adam, O. Mallow, D. Blasenbauer, J. Fellner, Combined disc pelletisation and thermal treatment of MSWI fly ash. Waste Manag. **73**, 381–391 (2018). https://doi.org/10.1016/j.wasman.2017.12.020
35. B. Nowak, A. Pessl, P. Aschenbrenner, P. Szentannai, H. Mattenberger, H. Rechberger, L. Hermann, F. Winter, Heavy metal removal from municipal solid waste fly ash by chlorination and thermal treatment. J. Hazard. Mater. **179**, 323–331 (2010). https://doi.org/10.1016/j.jhazmat.2010.03.008
36. K.Y. Chiang, J.C. Jih, M.D. Chien, The acid extraction of metals from municipal solid waste incinerator products. Hydrometallurgy **93**, 16–22 (2008). https://doi.org/10.1016/j.hydromet.2008.02.014
37. K. Kahle, B. Kamuk, J. Kallesøe, E. Fleck, F. Lamers, L. Jacobsson, J. Sahlén, Hannemanns: report 2015 bottom ash from WTE plants metal recovery (2015)
38. D. Glushkov, K. Paushkina, D. Shabardin, P. Strizhak, Environmental aspects of converting municipal solid waste into energy as part of composite fuels. J. Clean. Prod. **201**, 1029–1042 (2018). https://doi.org/10.1016/j.jclepro.2018.08.126
39. S.T. Tan, W.S. Ho, H. Hashim, C.T. Lee, M.R. Taib, C.S. Ho, Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. Energy Convers. Manag. **102**, 111–120 (2015). https://doi.org/10.1016/J.ENCONMAN.2015.02.010
40. K.M.N. Islam, Municipal solid waste to energy generation in Bangladesh: possible scenarios to generate renewable electricity in Dhaka and Chittagong City. J. Renew. Energy. **2016**, 1–16 (2016). https://doi.org/10.1155/2016/1712370
41. E. Allegrini, S. Butera, D.S. Kosson, A. Van Zomeren, H.A. Van der Sloot, T.F. Astrup, Life cycle assessment and residue leaching: the importance of parameter, scenario and leaching data selection. Waste Manag. **38**, 474–485 (2015). https://doi.org/10.1016/j.wasman.2014.12.018
42. E. Allegrini, A. Maresca, M.E. Olsson, M.S. Holtze, A. Boldrin, T.F. Astrup, Quantification of the resource recovery potential of municipal solid waste incineration bottom ashes. Waste Manag. **34**, 1627–1636 (2014). https://doi.org/10.1016/j.wasman.2014.05.003
43. E. Allegrini, C. Vadenbo, A. Boldrin, T.F. Astrup, Life cycle assessment of resource recovery from municipal solid waste incineration bottom ash. J. Environ. Manage. **151**, 132–143 (2015). https://doi.org/10.1016/j.jenvman.2014.11.032
44. D. Dabo, R. Badreddine, L. De Windt, I. Drouadaine, Ten-year chemical evolution of leachate and municipal solid waste incineration bottom ash used in a test road site. J. Hazard. Mater. **172**, 904–913 (2009). https://doi.org/10.1016/j.jhazmat.2009.07.083

Sustainable Uses of Sewage Sludge as a Construction Material—A Review

Neelam Singh and Vikas Kumar

1 Introduction

Proper disposal of waste materials is going to become difficult due to the industrial revolution and the growth of the population faced by many countries. India produces a huge quantity of waste from different sources like industrial, commercial, domestic, construction and demolition, etc. The quantity of waste materials increases day by day. A non-decaying waste material remains in the environment for a hundred to a thousand years and creates disposal issues and hazardous environmental pollution worldwide. Most of the waste materials are used as landfill materials, left as stockpiles or dumped in fields without any treatment. Sustainable use of these waste materials reduces the harmful environmental impact. It is known as the "waste hierarchy". The aim of the waste hierarchy is to reduce, reuse and recycle waste and after that prefer to dispose of it. Some of the waste materials such as sewage sludge, fly ash, stone dust, construction waste, granite and marble polishing waste, blast furnace slag, copper slag, red mud and silica fumes can be used in construction, as investigated by many researchers.

Sludge is generated by sewage treatment plants as solid waste by-products which contain some harmful elements to the environment. Approximately, 62,000 MLD of sewage is produced every year in India. Out of that sewage, approximately 20,120 MLD is treated; for 3157 MLD of sewage, there are under construction or proposed treatment plants and treatment facilities [37]. Approximately, 3955 metric tonnes of dry sewage sludge are produced after the full treatment of sewage sludge per year.

N. Singh (✉) · V. Kumar
Central University of Haryana, Mahendragarh, India
e-mail: neelam202327@cuh.ac.in

V. Kumar
e-mail: vikask@cuh.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_9

In India, mostly produced sludge is disposed at dumpsites. There is inappropriate management or lack of sewage treatment plants and facilities in India.

Disposal of sewage sludge is a serious environmental issue at the global level. In general, waste sewage sludge after the pre-treatments (dewatering, drying and firing) is burned in incinerators used as landfills. Because of the limited availability of land and public unawareness, sludge disposal will become a critical issue, so there will be a need for an alternative method of disposal, as direct dumping of sludge on land is not an ideal method of disposal for the waste. Thus, disposal of sewage sludge should be in a proper and sustainable manner so that the harmful environmental impact of such a type of waste can be controlled.

In this review paper, we focus on the collection of knowledge about the uses of sewage sludge in various aspects of construction that has been done by many researchers. The aim of the study is to collect the knowledge from various research studies about the past and present practices of sewage–sludge use for different purposes, with the necessary elements for assessing the environmental, economic and social impacts and providing an overview of prospective risks and opportunities.

An evaluation of the uses of ash of sludge and fly ash as soil stabilizer and a comparison between them has been done by Lin et al. (2012). To find out the improved strength of established soil by mixing sludge ash and fly ash separately has been investigated with the help of experimental work. Fly-ash and ash of sewage sludge mixes with soft soil, then performed CBR test, unconfined compressive strength test, PH value, compaction and triaxial compression test. The results of executed tests indicate the improvement in the behaviour of soil, such as the unconfined compressive strength of sludge-mixed soil behaving 1.4–2 times better than the soft soil that is untreated. Sludge ash mixed soil shows a compressive strength of 20–30 kPa, which is less than the fly-ash mixed soil. It is found that bearing capacity increases for both the ash of sewage sludge-mixed soil and fly-ash mixed soil. Cohesive parameters increase with an increase in the amount of either ash added. With the increase in the amount of any ash, the friction angle decreased.

With the help of experiments performed by Alleman et al. [1], it was found that the ingredients of brick (clay and shale) can be partially replaced by sewage sludge. For making brick specimens, less than 25–30%, volumetric sludge was added, which fulfilled the criteria under ASTM, and manufactured bricks were sold at a standard commercial price. The experimental result shows that the property of brick maintains the ASTM standards. The compressive strength of manufactured brick is 20.7×10^3 kPa, while 5 h boiling water absorption is less than 17%.

Many cities face problems with the disposal of waste sludge in the world due to the urbanization process, which is increasing day by day. So, many researchers have given their views and worked on these issues of disposal of sludge in which they have utilized sludge as a construction material in past decades on the basis of suitability. Innovative materials are discussed in the paper written by Tay et al. [2].

The concrete cube was prepared by using sewage ooze, as explained by Subramani et al. [3]. In this paper, it is discovered that using this sewage ooze stabilizer has no negative effects on the critical quality of concrete cubes. It was investigated by the experimental work that the strength loss increased by 17% if we added 10% of high organic sludge to the concrete mix by weight of cement.

Pellets of dried sewage sludge are used in the making of Portland cement as raw material, and it is also used as a fuel by the manufacturer of cement in the production process of Portland cement. During the entire process of manufacturing of cement, quality of product, plant safety, sludge and moisture content, energy conservation, all the above points should be kept in mind carefully. It is shown that by the investigation, the use of the sewage sludge pellets is profitable for the manufacturer of Portland cement, Onaka [4]. Utilization of sludge effectively as a component of mortar or concrete obtained from a wastewater treatment plant reduces the problem of sludge disposal. A number of leaching tests have been performed to ensure that the prepared product meets the required quality standards for construction purposes.

With the different ratio of cement sludge mortar and cement sludge coal fly ash, it was investigated by Vall and Vazquez [5]. Sludge found from the treatment plant for textile effluent is used up to 30% by partially replacing cement for making the structural and nonstructural components, as examined by Balasubramanian et al. (2005). The composite textile sludge for the experiments was collected from southern India and examined its physio-chemical properties and engineering properties. To find out the efficiency of textile sludge for the construction of structural and nonstructural components, tests were performed as per the Bureau of Indian Standards. Experimental investigation shows that textile sludge was effective in making nonstructural components like pavement blocks, flooring tiles and bricks. All nonstructural components made from textile sludge fulfil the requirements of BIS, but sludge is not suitable for making structural components because it does not fulfil the BIS specification.

2 Application of sewage sludge

2.1 Use of Waste Sludge in Bricks Production

A mixture of sludge with shale and clay is used to make bricks, called bio-brick, by Alleman and Berman [6]. The solid content of wastewater sludge (15–25% solid content) can be combined with conventional clay and shale to produce bio-brick, it looks like regular brick, and the smell of bio-brick is like regular brick, founded by Chin et al. [7].

By using dried wastewater sludge with different percentages of clay, a novel brick was produced. Tay et al. [8]. The result shows that dried sludge can be used in the range of 0–40% of the weight of brick. If sludge content increases, the compressive strength of brick will decrease. An uneven texture surface and porosity arise in brick, due to the firing process in which the organic content of sludge is burned off. This type of problem can be solved by replacing dried sludge with sludge ash (zero % organic content). Test results show that up to 50% of the sludge can be used. Also, the results showed that bricks had higher strength when they contained crushed sewage sludge than when they contained sewage sludge-contained bricks. Bricks made with 10% sludge ash have higher strength than conventional clay bricks.

In the manufacturing of bricks, the potential use of dry pulverized sludge was explained by Yague et al. [9] uses dry pulverized sludge in the manufacturing of prefabricated brick by 2% in the prepared sample. Testing of specimens had been done, and the results showed that there had been a decrease in water absorption and in porosity, and significant increases in the compressive strength of specimen brick as compared to brick without using sludge. The use of ash produced by the paper industry and sludge in the production of bricks has been done by Chin et al. [7]. It is found that the compressive strength of prepared bricks and their water absorption satisfy the required standards. It is recommended that manufactured brick be used as a non-load-bearing component.

Dried sludge which is obtained from the water treatment plant is mixed with the rice husk ash and agricultural waste to make lightweight bricks examined Chiang et al. [10]. The results showed that bricks which have rice husk (40% by weight) heated at a temperature of 1100 °C give good strength, fulfil the requirements of lightweight bricks and can be used in future green buildings to fulfil the Taiwan standards. A result showed that from the Toxic-Characteristic-Leaching-Procedure (TCLP), the concentration of Zn, Cu, Cr, Pb and Cd in used products was less than the acceptable level given in standard regulation.

Chih-Huang et al. investigated the production of bricks by using sludge collected from the industrial waste water treatment plant [11]. All the necessary tests were performed. The results showed that the quality of manufactured bricks depends upon the proportion of sludge and burnt temperature. Bricks produced by using up to 20% sludge content at 960–1000 °C temperature. Strength of bricks fulfil Chinese standards and results of leaching of the product showed low leaching level of material.

In the manufacturing of clay bricks, sewage sludge with forest debris is used as raw material by Cusido et al. [12]. As compared, the conventional bricks with the manufactured sample of bricks are more acoustic insulator, thermal and lighter. Drying of bricks has been done at 100 °C. After that, they are fired at 1000 °C. A significant increase occurs in the emission level of greenhouse gases, which is shown in the result, which is nearly 20 times more than the conventional ceramic firing (it is within the permissible limit permitted by the Environmental Protection Agency).

Sewage sludge as a raw material is used in the production of bricks examined by Abdul et al. [13]. Manufactured bricks were tested for physical and mechanical properties. The result shows that manufactured bricks fulfil the required criteria standards. It was recommended that up to 30% sewage sludge content was used in making bricks. Water Treatment Residual (WTR) and excavated soil are used to produce ceramic bricks and artificial aggregates explained by Chihpin et al. [14]. Although as compared to the temperature required for conventional brick work, the sintering temperature required by WTR was higher because of the lower SiO_2 content and the higher content of Al_2O_3. The result shows that the water absorption, compressive strength and specific gravity of ceramic bricks proved their use and suitability in construction. Fly-ash slag is used by Municipal Solid Waste Incineration (MSWI) to make bricks, sample bricks were fired at a temperature of 1000 °C, investigated by

Kae [15]. The environmental effects of leaching as well as the mechanical properties of manufactured products were investigated. The result shows that the mechanical properties of bricks fulfil the requirements of second-class bricks as per the Chinese National Standard Code.

A mixture of recycled industrial waste and clay used to make bricks is explained by Eliche-Quesada et al. [16]. Test results indicate that with an increase in the sintering temperature the compressive strength of manufactured products increased also. It fulfils the requirements of water absorption and compressive strength of products.

Lightweight bricks were produced using rice husk and sintered mixture of dried water treatment sludge examined by Kung-Yuh et al. [17]. With increase in sintering temperatures, the compressive strength of bricks increased and the porosity of sintered samples increased by the addition of rice husk. Materials contained rice husk (15% by weight) sintered at 1100 °C, which formed higher compressive strength and low bulk density that were compliant as lightweight bricks with relevant Taiwan building code standards.

Clay and wastewater sludge obtained from textile laundry were used to produce bricks as proposed by Luciana et al. [18]. In the manufacturing of sample bricks, different quantities of sludge were used, which was dried at 100 °C. After that, the process of burning was completed at 900 °C. The mechanical properties of the final product were tested, and the result shows that the flexural strength of ceramics and the water absorption of the product were found satisfactory under Brazilian legislation. The leaching test has been done, and it shows the produced bricks are safe without any harmful outcome for the users or the environment. The mechanical properties of the brick are found to be better if the sludge content is used by 20% as per the obtained result.

The effects of the use of bricks made from sewage sludge on the environment were investigated by Joan and Lázaro [19]. The results, including tests of leaching ability and toxicity, show that sludge can be used effectively in the manufacturing of bricks. The range of sludge addition for making bricks can be from 5 to 25% in weight, or we can add more sludge if there is no need to fulfil the criteria limit for mechanical properties, and there are no harmful effects on the user's health and the environment.

Replacement of bricks which is made from clay by using sludge and agricultural or industrial waste (e.g., silica fume and rice husk) is explained by Badr et al. [20]. A sample of dried bricks was fired at different temperatures. Manufactured product properties were investigated, and a comparison was made between the products and conventional bricks under the Egyptian standard specification. It is found that bricks made from 25% silica fume and 50% sludge give better results than conventional bricks.

2.2 Use of Waste Sludge in Cement Manufacturing

Sludge (which is digested and dewatered) was used for making the material like cement examined by Tay et al. [8]. Dried sludge mixed with limestone powder is used to prepare the specimen. It is found that, as compared to ordinary cement, sludge cement has a high demand for water and a quick setting time. There is a possibility to produce binding material for masonry made from the sludge determined by estimating the cube strength test that meets the requirements of the ASTM standard for cement masonry work. We need more research to find out the long-term properties like durability of masonry binder made up of cement sludge.

To replace the raw material by sewage sludge pellets (SSP) in the mix formulation for the production of Portland cement explained by Monzo et al. [21]. Fifteen percentage and 30 percentage of sewage sludge ash (SSA) by weight were substituted for cement in mortar. It is obtained from the results that the compressive strength of the mortar containing 15% sewage sludge ash (SSA) is found to be similar to that of the reference mortar. A decrease appeared if the content of sewage sludge ash (SSA) increased to 30%. As compared to cement produced with normal clinker, the cement clinker can be replaced by 11% sewage sludge pellets by dry weight without any problems or a large difference.

The use of pulverized sludge ash combined with cement in concrete mixes was investigated by Goh et al. [22]. The organic material was removed by treating the sewage sludge at 55 °C so that it could be used as a filler in concrete. The ash was collected, ground to a fineness of no more than 150 μm and then mixed with cement for this purpose. According to the findings, increased sludge ash content improved concrete workability. When 10% sludge ash is added to cement, the compressive strength of concrete cubes at 28 days is comparable to that of regular cement concrete, but when the sludge ash concentration is increased to 40%, the strength drops by 50%.

Sewage sludge is treated and utilized to replace the binding material in mortar preparation at different temperatures, as investigated by Arlindo et al. [23]. Dry sludge heated to 105 °C was utilized to replace 20% of the cement's dry weight. As a result, it appears that no setting took place. Another test was carried out utilizing treated sludge at different temperatures as a replacement for 5% and 10% of the cement by weight, respectively. The findings revealed that the presence of any sort of previously treated sludge resulted in a reduction in the mortar's compressive strength.

The effects of dried sewage sludge on cement properties were examined by Yiming et al. [24]. The sample was made by combining dry sewage sludge and heating it to specific temperatures. It was discovered that the components of standard Portland cement and eco-cement clinkers are comparable. While the samples' compressive strength was found to be somewhat lower than that of plain paste, the leaching findings obtained from the samples were determined to meet the current Chinese regulatory acceptable requirement.

2.3 Use of Waste Sludge as Artificial Aggregate

Some results of crushing clay and dried industrial sludge (with low organic content) to a fine dust before mixing it with water to produce a paste were presented by Tay et al. [8]. The paste was sintered at high temperatures after being moulded into a composite shape. The compressive strength of a concrete specimen containing artificial aggregate was compared to that of granite aggregate to assess its performance. According to the findings, the 28-day compressive strength of concrete samples with artificial aggregate ranges from 31 to 38.5 N/mm^2, while concrete with granite yields 38 N/mm^2. When comparing granite aggregates to manufactured sludge clay aggregates, significant porosity and low density were discovered.

A combination of sludge ash and sintered sewage sludge is potentially used to produce synthetic aggregate, as explained by Chow et al. [25]. Results suggest that the combination of clay and sewage sludge ash showed a better outcome for manufacturing of the normal weight aggregate, whereas the mixture of the sewage sludge with 20–30% was found to be sufficient for the production of a more lightweight aggregate. A hot mixture of sewage sludge ash can be used as a fine aggregate in asphalt pavement construction. It was discovered that there is no noticeable difference between a pavement made of sludge ash with a total weight percentage of 2–5% and the conventional material. (For more information, visit http://www.rmrc.unh.edu/Partners/UserGuide/ss2.htm.) User guidelines for sewage sludge ash–asphalt concrete Shane et al. [26] revealed that sewage sludge ash (ISSA) from incineration may be used to manufacture low-energy construction materials. Material from huge UK sludge incinerators was used in this investigation. The product was put through a suitable standard test, and the results demonstrate that ISSA is more likely to boost reactivity and workability than conventional products.

Ten wt.% sewage sludge was used to modify the road base layers investigated by Leda et al. [27]. The process involved in soil stabilization was employed to ensure that the required parameters were met, and the strength of the stagnant soil was also assessed. With the help of various additives, the sludge soil mixture was created, compacted and then tested. Mechanical testing was used to pick the appropriate mix design. According to the results, sewage sludge could be used for soil stabilization and roadway construction.

Use of lime sludge, which is created during the process of purification of water, was explained by Yu et al. [28]. The impact of different types of mixing processes (dry and wet), optimal lime sludge content, and the durability of stabilized soils was studied. Mechanical characteristics and durability have been improved as a result of the study.

Potential use of industrial sludge in the industry of masonry and environmental impacts due to leaching was explored by Milica et al. [29]. After neutralization of the wastewater, the used sludge was collected by a hot dip galvanized process. Although some hazardous materials are also found in it due to the presence of toxic elements, as a result of the leaching test, it has been observed that the level of its effect after firing at 102 °C appears to be negligible. The results suggest that sludge can be used to manufacture ecologically sustainable bricks.

2.4 Use of Waste Sludge in Concrete Mixtures

Dry sewage sludge potentially used in the making of concrete as an additive was examined by Valls et al. [30]. To reduce the humidity of sewage sludge, it is dried to a certain extent to eliminate the microorganisms. Dried sludge was added to the concrete mix at different percentages, from 0 to 10%, to act as fine sand. The usage of sludge in the concrete mix was advantageous. As the mixed sludge reacts with the cement and forms the binding matrix, the amount of leachable heavy ions reduced as related to the free dry sludge. The results showed that increasing the sludge level decreased the concretes compressive strength, and it was discovered that sludge content of 10% or more should not be used since it delayed the setting time and reduced the mechanical properties inside the concrete.

Sludge is used as an additive in the concrete sample; durability of the concrete and long-term performance of the concrete prepared with sludge were assessed by Yague et al. [47]. One model was exposed to quick attack in it. A shared wet dry cycle involving fresh and seawater, accelerated ageing in autoclaves and carbonation was all used in these attacks. It was observed from the results that sludge-mixed concrete has the same durability as the reference concrete.

2.5 Sludge Water Uses in Concrete Mixtures

Replacing normal water with sludge water to making concrete was explained by Chatavira et al. [31]. Through this study, it was found that sludge water can be used by replacing it with normal water in the percentage range of 0–100%. Compressive strength of the concrete produced using sludge water was found to be 85–94% that of usual water-prepared concrete, however, sludge water was shown to have a significant influence on drying shrinkage and acid attack resistance of concrete.

Treated wastewater used in the manufacturing of concrete was explained by Al-Ghosain and Terro [32]. Concrete cube samples have been prepared using different types of water. The following types of water have been used: tap water (TW), primary-treated wastewater (PTW), secondary-treated waste water (STW) and tertiary-treated waste water (TTW). It is found that that the type of mixing water used did not have any effect on density and concrete slump. Samples made from primary-treated wastewater (PTW) and secondary-treated wastewater (STW) recorded lower compressive strength and slow strength development, higher corrosion potential and higher setting time than samples prepared with tap water (TW) and tertiary-treated wastewater (TTW). Higher power performance was observed for samples prepared with (TTW) as compared to samples made with (TW).

2.6 Waste Sludge Used for Ceramic and Glass Production

Making of ceramic samples by using sewage sludge, incinerated ash, and limestone, examined by Suzuki et al. [33]. By providing the sludge ash as a fine dust, it can be directly merged with other ceramic paste components. If ceramic specimens include up to 50% sludge ash, the strength, acid resistance and absorption coefficient will all be within normal limits. Leaching property of ceramics that contained sludge ash was investigated by Ferreira et al. [34]. As a result, the lowest spread values of heavy metals were observed.

The use of sludge in ceramics and its effect on the properties of ceramics was investigated by Monteiro et al. [35]. The marble sludge and urban sewage sludge were mixed into the clay in different proportions, which led to the closure of various ceramic materials, categorized by the composition and technical performance of different minerals. Linear contraction, absorption of water and bending strength of the prepared product were determined. The results show that the remaining residues (sewage and marble sludge) have high reactivity, reacting readily with clay minerals and quartz to offer enhanced sintering of the original powder.

In order to produce lightweight clay ceramics in the building industry, sewage sludge is used, as studied by Joan and Cecilia [40]. The results suggest that the prepared product has low thermal conductivity, although the leaching test results indicate that even after the heat treatment, the leachate includes large levels of hazardous metals.

The use of sludge instead of clay in a ceramic body can be used as a substitute for clay at different percentages, as investigated by Martínez-García et al. [36]. The manufactured products' mechanical qualities were examined. The results of the tests revealed that products containing 5% sludge had good mechanical properties in terms of compressive strength, water absorption and water suction.

2.7 Properties of Building Materials Contained Sewage Sludge

Prepared building material by using sludge	Sewage sludge content in product mass (%)	Kind of sewage sludge used	Other admixtures used	Compressive strength (after 28 days of curing) (MPa)	Other probable application	Results	References
Bricks	10	Pharmaceutical sludge	Cement, fly ash, silica dust, lime, bentonite, mine dust	17.2–18.6	–	As a binder, cement, lime and bentonite were mixed in a ratio of 1: 1: 0.5	Yang et al. [43]

(continued)

(continued)

Prepared building material by using sludge	Sewage sludge content in product mass (%)	Kind of sewage sludge used	Other admixtures used	Compressive strength (after 28 days of curing) (MPa)	Other probable application	Results	References
	6.5	Mixture of primary and secondary sludge from municipal sewage treatment plants	Fly ash, cement, lime, slag	32.1–36.9	As a Covering material for landfills	Cement and lime in a 1:3:6 ratio	Amin et al. [41]
	25–30% volumetric sludge	Sewage sludge	Sewage sludge, clay, shale	20.7	–	Water absorption is less than 17%	Alleman et al. [1]
Landfill sites	–	–	Sewage sludge ash and fly ash	0.02–0.03	Construction of road base and embankments	Cohesive parameters increase with increase the amount of either ash added	Lin et al. (2012)
	33.4	Primary and secondary sludge mixed together (hydration approx. 97%)	In a ratio of 1:1:0.3, ash from coal combustion, lime and iron chloride	0.7–0.8	In the buildings and construction industries	In the calculations, the ash, lime and iron chloride mixture were used as a binder	Li et al. [48]
Concrete	0–10%	Dry sewage sludge	Sewage sludge, cement		To making sludge-mixed concrete and in other construction	The mixed sludge reacts with the cement and forms the binding matrix	Valls et al. [30]
	4.1	Sludge that has been Aerobically stabilized	Cement	39		The proportion of sewage sludge (wet weight)	Roccaro et al. [45]
Mortar	0.32	Sludge from a sewage treatment plant. (97.5% hydration)	Ash from coal combustion, cement, sand	12–14	Materials for road construction , mortar for inside use	The amount of ash in the binder mass is 10%	Hamood et al. [46]
Sintered products/ceramic and glass production	5%	Sewage sludge	Sewage sludge, clay	–	Other construction product	Good mechanical property in terms of compressive strength, water absorption and water suction	Martínez-García et al. [36]

(continued)

(continued)

Prepared building material by using sludge	Sewage sludge content in product mass (%)	Kind of sewage sludge used	Other admixtures used	Compressive strength (after 28 days of curing) (MPa)	Other probable application	Results	References
	5 10 5	Sewage sludge from a municipal sewage treatment plant that was dried	A standard mix is used for the making of tiles	23 18 17	In accordance with ISO 13006/2012, floor tiles can be used	Temperature of burning: 1150 °C 1150 °C 1100 °C	Amin et al. [41]
	5	Dry sewage sludge	85% lake sediments, 10% slag	20.5	Production of bricks	Firing temperature at 950 °C	Zhang et al. [44]
Lightweig ht aggregate	–	Industrial sludge	Clay and dried industrial sludge	31–38.5 N/mm2	–	Artificial sludge clay aggregate has high porosity and low-density performance were observed compared to granite aggregates	Tay et al. [8]
	20–30%		Clay and sewage sludge ash	–	Construction of asphalt paving	Result shows better outcome for manufacturing of the normal weight aggregate	Chow et al. [25]
	10	Sewage sludge from a municipal sewage treatment plant. (Dried)	Clay	–	Aggregate can be used in the manufacturing of light concrete	The firing temperature is 1150 °C. The concrete had a compressive strength of 11.1 MPa with the addition of 35% aggregate	Suchorab et al. [42]

3 Discussion

Many researchers have worked on the application of waste sludge in the construction field. From the literature reviews, it has been discovered that waste application of sludge is manly in brick making, cement manufacturing, concrete mixture, ceramic production, glass production and stabilized poor soil, etc. A range of tests are conducted in order to find out the product properties that meet all requirements as per the specification of the standards. All the major properties of the product were investigated by many researchers, while the impact of the product on the environment was also investigated by some researchers. In the construction industry, the use of sewage sludge has a positive impact on the direction of the sustainable use of waste materials. It is also environmentally friendly; there is no significant harmful effect on humans or on the environment.

By using sludge in the building industry, we are able to produce bricks with low-energy usage. It is necessary to examine the need to produce energy-saving items for future use. More and more studies should be carried out on production of eco-friendly building materials using different types of sludge, economical in terms of energy use and emissions. Since waste sludge includes all types of industrial and agricultural solid waste, petroleum sludge is one of the largest major solid wastes generated in the oil industry in terms of petroleum exploration and production, and its disposal poses a serious threat to the environment; our efforts should not be focused solely on treatment, but also on how we can use waste with or without treatment in the development of sustainable structures.

4 Conclusion

This study has provided a comprehensive state-of-the-art overview of the application of sewage sludge usage in various industries, from its early use to the current research trends. This review study shows that the use of sewage sludge as a raw material in the construction sector is acceptable without compromising the product quality that the material requires in accordance with applicable standards. In the construction industry, sewage sludge is used in various forms to provide a complete solution to the sewage disposal problem. Sustainable use of waste helps to make the environment clean and eco-friendly with a low-cost or reduced-cost raw material.

References

1. J.E. Alleman, N.A. Berman, Constructive sludge management: biobrick. J. Environ. Eng. **110**(2), 301–311 (1984)
2. J.-H. Tay, K.-Y. Show, Resource recovery of sludge as a building and construction material—a future trend in sludge management. Water Sci. Technol. **36**(11), 259–266 (1997)
3. T. Subramani, A. Anbuchezian, Experimental study on replacement of concrete material by water treatment plant waste sewage. Int. J. Appl. Innov. Eng. Manage. (IJAIEM) **6**(3) (2017). Web Site: www.ijaiem.org, ISSN 2319-4847
4. T. Onaka, Sewage can make Portland cement: a new technology for ultimate reuse of sewage sludge environment business planning and promotion div., Nippon Aluminium Co. Ltd., 3-9-39 Mikunihonmati, Yodogawaku, Osaka, Japan (2000)
5. S. Valls, E. Va'zquez, Leaching properties of stabilised/solidified cement-admixtures-sewage sludges systems. Waste Manage. (2002) **22**, 37–44 (2001)

6. J.E. Alleman, N.A. Berman, Constructive sludge management: biobrick. J. Environ. Eng. 1984 **110**(2), 301–311 (1984)
7. T.L. Chin, L.C. Hui, H. Wen-Ching, R.H. Chi, A novel method to reuse paper sludge and co-generation ashes from paper mill. J. Hazard. Mater. **58**, 93–102 (1998)
8. J.H. Tay, K.Y. Show, S.Y. Hong, C.Y. Chien, D.J. Lee, Potential reuse of wastewater sludge for innovative applications in construction aggregates. Water Sci. Technol. **50**(9), 189–196 (2002)
9. A. Yague, S. Valls, E. Vazquez, V. Cushion, Use of dry sludge from waste water treatment plants as an additive in prefabricated concrete bricks. Constr. Mater. **52**(267), 31–41 (2002)
10. K.Y. Chiang, P.H. Chou, C.R. Hua, K.L. Chien, Novel lightweight building bricks manufactured from water treatment plant sludge and agricultural waste. A case study in Feng-Chia University, Tai-Chung, Taiwan (2000)
11. W. Chih-Huang, L. Deng-Fong, C. Pen-Chi, Utilization of sludge as brick materials. J. Adv. Environ.
12. J.A. Cusido, L.V. Cremades, M. Gonza´lez, Gaseous emissions from ceramics manufactured with urban sewage sludge during firing processes. J. Waste Manage. **23**, 273–280 (2003)
13. G.L. Abdul, I. Azni, H.K.W. Calvin, A.S. Abdul, J. Megat, M.M. Noor, M.B. Aminuddin, Incorporation of sewage sludge in clay brick and its characterization. J. Waste Manage. Res. **22**, 226–233 (2004)
14. H. Chihpin, R.P. Jill, L. Yaorey, Mixing water treatment residual with excavation waste soil in brickand artificial aggregate making. J. Environ. Eng. **101**, 272–277
15. L.L. Kae, Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. J. Hazard. Mater. **137**, 1810–1816 (2006)
16. D. Eliche-Quesada, C. Martínez-García, M.L. Martínez-Cartas, M.T. Cotes-Palomino, L. Pérez Villarejo, N. Cruz-Pérez, F.A. Corpas-Iglesias, The use of different forms of waste in the manufacture of ceramic bricks. J. Appl. Clay Sci. **52**, 270–276 (2011)
17. C. Kung-Yuh, C. Ping-Huai, H. Ching-Rou, C. KuangLi, C. Chris, Lightweight bricks manufactured from water treatment sludge and rice husks. J. Hazard. Mater. **171**, 76–82 (2009)
18. C.S.H. Luciana, E.H. Carla, H.M.R. Miria, D.M. Nora, R.G.G.T. Celia, B. Rosangela, Characterization of ceramic bricks incorporated with textile laundry sludge. J. Ceram. Int. **28**, 951–959 (2011)
19. A.C. Joan, V.C. Lázaro, Environmental effects of using clay bricks produced with sewage sludge: leachability and toxicity studies. J. Waste Manage. **32**(6), 1202–1208 (2012)
20. E.D.E.H. Badr, A.F. Hanan, M.H. Ahmed, Incorporation of water sludge, silica fume and rice husk ash in brick making. J. Adv. Environ. Res. **1**, 83–96 (2012)
21. J. Monzo, J. Paya, M.V. Borrachero, J.J. Morenilla, M. Bonilla, P. Calderon, Some strategies forreusing residues from waste water treatment plants: preparation of building materials, in *Proceeding of the Conference on the Use of Recycled Material in Building and Structures* (Barcelona, Spain, 2004)
22. C.C. Goh, K.Y. Show, H.K. Cheong, Municipal solid waste fly ash as a blended cement material. J. Mater. Civil Eng. **15**(6), 513–523 (2003)
23. G. Arlindo, M.E. Ana, C. Martha, Incorporation of sludges from a water treatment plant in cementmortars, in *Proceeding of the Conference on the Use of Recycled Material in Building and Structures* (Barcelona, Spain, 2004)
24. L. Yiming, Z. Shaoqi, L. Fuzhen, L. Yixiao, Utilization of municipal sewage sludge as additives for the production of eco-cement. J. Hazard. Mater. **213**(214), 457–465 (2012)
25. I.J. Chou, K.S. Wang, C.H. Chen, Y.T. Lin, Lightweight aggregate made from sewage sludge and incinerated ash. Waste Manage. **26**, 1453–1461 (2006)
26. D. Shane, C. Chris, T. Mark, B. Andy, *Sustainable Construction Products Containing Sewage Sludge Ash.* Retrieved from: http://www.imperial.ac.uk/pls/portallive/docs/1/31723699.PDF (2008)
27. C. Leda, L. de Figueiredo lopes Lucena, J. Thome Juca, J. Soares, M. Portela, Potential uses of sewage sludge in highway construction. J. Mater. Civil Eng. **26**(9), 04014051 (2013)
28. X. Yu, B. Zhang, J. Lang, X. Yu, Sustainability through beneficial use of lime sludge for construction, in *Proceeding of the U.S.-China Workshop on Advanced Ground Improvement Technology* (2009), pp. 260–270

29. A. Milica, R. Zagorka, S. Slavka, Removal of toxic metals from industrial sludge by fixing in brick structure. J. Constr. Build. Mater. **37**(2012), 7–14 (2012)
30. S. Valls, A. Yague, E. Vazquez, F. Albareda, Durability of concrete with addition of dry sludge from waste water treatment plants. Cement Concrete Res. **35**, 1064–1073 (2005)
31. B. Chatveera, P. Lertwattanaruk, N. Makul, L.W. Cheng-Fang,Effect of sludge water from ready-mixed concrete plant on properties and durability of concrete. J. Cement Concrete Compos. **28**(5), 441–450 (2005)
32. I. Al-Ghusain, M.J. Terro, Use of treated wastewater for concrete mixing in Kuwait. Kuwait J. Eng.Sci. **30**(1) (2003)
33. S. Suzuki, M. Tanaka, T. Kaneko, Glass ceramic from sewage sludge ash. J. Mater. Sci. **32**(7), 1775–1779 (1997)
34. C. Ferreira, A. Ribeiro, L. Ottosen, Possible applications for municipal solid waste fly ash. J. Hazard. Mater. **96**, 201–216 (2003)
35. M.A. Montero, M.M. Jordán, M.S. Hernández-Crespo, T. Sanfeliu, The use of sewage sludge and marble residues in the manufacture of ceramic tile bodies. J. Appl. Clay Sci. **46**, 404–408 (2009)
36. C. Martínez-García, D. Eliche-Quesada, L. PérezVillarejo, F.J. Iglesias-Godino, F.A. CorpasIglesias, Sludge valorization from wastewater treatment plant to its application on the ceramic industry. J. Environ. Eng. **95**, 5343–5348 (2012)
37. CPCB (2015), Consolidated annual review report on implementation of Municipal solid wastes (Management and handling) rules, 2000, Annual review report: 2013–14
38. D. F. Lin, K. L. Lin, H. L. Luo, A Comparison between Sludge Ash and Fly Ash on the Improvement in Soft Soil, J Air & Waste Manage Assoc. **57**:1, 59–64, https://doi.org/10.1080/10473289.2007.10465294 (2007)
39. J. Balasubramanian, P. C. SabumonaJohn, U. Lazara, R. Ilangovanb, Reuse of textile effluent treatment plant sludge in building materials Author links open overlay panel
40. A.C. Joan, and S. Cecilia, Valorization of pellets from municipal WWTP sludge in lightweight clay ceramics. J. Waste Manage. 31(6):1372–1380 (2011)
41. S.K. Amin, E.M. Abdel Hamid, S.A. El-Sherbiny, H.A. Sibak, M.F. Abadir, The use of sewage sludge in the production of ceramic floor tiles. HBRC J (2017)
42. Z. Suchorab, D. Barnat-Hunek, M. Franus, G. Łagód, Mechanical and physical properties of hydrophobized lightweight aggregate concrete with sewage sludge (2016)
43. J. Yang, Y. Shi, X. Yang, M. Liang, Y. Li, Y. Li, N. Ye, Durability of autoclaved construction materials of sewage sludge-cement-fly ash-furnace slag. Constr. Build. Mater. 48, 398–405 (2013)
44. Y.M. Zhang, L.T. Jia, H. Mei, Q. Cui, P.G. Zhang, Z.M. Sun, Fabrication, microstructure and properties of bricks fired from lake sediment, cinder and sewage sludge. Constr. Build. Mater. 121, 154–160 (2016)
45. P. Roccaro, A. Franco, L. Contrafatto, F.G.A. Vagliasindi, Use sludge from water and wastewater treatment plants in the production of concrete: an effective end-ofwaste alternative. In: Proceeding of the 14th International Conference on Environmental Science and Technology (2015)
46. A. Hamood, J.M. Khatib, C. Williams, The effectiveness of using Raw Sewage Sludge (RSS) as a water replacement in cement mortar mixes containing Unprocessed Fly Ash (u-FA). Constr. Build. Mater. 147, 27–34 (2017)
47. A. Yague, S. Valls, E. Vazquez and V. Cushion, Use of dry sludge from waste water treatment plants as an additive in prefabricated concrete bricks. Constr. Mater. 52(267): 31–41 (2002)
48. Y.L. Li, J. W. Liu, J. Y. Chen, Y. F. Shi, W. Mao, H. Liu, ... & J. K. Yang, Reuse of dewatered sewage sludge conditioned with skeleton builders as landfill cover material. Inte. J. Environ. Sci. Technol. 11(1), 233–240 (2014)

Enhanced Landfill Mining Waste Valorization Techniques: A Methodological Review

Shakeel Ahmad Dar, Pushpendra Kumar Sharma, and Bishnu Kant Shukla

1 Introduction

World produces about 2000 billion kg of municipal solid waste (MSW) every year as per latest statistical data at rate of 0.74 kg per capita per day amounting to 3.40 billion metric tons by 2050 with the present rate of generation. At present, 33–40% of waste generated is not managed properly, but just dumped or openly burnt (internet sources). In low-income countries, this unregulated disposal is often up to 90% of that generated. This mismanaged waste often invites diseases and people, especially in slum areas are severely affected by these mismanaged waste. However, more significant is the impact on the environment, which is nowadays most critical global concern. Global waste production accounted for 5% of green-house gas emissions in 2016 with an output of about 1.6 billion metric tons CO_2 equivalents and likely to rise to 2.6 billion tons by 2050. These emissions are both from open dumping as well as that from unmanaged landfills without a gas recovery system.

Developing countries like India generate 62 million tons of waste of mixed type every year from urban areas only (2014) and growing annually by a rate of 4% because of growing urbanization (PIB-2016). As of 2016, in India only less than 60% of waste is collected from households and only 15% of wastes from urban areas is processed. The most prevalent method of disposing waste round the globe is by landfilling. A landfill is a carefully designed dump, built onto or on the top of ground in which trash is stored or dumped on daily basis just to prevent contamination to the surrounding environment and ground water. However, non-engineered landfills lead to emission of methane gas, leading to landfill fires in addition to its threatening impact of global

S. A. Dar · P. K. Sharma
School of Civil Engineering, Lovely Professional University, Phagwara, India

B. K. Shukla (✉)
Department of Civil Engineering, JSS Academy of Technical Education, Noida, U.P., India
e-mail: bishnukantshukla@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_10

warming. Further, precipitation percolation leads to leachate production entering the ground water and polluting it. Scientific or engineered landfills reducing the same by use of a linear material at bottom and cover system at top, and drainage system for that leachate produced and collection system for gases produced, reducing environmental risks.

2 Landfill Mining and Enhanced Landfill Mining

Engineered landfills, however, are not the last resorts of waste management. Even the scientifically constructed landfills have their limitations. The issues begin with the idea of setting up of landfill construction/setting up and most frequent response from public domain is that "not in my backyard" about setting up. Landfills require large vast open surfaces leading to land scarcity, and restricting growth of development of human society an ecosystem. Landfills are a source of gases production (release) during their entire life span especially methane, a notoriously powerful greenhouse gas, potentially 25 times detrimental than that of CO_2 to environment. Landfills cause surface and ground water contamination through leachate. Still landfills are the highest contributors to waste disposal and even in countries falling in European Union, adopting the maximum possible recycling and reuse of waste, still at least 40% of the waste in EU-27 goes to landfills, and they need remediation measures. However, there is a hope as these landfills are also potential reservoirs of resources in the form of metals, materials and energy. Given the extincting nature of natural resources, increasing demand of raw materials, and growing energy hunger of nations for its sustenance, these potential gold mines cannot be left unexplored. Landfills store abundant quantities of combustibles and fines in addition to that of accumulated metals and as such can be explored for possible fuels and building ingredients [1, 2]. Earlier landfill withdrawal was carried with a focus on land reclamation and metal recovery and reducing gas emission, but a shift into a more innovative waste management system that could complete an overall sustainable material management cycle (MMS) was needed with a view to energy generation. This lead to the concept of "Enhanced landfill mining".

In Enhanced landfill mining, more focus is given to prevention, material recovery and recycling and "landfilling" as last step of disposal cycle is discarded. In this approach of waste management, landfills are a temporary store houses of energy and materials, till the time advances in technology of such a calibre develops that can completely valorize it and put it back into economy, there by completing a circular loop of SSM [2]. Figure 1 shows outline of circular system of economy with landfill mining forming its major component. Although valorization of wastes by high temperature burning-incineration was earlier available, the term "enhanced" of ELFM, incorporates the goal of producing least possible GHG pollutants in valorization of wastes under ELFM [2]. Landfill mining an excavation of ancient landfills for retrieval of minerals/metals; forms one step of an overall process of ELFM. Thus summing up, the ELFM can be defined as "an integrated process of receiving,

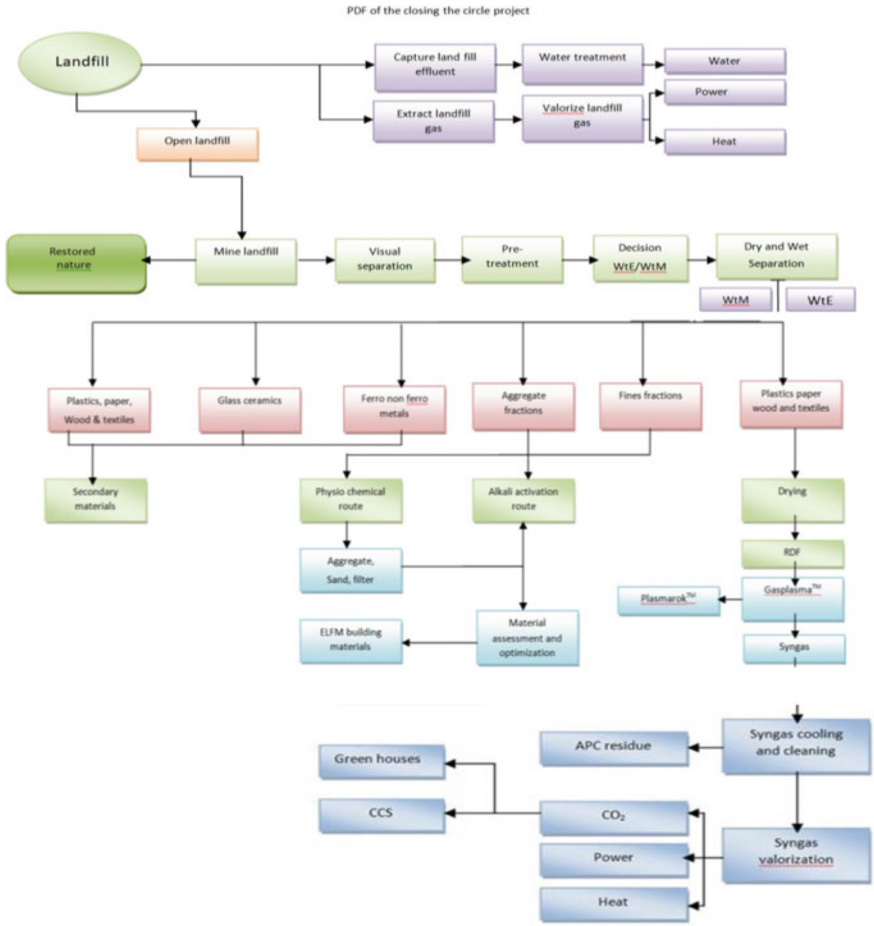


Fig. 1 Flow diagram ELFM process for the closing the circle project [2]

and extracting minerals, energy and construction materials out of waste dumped previously into ground, thereby reducing last remainder to nearly zero volume and applying methods to diminish carbon dioxide emission [3]. ELFM stresses planned storing of presently non-recyclable constituents and energy means to be exploited at a later stage for materials and energy [1, 2]. ELFM converts landfills from a cost-to-society into a resource recovery opportunity. Although landfill mining had a genuine start in 1990, but was limited to land reclamation, partial recovery of materials, and extraction of methane [3, 4]. ELFM is still developing with a clear view on efficient resource recovery. While waste valorization reassigns it a value by converting it into energy or recycled valuable products, ELFM is an iterative process of this valorization, applicable to freshly generated waste as well as already dumped with a sustainable goal. ELFM provides a tool to choice the appropriate time to valorize certain waste to usable materials through various approaches like waste to product or to energy (WtPorE), etc., compatible to the existing state/standard of technology available [5].

3 Methodological Review

The sustainable landfill reclamation is possible through ELFM for closed landfills requiring reclamation on urgent basis as well those of active ones, the two channels of SMM are waste to products or to energy (WtPorE) and enhanced ELFM technologies can achieve these simultaneously waste converted to energy belongs to integrated solid waste management systems for developed nations and is being practiced at different levels of advancement. In these nations, main focus is the mitigation environment issues [6–9], besides obtaining bi-products in the form of energy and composite construction materials (WtP). From energy point of view waste to energy technologies are classified into biochemical treatment technologies (or biochemical processes) and thermochemical processes. The biochemical processes under biological treatment through anaerobic and aerobic digestion techniques and landfill gas utilization techniques, to produce methane and bio-fuels will be reviewed later especially with respect to Indian wastes. In thermochemical processes, incineration, pyrolysis and gasification methods are being employed already, but the latest plasma gasification is the leading candidate and trending one in terms of efficiency both for recovery of energy and products. An overview of these technologies is given in Fig. 2.

3.1 Thermal Treatment Processes (Thermochemical Technologies)

The most general process of thermal treatment for filled landfills begins with the processes of pre stabilization, i.e. removal or extraction of landfill gasses, especially CH_4, or odorous gasses like ammonia and H_2S, at landfill site without landfill extraction, a process called as insitu landfill mining [2]. Prestabilization is followed by extraction of stabilized landfill area, then transportation of extract to separate areas, separation or sorting into incombustible and combustible fractions. Here, recovery of some metals occurs. The soil and incombustible materials can be recycled by putting to use as fill material for embankments, etc., as cover material in active landfills, or as sub-base soil in pavement constructions, etc. Next is the production of the new raw material or fuel from combustibles waste portion called as refuse derived fuel (RDF) which will be subjected to high temperature burning to release energy. This processing of MSW into RDF is done to make a homogenous input, make handling convenient, to get a sufficiently high calorific fuel from an otherwise heterogeneous

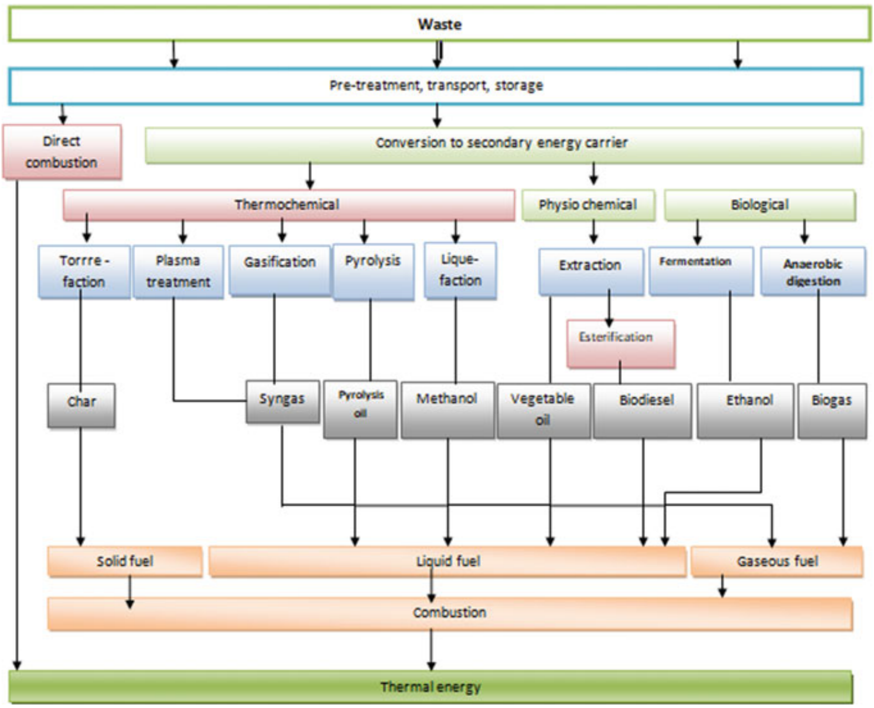


Fig. 2 Waste-to-energy technologies [5]

feedstock of MSW. It is generally achieved by shredding, screening, sorting, drying and conversion into pellet sized granules from combustible portion [5]. The thermal conversion processes are reviewed below hierarchically from conventional method to the latest advanced one.

3.2 Full Oxidative Combustion-Incineration

Incineration is the most basic or conventional method of thermal treatment of waste, converting this mixed nature combustible waste into heat, ash and flue gas. It converts organic wastes into energy in the form of utilizable high heat by burning at temperatures ranging from 300 to 800 °C, while inorganic fraction and metals are changed into ash and flue gases. During incineration, flue gasses (CO_2, H_2O, O_2, N_2) are generated that carry the major portion of energy as heat [5]. The limiting factor for its use is the emission of minor quantities of HCL, CO, HBR, BF, SO_2 and VOCs along with heavy metal contamination. Adopting latest gas cleaning equipments, recovery of energy produced for useful purposes and adopting appropriate disposal techniques for ultimate waste left after burning can transform incineration into non-harming to environment. The same has led to advancements in incineration technology from time to time, driven by legislations specific to this industry and going on. Relatively bigger volumes of bottom ash produced-about 30% of input solid content has shown the potential for re-use as inert granulate materials in concrete aggregates [10]. The superheated steam generated is used within system for heating and rotating turbines connected to a generator for generating electric energy.

Although material recovery is very small compared to energy, still incineration has shown potential for metals recovery from bottom ash (Al, Cu and Fe) and residue converted to granulate form for use in construction industry. Fly ash, separated by electro-filters has been found potentially useful in asphalt concrete manufacturing [5].

The incinerators are of three types mainly-grate incinerators, rotary kilns and fluidized beds. They detailed design of any one type will depend upon waste characterization, i.e. its chemical composition thermal properties, etc.

3.3 Thermal Degradation-Pyrolysis

In pyrolysis method, organic materials of waste can be degraded thermally into three types of products in all three states of maters, i.e. solid, liquid and gaseous. This thermal degradation is carried out in a pyrolysis reactor either in lack of an air or without so as to get the heat energy essential for pyrolysis. Temperature goes up to 900 °C from 400 °C relatively lesser than gasification process, in this pyrolysis reactor, giving a mixture of solid carbonaceous residue-char, a liquid bio-fuel or bio-oil and a high energy synthesis gas. The relative proportion of these products depends upon reactor parameters especially temperature and rate of heating [11, 12].

Dark brown bio-oil is improved to syngas/engine fuel via gasification or liquid fuel may be used for gas turbines connected to generator for electric power generation. Syngas produced in pyrolysis especially when RDF is used, has high calorific value, is cleaned of particulates and combusted to generate electricity. Solid residue/char/pyrolysis coke rich in carbon may be used as activated carbon for filtering processes. The commonly used pyrolysis reactors are rotary hearth furnaces, rotary kilns, fluidized bed furnaces, etc. Often pre-treatment of wastes is required for effectiveness. Representation of pyrolysis is shown in Fig. 3.

3.4 Thermal Gasification

More efficient than incineration and pyrolysis for energy production. In thermal gasification the organic part of MSW is oxidized at 500–1800 °C temperature, producing a fuel-rich gaseous product called synthesis gas (especially when using steam as gasifying agent). For gasification, using steam as gasifying agent, products are an energy rich synthesis gas majorly composed of CO_2 and H_2, while that using pure oxygen

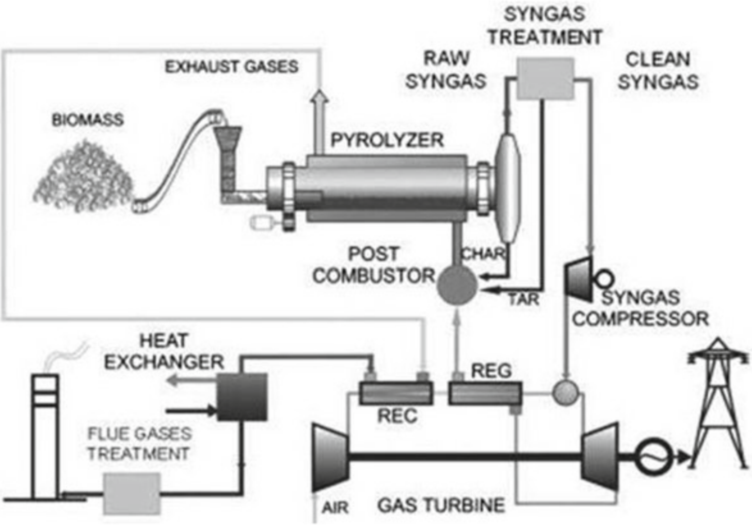


Fig. 3 Representation of pyrolysis process [13]

produces higher quality gaseous fuel rich in CO and H_2 [12]. These synthetic gases when cleaned of contaminants can be fed as fuel to boilers of electricity generating systems or to chemical industries for ammonia generation [5].

The gasification reactors in practice are entrained flow, fluidized or fixed bed gasifiers. For efficient recovery of the fuel gas, pre-treatment of wastes to convert them into finely granulated feed stock is required in all types of the reactors [5]. In fixed bed gasifier, feed stock is supported over a grate maintaining a stationary zone for reaction. Gas mixing is not adequate and gas yields can be unpredictable, and thereby this process is optimal for small scale plants [14]. In fluidized bed gasifier, a stream of gas (of steam or air at a very high temperature) is made to flow vertically through a bed of solid wastes or RDF mixed with inert materials like sand or limestone, fluidizing the wastes into fuel gases. Fluidized beds are more suitable for greater capacity generators (>10 MW) due to good mixing conditions resulting in uniform bed conditions, efficient reactions and high heat transfer. A general overview of gasification are given in Fig. 4.

3.5 *Plasma Gasification and Vitrification*

The recently developed or most advanced and efficient of thermal conversion technologies is the plasma gasification process. Plasma is a charged gaseous mass containing electrons, positive charges (cations), photons, etc, produced when a gas is exposed to an extremely high temperature of about 8000 °C. The source of energy

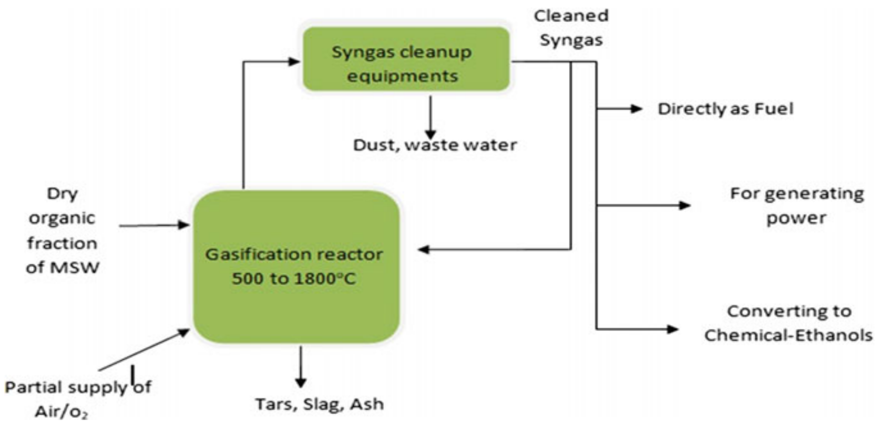


Fig. 4 An overview of gasification (*Source* Planning Commission of India report 2014)

may be thermal or an electric current produced from an electric arc. Plasma gasification process of solid waste treatment involves use of a plasma generated to produce a cleaner synthesis gas (almost containing only CO and H_2) than other thermal processes (pyrolysis, gasification, etc.) as well as the inorganic fraction, metals and glass is condensed into an inert, environmentally stable, non-leeching product called vitrified slag or plasmarok (as it resembles basalt rock in formation). Thus, plasma gasification technology adds energy efficient and environmentally compatible method of waste management to ELFM. This process can give efficiently both energy and products.

3.5.1 The General Process of Plasma Gasification

The processed waste (shredded to increase surface area per unit volume, RDF) is fed to a plasma reactor, where it is heated by thermal plasma torch to convert using its high temperature, the waste materials into their elemental components, i.e. hydrogen, carbon, sulphur, oxygen, halogens, etc. (organic matter portion), and inorganic matter melted into an inert slag. The synthesis gas is rich in H_2 and CO. A DC plasma torch is used in gasification process of waste. It has an arc ignitor coupled to torch to facilitate breakdown of gases. By sparking this high frequency, high-voltage igniter, it produces sufficient electrons to ignite arc discharge. Air, oxygen or steam can be injected through igniter to stretch and maintain arc throughout the process. This current converts gases into plasma, thus rearranging it into a cleaner form of synthesis gas containing H_2 and CO abundantly. The plasma at high temperature (8000 °C) breaks down the long chains of hydrocarbons into elemental particles and rearranges them into most basic and kinetically stable compounds of CO and H_2 (pure syngas). Syngas produced is now subject to cooling and cleaning. Cooling prevents reactions of reactive species to produce toxic dioxins, and cleaning removes undesirable

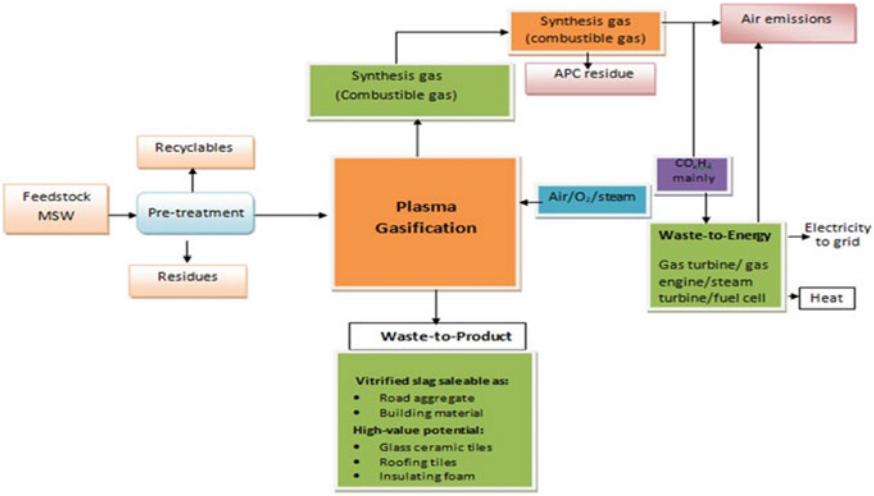


Fig. 5 WtE and WtP e from MSW to electricity, heat, and other valuable products through plasma gasification/vitrification [5]

chemicals and particulate matter which is harmful to environment. The heat exchange during cooling can be utilized. For cleaning of the gas, cyclone separator is usually employed where particles settle down and gas leaves at the top, it is passed through filters to remove other particles and chemical treatment is done for removal of toxic substances (nitrogen oxides, etc.) by catalytic converters (Internet sources).

Cleaner syngas can either be used for steam to generate electricity or be compressed to bio-fuels like methanol (Fig. 5).

3.5.2 Two Stage or Twin-Stage Plasma Process-an Efficient Integration of Thermal Processes

Here, design of the system utilizes plasma to improve mixture gases formed through waste transformation e.g. by gasification into syngas in first process [5]. The practical example of this twin-stage process is the two-stage thermal Gasplasma^{TM} process developed by Advanced Plasma Power (APP) in Swindon, UK along with Tetronics Company. This system has shown efficiency as it produced a high energy refined syngas and vitrified slag with end use as aggregate material. It has been built for MSW and commercial wastes. This process utilizes a fluidized bed gasifier (FBG) in its first stage to which processed RDF is added and utilizing oxygen and steam for gasigying it into a raw syngas. This syngas laden with tar, char and dioxins and carbonic ash is then treated with high temperature plasma converter in the second stage, which reforms it into high quality energy rich syngas. This syngas after cleaning off acids and particulate matter can be used for energy production.

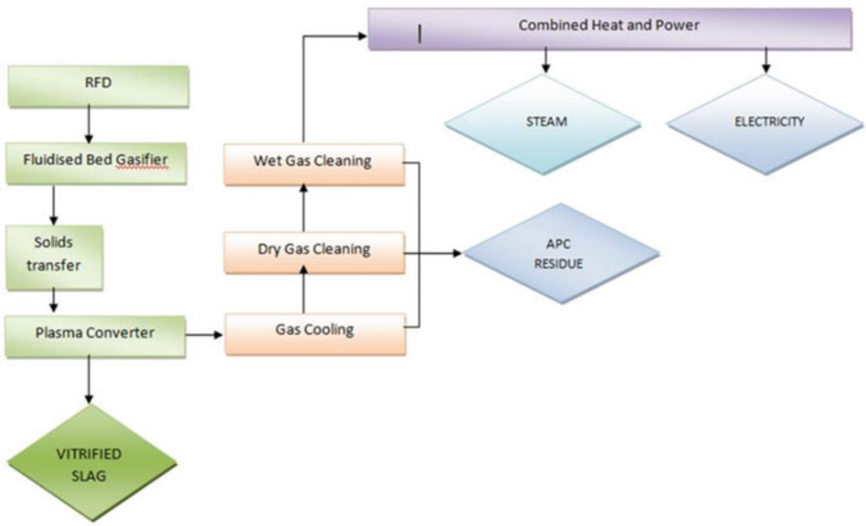


Fig. 6 Gasplasma TM process flow sheet (Online information by advanced plasma power (APP, 2012))

The plasma vitrifies inorganic ash fraction into dense non-leeching glass like shining product called Plasmarok^{TM}. Thus, we get a source of secondary construction material (WtP) besides waste to energy (WtE) treatment facility has shown equally satisfying results for other types of wastes like waste food, wood wastes, rubber scrap, Automobile Shredder Residue (ASR), etc. [15].The environmental testing of the plasmarok product conducted for leaching of certain organic and heavy metal pollutants by Water Research Council (WRC) in the UK showed results well blow permissible limits as prescribed for its use as inert fill materials [16] (Fig. 6).

4 Advantages of Plasma Gasification

Plasma gasification provides for breaking down of tar, char and dioxins of raw syngas resulting in a cleaned or refined syngas compared to other thermal processes. This cleaner syngas might be suitable for production of the liquid fuels or renewable hydrogen gas. The high energy density and temperature attained in plasma process facilitates great heat and reactant transferal rates and allows attaining a significant volume reduction, resulting reduced reactor size to be installed for a specified waste amount and thereby maintaining economic sustainablity.

The heat for plasma production is provided by electricity externally and not a portion of heat generated from treated substances is re circulated, making this process controllable and flexible i.e. waste input variability doesn't cause problems [5]. Raw MSW can be fed to gas plasma treatment avoiding need for landfills and reuse of vitrified slag as construction material (potentially marketable tiles, bricks, etc.) makes it a lead runner of sustainable waste management.

5 Landfill Mining Practices in India

India with world's 2nd largest population (1.27 billion), being in an industrialization phase, which adds to its rapidly changing to urbanization, i.e. people migrating from rural to city life. Unmanaged growth of population, increased industrialization, unplanned urbanization, are all increasing its per capita waste generation [17]. According to a data from central pollution control board (CPCB) 1.27 lac tonnes of MSW are generated per day and as per Ministry of State for Environments, Forests and Climate Changed (MOEF-2016). Out of 63 million tonnes of waste per year, 5.6 million tonnes plastic waste, 0.17 million tonnes biomedical, 7.9 million tonnes hazardous waste and 50 lakh tonnes e-waste is reported (MOEF-2016). Contrary to this, a report by planning commission of India-2014 reveals that this much waste of 62 million tonnes is only produced by 37.7 crore people living in urban areas per annum. And, at the current growth rate of generation it may reach 165 million tonnes per annum by 2031. Nearly 80% of this waste goes indiscriminately to landfills for dumping (which is the highest level of management so far achieved). On per capita basis, India produces 0.45 KG wastes per capita per day. The land area required for disposal by land filling is increasing by 1175 ha per year and by 2031, area required for dumping wastes would raise to 66 thousand hectors of land area for setting of 10-m-high waste pipe for a projected life of 20 years of landfill (Fig. 7). India with only 5% of world's land area could not afford this much land space for wastes. There are uncertainties in the data of waste and its characteristics; therefore, it is very much challenging to evaluate the land prerequisite as different reports give different data.

The working process including the air flow path and other mechanisms have been shown in the Fig. 5.

6 Waste Characteristics and Composition

The MSW generated in India is composed majorly of

(a) Biodegradable wastes: Green wastes (vegetables and fruits), food wastes, kitchen wastes, etc.
(b) Paper, glass, metal scrapes, empty bottles, plastic fractions, etc.
(c) Construction and demolition wastes, dirt, debris-inert waste matters.
(d) Medical wastes, e-wastes, paints, chemicals, spray cans, fertilizer bags, containers, etc.
(e) Domestic hazardous waste, toxic wastes.

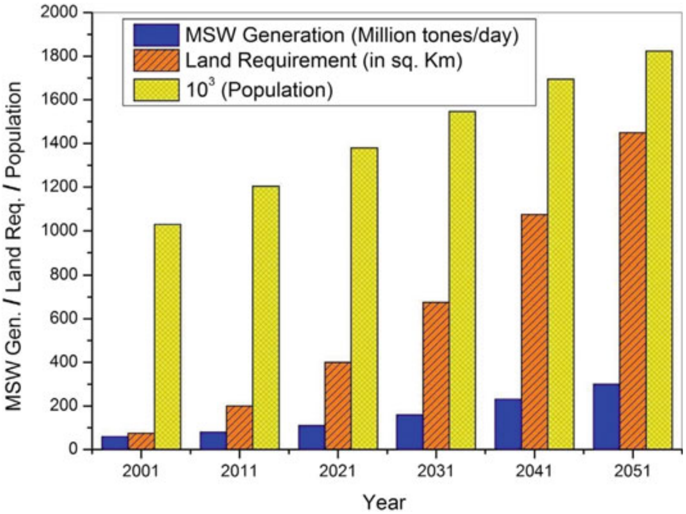


Fig. 7 Forecast plot for MSW generation, land requirement and population from 2001 to 2051 [18]

In broader terms, Indian MSW contains large organic matter portion, ashes, fine earth, glass, paper, metals and plastics. The MSW has an organic matter fraction of 40–60%, recyclables 10–30% and others, i.e. inert fractions 30–50%. In addition to these industrial sectors produces 100 million tonnes per year of non-hazardous solid wastes comprising of 70% or more of coal ashes, about 8% of hazardous wastes, i.e. about 8 MT per annum comprising 4.8 MT recyclables [17].

7 Indian Scenario of Solid Waste Management and Energy Production

The Indian municipal solid waste management is a set of rules and regulations executed through urban local bodies (ULBs). These rules are in the form of municipal solid wastes management rules (MSWR-2000) and latest amended in 2016. Only 70% of total waste generated is treated and rest 30% is thrown untreated. These ULBs are weak in execution to such a level that no city could even achieve 100% separation of wastes at source level. Scientific ways of disposing are achieved up to 12.45% only so far and the rest goes to dumpsites.

7.1 Disposal Techniques Adopted

Unscientific disposal is practised at every level of civilization from village to cities. A lot of waste produced could not even reach the designated dumping sides, is found in city peripheries, over the road sides, along the drains, scattered in green outskirts. The uncontrolled dumping is most common form of disposal in almost every city [19]. The direct disposal on low lying areas of city outskirts is prone to floods during monsoons leading to surface water contamination, non-sanitary conditions and leachate percolation to contaminate ground water resources [20, 21].The disposal to landfills is the final destiny of solid wastes after subjecting it to some treatment processes to reduce adverse environment impacting potential.

7.2 Waste to Energy Scenario/Statistics

The common treatment methods adopted are compositing, landfilling, thermal processes, etc., adopted for MSW and other wastes. These treatment processes depend up types of wastes, capacity of process to treat a specific waste, amounts of residue generation, cost involved, risk associated and safety to the environment issues [5].

The Indian MSW is reported to have a calorific value of 19.43 MG per metre cube and can yield on an average of 95 m^3 CH4 per ton [19]. This calorific value/energy content is dependent upon composition and moisture content. This is equivalent to energy of 12.98×10^5 KWh per year given 80% efficiency of generators and 25% conversion efficiency [19]. The common disposal observes in in hierarchical order are as follows.

7.2.1 Landfill Gas-to-Energy Plants

Decomposition in landfills produces two major greenhouse gases CH_4 and CO_2. Indian landfills produce nearly 16 MMT CH_4 per year of CO_2 equivalence of from its landfills which accounts for about 1.95% of total global annual release. This landfill gas can be utilized to produce energy as electricity. The annual production of 62 million tons of MSW carries a potential of 72 MW of electricity from landfill gas burning per day. The schematic of electricity generation from land fill gases is shown in Fig. 8. This energy utilization of CH_4 breaks it into CO_2 and H_2O which are less harmful as greenhouse gases. The biogas can be used for in-situ energy generation. Ministry of New and Renewable Energy (MNRE, GOI) has as per its report installed some plants like Solapur Plant (Maharashtra)—3 MW Capacities, 16 MW Okhla Delhi Plant and planned to support many such projects. But, the lack of high calorific value matter in MSW, presence of inert wastes and non-permission

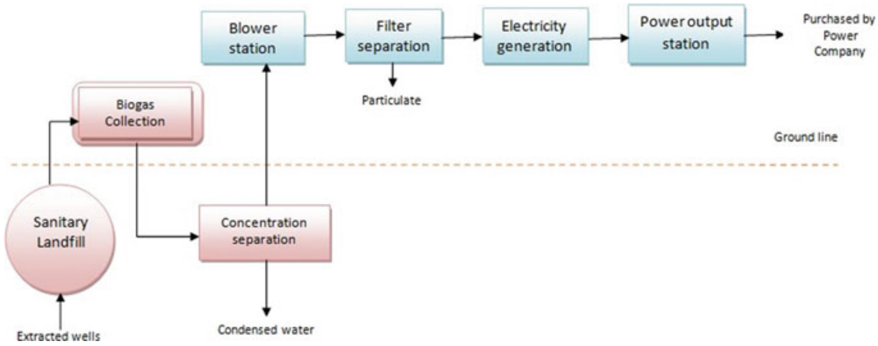


Fig. 8 Electricity generation diagram from landfill biogas [22]

by MSWR of leachate re-circulation in landfill sites to enhance gas production as is adopted in developed countries has made it a non-efficient process.

7.2.2 Aerobic Digestion

Aerobic bacteria decompose organic fractions of waste at a suitable moisture content and warmness into a nutrient rich product called humus or compost [18]. It can help to reduce volume of wastes by 50–85% [17]. The composting centre at Indore (MP) is one of the best maintained MSW composting centres. Mechanical composting units at Delhi, Bangalore, Vadodara and Mumbai were set up with capacities 150–300 tonnes per day. Other methods employed for composting is vermin-composting which is brought about by use of earth worms on semi-decomposed organic wastes. The largest vermin composting plant of India is located in Bengaluru; this plant has potential of 100 million tonnes per day. Smaller plants are located in other cities across India like Mumbai, Faridabad and Bangalore.

7.2.3 Anaerobic Digestion/Bio-methanation

The bio-methanation is an anaerobic break down of organic fractions of wastes to liberate bio-gas. The bio-gas richly contains methane (55–60%) and can be used as a fuel for generation of electricity, cooking purposes and inert residue can be used as manure. The utilization of industrial, agricultural and municipal wastes to bio-gas through this sustainable technique is highly encouraged by GOI. A number of such schemes are at planning and inception steps across India.

7.2.4 Thermo-Chemical Technology

The various waste-to-energy thermal processes (transformational facilities) are: incineration, pyrolysis, gasification and plasma gasification. These can create energy in the form of electricity, fuel or heat by mass burning of wastes. However, for effective results, MSW after pre-processing is used for these processes.

7.2.5 Incineration or Mass Burning

Incinerations simply means mass drying and high-heat burning of wastes. It reduces the volume of wastes by about 70% approximately. The products are large amount of heat, CO_2, H_2O in vapour form and ashes. This heat can be tapped to produce electricity. The low calorific value of waste, large biological part 40–60%, large moisture 40–60% and non-homogeneity due to inert faction makes Indian MSW unsuitable for effective incineration. In India, incineration is usually employed for medical wastes burning through small scale incinerators. Presently, no large-scale incineration plant in India. The other unsuitability of this process is the release of harmful dioxins and heavy metals like sulphur, nitrogen, and chlorine, etc., which are detrimental to environment.

7.2.6 Pyrolysis

Pyrolysis is thermal degradation of solid wastes at relatively lower temperature in the absence of air to release recyclable products in all three states of matter. The major benefit over incineration is very minute adverse impact on environs and relatively lower temperature range (400–900 °C) of operation. But, the high initial cost and operational cost hinder its use on commercial scale.

7.2.7 Gasification

Gasification is most attractive alternative to thermal treatment of solid wastes and produces combustible gas like hydrogen and synthetic fuels from carbonaceous wastes at elevated temperatures (500–1800 °C). It decreases pollution and upsurge heat recapture. India has few gasifiers are in action and are used to burn only agro bio-masses [18], e.g., NERIFIER Gasification Unit at Nohar, Rajasthan burns only agro wastes, forest wastes and sawmill dusts. Another unit is Tata Energy Research Institute (TERI) gasification unit at Gaulpahari, New Delhi. The effectiveness of gasification process depends upon supply of raw fuel as homogenous refuse-derive fuel (RDF), however, operating costs of RDF plant are higher (PCI-report).

8 Conclusion

Waste generation is inevitable with the present standards of life, so it has to be managed scientifically. With the available advancements in technology, waste generation can no longer be treated as a burden and its disposal can be made a potential source of much needed energy for day to day needs of anation. The review carried out for enhanced landfill mining forming important component of such waste management system with respect to available technologies can be concluded as below:

- Although high temperature burning of wastes has been there since a long time, but impacts of end products on environment, shortage of land space for final disposal, etc., has led to highly advanced methods like gasification of wastes and plasma gasification.
- Processes like twin-stage gas plasma process have actually been able to reduce wastes to almost zero level and recovery of both energy and products achieved.
- With processes like plasma gasification, we may not require to store wastes in landfills, but burn it directly and even low calorific value wastes can be disposed.
- Indian MSW being highly organic in nature is suitable for bio-chemical disposal. Although same is carried out at small scale, such treatments needs to be considered at large scale to meet country's rising needs as well to enhance agricultural productivity.
- At present, India should dispose wastes unsuitable for bio-chemical treatment, i.e. inorganic portion of MSW in engineered landfills with an intention of temporary storage till suitable economic and technological conditions arise for recovery of resources, at least these engineered landfills should be constructed with landfill gas recovery systems.

References

1. W. Hogland, M. Hogland, M. Marques, Enhanced landfill mining: material recovery, energy utilisation and economics in the EU (Directive) perspective, in *International Academic Symposium on Enhanced Landfill Mining* ed. By P. Jones, Y. Tielemans. (Houthalen-Helchteren, Belgiump, 2010), pp. 233–247
2. P.T. Jones, D. Geysen, Y. Tielemans, S. Van Passel, Y. Pontikes, B. Blanpain, M. Quaghebeur, N. Hoekstra, Enhanced Landfill Mining in view of multiple resource recovery: a critical review. J. Clean. Prod. **23**(1), 147–157 (2012)
3. J. Krook, N. Svensson, M. Eklund, Landfill mining: a critical review of two decades of research. Waste Manag. **32**(3), 513–520 (2012)
4. T. Prechthai, M. Padmasri, C. Visvanathan, Quality assessment of mined MSW from an open dumpsite for recycling potential. Resour. Conserv. Recycl. **53**, 70–78 (2008)
5. A. Bosmans, I. Vanderreydt, D. Geysen, L. Helsen, The crucial role of waste-to-energy technologies in enhanced landfill mining: a technology review. J. Clean. Prod. **55**, 10–23 (2013)

6. B.K. Shukla, A. Khan, G. Saikiran, M. Sriram, A comparative study on effect of variation in opening shape on oxygenation performance of surface jet aerators used in water and wastewater treatment. J. Green Eng. **9**(3), 427–440 (2019)
7. B.K. Shukla, A.R. Bhowmik, R.B. Raj, P.K. Sharma, Physico-chemical parameters and status of ground water pollution in Jalandhar–Phagwara region. J. Green Eng. **9**(2), 212–223 (2019)
8. B.K. Shukla, A. Goel, Study on oxygen transfer by solid jet aerator with openings. Eng. Sci. Technol. Int. J. **21**(2), 255–260 (2018)
9. B.K. Shukla, V. Rajesh Kumar, A. Goel, A comprehensive review of surface jet aerators. Poll. Res.**37**(May suppl.), 19–24 (2018)
10. L.M. Schabbach, G. Bolelli, F. Andreola, I. Lancellotti, L. Barbieri, Valorization of MSWI bottom ash through ceramic glazing process: a new technology. J. Clean. Prod. **23**(1), 147–157 (2012)
11. A.V. Bridgwater, Renewable fuels and chemicals by thermal processing of biomass. Chem. Eng. J. **91**(2–3), 87–102 (2003)
12. L. Helsen, E. Van den Bulck, S. Mullens, J. Mullens, Low-temperature pyrolysis of CCA-treated wood: thermogravimetric analysis. J. Anal. Appl. Pyrol. **52**(1), 65–86 (1999)
13. B.D. Alessandro, M.D. Amico, U. Desideri, F. Fantozzi, The IPRP (integrated pyrolysis regenerated plant) technology: from concept to demonstration. Appl. Energy **101**, 423–431 (2013)
14. A. Klein, Gasification: an alternative process for energy recovery and disposal of municipal solid wastes.Ph.D. thesis (Columbia University, New York, 2002)
15. Fichtner: Advanced Plasma Power—Gas Plasma—Stage 5: Assessment Report. Fichtner Engineering and Consulting Services (Cheshire, United Kingdom, 2008)
16. L. Machiels, L. Arnout, P. Yan, P.T. Jones, B. Blanpain, Y. Pontikes, Transforming enhanced landfill mining derived gasification/vitrification glass into low-carbon inorganic polymer binders and building products. J. Sustain. Metal. **3**, 405–415 (2017)
17. A. Nandan, B.K. Yadav, S. Baksi, D. Bose, Recent scenario of solid waste management in India. World Sci. News **66**, 56–74 (2017)
18. R. Joshi, S. Ahmed, Status and challenges of municipal solid waste management in India: a review. Cogent Environ. Sci. **2**, 1139434 (2016)
19. S. Kumar, J. Bhattacharyya, A. Vaidya, T. Chakrabarti, S. Devotta, A. Akolkar, Assessment of the status of municipal solid waste management in metro cities, state capitals, class I cities, and class II towns in India: an insight. Waste Manage. **29**, 883–895 (2009)
20. I.M.C. Lo, Characteristics and treatment of leachates from domestic landfills. Environ. Int. **22**, 433–442 (1996)
21. S. Mor, K. Ravindra, R.P. Dahiya, A. Chandra, Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Environ. Monit. Assess. **118**, 435–456 (2006)
22. W.T. Tsai, Bioenergy from landfill gas (LFG) in Taiwan. Renew. Sustain. Energy Rev. **11**(2), 331–344 (2007)

A Comprehensive Review of Mass Transfer Phenomenon in Gas-Liquid Phase Flow During Aeration in Wastewater Treatment

Insha Imtiyaz, Krishnakant, Bishnu Kant Shukla, S. Varadharajan, and Gaurav Bharti

1 Introduction

Environmental pollution is one of the serious global challenges which touches almost all parts of the planet. There are various types of pollution like water, land, air and noise pollution and among them, water pollution is the most pernicious because water being a universal solvent can dissolve more substances than any other liquid on the earth [1]. One of the ways to prevent water bodies from getting polluted is to treat the wastewater before it is being discharged into the ecosystem. Liquid–gas mass transfer mechanism plays a major role in wastewater treatment because the oxygen level of wastewater is very less due to the presence of unwanted materials. The gas–liquid mass transfer mechanism is used in wastewater treatment for transferring O_2 in biological treatment processes, for stripping solvents from wastewater, and removing volatile gases such as H_2S, NH_3. Aeration is one of the examples of mass transfer process where interphase diffusion occurs. This process is all about the interaction between ambient air and water with aerodynamic and hydrodynamic forces acting between them. The mass transfer mechanism is used in many processes which include absorption, evaporation, drying, precipitation, membrane filtration and distillation and hence plays a major role in those industries where this mechanism is used in working, such as biological engineering industries, petrochemical industries. Different methods of gas–liquid mass transfer are available to induce dissolved oxygen into water bodies such as diffusion through bubbles, aeration by jet mixtures, gas jet aerators, plunging jet aeration by the means of surface jet aerators and static tube mixtures. The surface jet aeration mechanisms are widely used in this

I. Imtiyaz · Krishnakant
School of Civil Engineering, Lovely Professional University, Phagwara 144411, India

B. K. Shukla (✉) · S. Varadharajan · G. Bharti
Department of Civil Engineering, JSS Academy of Technical Education, Noida 201301, India
e-mail: bishnukantshukla@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_11

process because of their ease in installation and reliable operation and maintenance cost along with high oxygen transfer efficiency. Factors that affect the gas transfer, like Physical properties of gas and liquid medium are temperature-dependent [2]. A substantial number of researchers carried several experiments in which they used plunging water jets [3–7] to get more insights on the mechanism of gas–liquid interphase mass transfer. In further studies. [7, 8] examined the factors affecting rate of mass transfer. Furthermore, researchers examined the efficiency of gas–liquid diffusion in aerated filters used by biochemical industries [9]. Deswal and Verma [10] studied further and various other models like multiple inclined plunging jets [11] and hollow plunging water jets [12] were tested for oxygen transfer efficiency and gas–liquid mass transfer rate.

2 Theory

Mass transfer in gas–liquid interphase is an integral mechanism followed in various chemical, petrochemical industries and water treatment plants. Therefore, it becomes important to estimate the parameters for measuring the efficiency of the mass transfer mechanism. Furthermore, it is important to determine the factors affecting mass transfer rate like velocity of liquid jet, length of jet, number of jets, diameter of jet during testing several models, discharge through the liquid jet, nozzle shape, etc. to gain better understanding of the mechanism involved in mass transfer. Equations have been presented in this section to determine different parameters affecting mass transfer rate.

$$\frac{dc(t)}{dt} = K_L A \frac{1}{v_t}[c_s - c(t)] - \frac{Q}{v_T}\left[c(t) - c\left(t - \frac{v_p}{Q}\right)\right] \tag{1}$$

where c_s is saturated concentration of DO, Q is the jet flow rate, v_t represents the quantity of the water in the model tank, v_p denotes the volume of water contained in pipes used for circulation and $K_L A$ implies to oxygen transfer factor at non-standard conditions. Further, when, v_p is negligible as compared to v_t, further when we simplify Eq. (1) we get.

$$\frac{K_L A}{V} = \frac{1}{c_s - c}\frac{dc}{dt} \tag{2}$$

where V denotes the quantity of water in closed testing system and for calculation purposes, its quantity is assumed to be same as the water that tank contains. Now if we integrate Eq. (2) we will get:

$$\frac{K_L A}{V} = \frac{1}{t}\ln\left[\frac{c_s - c_0}{c_s - c_t}\right] \tag{3}$$

where c_0 is the DO concentration at the start of the experiment. Since the conditions when the experiments were conducted was not standard, therefor we need to find $K_L A$ value at standard conditions when pressure is 1 atm, and temperature is of 20 °C denoted as ($K_L a(20)$). We can compute its value by using the relationship given below:

$$K_L a(20) = \frac{K_L A}{(1.024)^{(T-20)}} \tag{4}$$

where by $K(20)$ is Volumetric oxygen transfer factor at standard conditions and non-standard temperature during experiment is denoted by T ($c°$). Moving further, jet power in mass transfer phenomenon, denoted by P (in kW) can be determined using this relationship.

$$P(KW) = \frac{1}{2\left(\rho Q v_j^2\right)} \times 10^{-3} = \pi/8 \times \left(\rho n d_j^2 v_j^3\right) \times 10^{-3} \tag{5}$$

where ρ is density (Kg/m^3), Q is discharge (m^3/s), v_j is velocity of jet (m/s), j is the jet diameter (m). It can be observed from the Eq. (5) that jet power for mass transfer has a direct proportionality with the jet velocity, the diameter of jet and the number of jets.

3 Literature Review

A compendious review of literature is a crucial part of the research study to understand what work had been done in a particular field along with the main methodology and research techniques used. It helps to understand the gap areas and open questions left in those study, and how further research can help to fill those gap areas. So a comprehensive literature review comprising of major breakthrough in surface jet aeration technology has been presented in the following paragraphs.

Van de Sande and Smith [13] Conducted a comprehensive study to measure the gas transfer rate from bubbles to the liquid media. Experiments were performed with the fixed diameter (d_n) of nozzle, velocity of jet and only length of the nozzle was varied and it was found that the amount of air entrained depends on entrainment region. Furthermore, a direct proportionality was observed between total mass transfer from bubbles and the airflow rate.

Tojo and Miyanami [14] Studied distinctive features of the down-flow jet mixer and compared it with up-flow jet mixer based on mass transfer rate using two types of tanks (rectangular and circular) and a circular nozzle. It was found that in a down-flow jet mixer, the gas–liquid mass transfer may increase with upsurge in jet length and velocity of liquid jet while in the up-flow jet mixer with increase in airflow rate, mass transfer rate increases. Based on experimental results, it was concluded that the down-flow jet mixer is more competent for oxygen–transfer (K_a) as compared to the up-flow jet mixer.

Comprehensive study was conducted on plunging liquid jet absorber to study the mechanism of gas–liquid interphase mass transfer on two different systems: one had complete liquid phase and the second had ionic salts mixed in the liquid medium to test the mass transfer behavior [3]. After substantial analysis, it was found that unlike jet length, jet velocity and the angle of inclination had a significant effect on the mass transfer factor. In addition to this, it was found that through an interfacial area of the range 500 to 1000 m^2/m^3 gas fused rigorously into the liquid phase.

Study was done on plunging jet systems concerning CO_2 absorption in water and dependency of the absorption rate was investigated for various factors like diameter of nozzle, velocity of liquid and length of the jet [4]. A set of experiments were conducted by varying nozzle diameter of 1.2, 2, 3, 3.5 and 6 mm and with a liquid flow rate between 1.1×10^{-5} and $23.3 \times 10^{-5} m^3 s^{-1}$. After substantial analysis, it was found that the rate of CO_2 absorption increases with upsurge in value of nozzle diameter, the liquid velocity at the nozzle and jet length through the gas phase.

A comprehensive study was done by researchers [2] to check variation of liquid film coefficient when there was change in temperature for gas transfer through the water–air interface. Earlier an empirical formula was used to depict the dependence of K_L (liquid film coefficient) on Schmidt number and θ (θ is constant and its value is 1.0241). After the substantial study, an equation was derived to accurately determine the Temperature Correction Factor (f_c), which had its dependence on $Sc^{-1/2}$ (Sc = Schmidt number) and it gave better results than the empirical equation with $\theta = 1.0241$. Different aspects thoroughly related to entrainment of gas by plunging liquid jet such as mechanism involved, conditions of onset environment, amount of the entrained gas and mass transfer was studied in detail in 1988 [6]. After extensive analysis, it was concluded that for nozzles with $l/d_0 \geq 4$ the entrainment ratio is proportional to $\left(\frac{L_j}{d_0}\right)^{0.5}$ to $\left(\frac{L_j}{d_0}\right)^{0.5}$ for the value of $L_j/d_0 < 100$ and if $L_j/d_0 > 100$ then it is proportional to $\left(\frac{L_j}{d_0}\right)^{0.7}$ where l, L_j, d_0 are the length of the cylindrical section of the nozzle, jet length, nozzle diameter, respectively.

Cummings and Chanson [15] examined the mechanism of air entrainment by plunging liquid jets along with new experimental evidence. He performed a set of experiments in large vertical supporting jets with the mean velocity at jet impact (v_1) between $0.3 < v_1 < 9$ ms^{-1}. He found that air bubble responsible for mass transfer is observed only when jet velocity exceeds the critical velocity of about 1.1–2 ms^{-1} for a two-dimensional vertical jet experiment.

Yamagiwa et al. [7] studied oxygen transfer rate of plunging jet reactors with varying viscosity of liquid. In the experiment Corn Syrup (Newtonian Fluid) of varying concentration from was used, corresponding values of viscosity and density ranged from 2.60–40.5 mPa to 1130–1277 kg/m^3, respectively. After substantial analysis, it was found that depending upon the viscosity of liquid air entrainment characteristic was divided into three regions, where oxygen transfer rate sharply decreased, remained constant and slightly increased with the liquid property depending upon jet Reynolds number.

Bagatur et al. [16] studied the aeration performance of plunging jet and conducted a set of experiments by using models of different nozzle shape and keeping velocity of jet between 2 and 20 m/s and with jet length = 0.15 m. It was found that nozzle of elliptical shape gave highest oxygen transfer coefficient for air entrainment by plunging jet and its efficiency to transfer oxygen was higher than circular nozzle.

Chanson et al. [17] examined the factors affecting bubble dispersion and rate of air entrainment by using vertical circular plunging jet models. Three models were studied with a jet nozzle diameter of 6.8, 12.5 and 25 mm & air–water dispersion was calculated wide number of flow conditions but for same Froud Number. After extensive analysis, similar flow patterns were observed for all the three models, for low velocities, no bubbles were observed at the jet impact surface but as the velocity increased bubble entrainment was seen, smaller bubbles in the size of range 0.5–1 mm followed a helicoidal path about the jet center-line. Furthermore, bubble chord size and bubble chord time were measured and the results depicted a direct proportionality between mean chord size and jet velocity for a give cross-section.

Emiroglu and Baylar [18] examined the air entrainment behavior of a venturi device having nozzle shape different than conventional nozzles by varying the numbers and positions of air holes along the convergent-divergent passage. They found that efficiency of oxygen transfer (OE) decreases with increase in jet velocity. Furthermore, air entrainment rate (QA) values of the venturi device was found to be greater than the models with circular shaped nozzle.

Baylar and Emiroglu [8] studied gas entrainment properties of circular nozzles with and without air holes by keeping velocity of water jet at different velocities, between 2.5 and 15 m/s and keeping the plunge angle of the water jet at 45°. Greater value was detected for rate of air entrainment and efficiency of gas transfer in case of circular nozzles with air holes as compared to nozzles without air holes.

Leung et al. [9] studied the effect of water and airflow rate, temperature of liquid and gas holdup on oxygen transfer coefficient by using a bench-scale up-flow BAF column setup (1.3 m high) with spherical support gravel nominal diameter of 19 mm and 25 mm). After extensive analysis of experimental results, it was detected that the coefficient of oxygen transfer ($K_L a$) increases with increase in water temperature and liquid velocity. In addition to that gas holdup in clean as well as wastewater increases with upsurge in superficial gas velocity.

Deswal and Verma [19] conducted a comprehensive study on a conical shaped plunging jet of diameter 64.5 mm and having plunge angle of 60^0, to determine the coefficient of oxygen transfer and its efficiency. The thickness of the jets was kept as 1.9 mm, 2.72 mm and 3.77 mm and results were analyzed for different flow rates. It was found that the coefficient of oxygen transfer increases with upsurge in the jet velocity, thickness of the jet and jet power.

Deswal and Verma [10] studied multiple plunging jets to compute its air entrainment efficiency and coefficient of oxygen transfer by varying number of jets and jet diameter used and the jet number was varied as 1, 4, 8 and16. After substantial analysis, it was detected that with increase in number of the jets both coefficient of oxygen transfer as well as air entrainment efficiency increases. Furthermore, air entrainment efficiency of multiple plunging jets was found to be greater than single jet when jet power is kept constant.

Deswal [11] conducted a set of experiments to compute coefficient of oxygen transfer ($K_L a(20)$) and efficiency of oxygen transfer of multiple inclined plunging liquid jets (plunge angle kept at 60°) at different jet flow rate of 1.33×10^{-3}, 1.8×10^{-3}, 2.5×10^{-3}, 3.1×10^{-3} m^3/s with varying jet diameters and number of jets. It was found that ($K_L a(20)$) for multiple inclined plunging liquid jets increases with upsurge in jet velocity. Coefficient of oxygen transfer of multiple inclined plunging jet was also found to be greater than that of single jet if jet power is not varied.

Deswal [12] conducted a set of experiments with hollow plunging jet models by varying thicknesses of jets ($t_j = 1.95$, 2.85 and 3.97 mm). The model was examined at different jet flow rate, viz., 1.33×10^{-3}, 1.88×10^{-3}, 2.5×10^{-3} and 3.1×10^{-3} m^3/s. It was found that coefficient of oxygen transfer in case of hollow plunging jet increases with upsurge in velocity of jet and (P/V) value of jet, while oxygen transfer efficiency decreased with upsurge in (P/V) (Fig. 1).

Kumar et al. [20] studied various regression techniques predict the coefficient of oxygen transfer ($K_L a$) and its efficiency for hollow jet aerator models. The models were tested for jet velocity and discharge maintained from 1.69 to 9.74 m/s and 2.18 to 15.5 L/s. it was found that ($K_L a$) value increases with the upsurge in jet velocity while oxygen transfer efficiency decreases with upsurge in jet velocity for all configuration of apparatus used in experiment. Furthermore, it was concluded that the RBF kernel-based Gaussian process regression (GPR) technique is best to predict coefficient of oxygen transfer.

Shukla and Goel [21] conducted a comprehensive study to estimate oxygen transfer factor ($K_L a(20)$) of aerator model by varying total number and area of opening. The experimental models were tested for different discharge rate viz., 1.11 $\frac{l}{s}$, 2.1 $\frac{l}{s}$, 2.96 $\frac{l}{s}$, 3.83 $\frac{l}{s}$, 4.69 $\frac{l}{s}$. It was found that the factor of oxygen transfer is directly proportional to discharge regardless of the number of openings of jets and when discharge was fixed aerators those had a larger area of openings had greater values of oxygen transfer (OE).

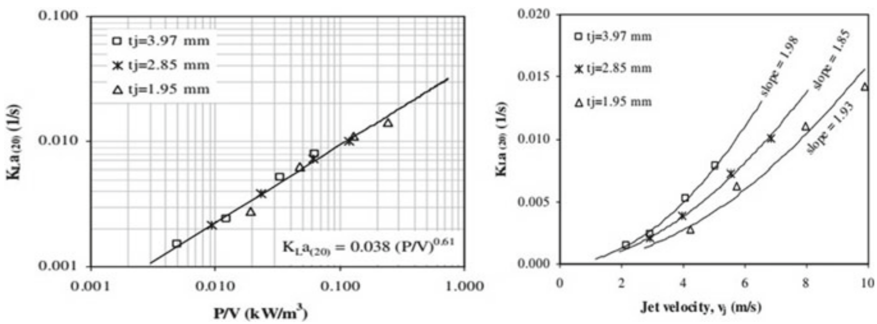


Fig. 1 Variation of oxygen transfer factor w.r.t. different inputs parameters [12]

Kumar et al. [22] studied the application of various regression techniques such as Gaussian Process Regression (GPR) techniques and Support Vector Regression (SVR) for determining the coefficient of volumetric oxygen transfer for plunging hollow jet models. It was deduced that SVR model can predict oxygen transfer factor more accurately by using radial basis function as kernel function as compared to other regression models using different kernel function.

Shukla et al. [23] conducted a set of experiments to examine solid jet aerators for their oxygenation performance with circular opening by varying length of the jet and area of the flow. It was found that Oxygen transfer coefficient ($K_L a$) for solid jet holds a direct proportionality with the jet velocity, length of the jet and discharge. Furthermore, it was observed that Oxygen transfer efficiency (OE) decreases with the upsurge in discharge and velocity.

Kumar et al. [24] studied different regression techniques of modeling such as multiple nonlinear regression technique (MNLR), artificial neural network (ANN), in addition to that he used adaptive neuro-fuzzy inference system (ANFIS) and multivariate adaptive regression splines (MARS) to analyze different experimental data. He compared different regression techniques to determine best modeling technique for predicting the value of oxygen transfer factor ($K_L a$) of hollow plunging liquid jets. He found that ANFIS as well as ANN are best regression techniques for predicting ($K_L a$) value in comparison to MNLR, MARS and GRNN.

4 Conclusion

This paper summarizes the extensive research done on gas–liquid multiphase mass transfer mechanism using various models with different liquid jet velocity, jet length, discharge through the liquid jet, nozzle shape, jet diameter and following conclusions have been drawn on basis of the present study:

- After substantial analysis, it was found that the rate of gas–liquid mass transfer increases if there is increase in nozzle diameter, velocity of jet and jet length through the gas phase. Furthermore, it was found that geometry of nozzle plays a significant role in mass transfer rate.
- Bubbles responsible for mass transfer were only observed when velocity of jet was larger than the critical velocity of about 1.1 to 2 ms^{-1} for a two-dimensional vertical jet experiment.
- Upsurge in coefficient of oxygen transfer ($K_L a$) was detected if there was increase in water temperature, velocity of jet, thickness of the jet, jet power and number of jets.
- Rate of mass transfer for circular shaped nozzles without air holes was found to be less than that of circular shaped nozzle with air holes.
- It was also concluded that inclined jets are more efficient for mass transfer in gas–liquid phase as compared to the vertical jets.

- There has not been any study to examine the effects of multiple aerators in a single model.

References

1. B.K. Shukla, A. Gupta, P.K. Sharma, A. Bhowmik, Pollution status and water quality assessment in pre-monsoon season: A case study of rural villages in Allahabad district, Uttar Pradesh, India. Mat. Today: Proceed. **32**, 824–830 (2020)
2. E.I. Daniil, J.S. Gulliver, Temperature dependence of liquid film coefficient for gas transfer. J. Environ. Eng. **114**(5), 1224–1229 (1988)
3. A.K. Bin, J.M. Smith, Mass transfer in a plunging liquid jet absorber. Chem. Eng. Comm. **15**(5–6), 367–383 (1982)
4. D. Bonsignore, G. Volpicelli, A. Campanile, L. Santoro, R. Valentino, Mass transfer in plunging jet absorbers. Chem. Eng. Process.: Process Intensif. **19**(2), 85–94 (1985)
5. K. Funatsu, Y.C. Hsu, M. Noda, S. Sugawa, Oxygen transfer in the water-jet vessel. Chem. Eng. Commun. **73**(1), 121–139 (1988)
6. A.K. Bin, Gas entrainment by plunging liquid jets. VDI Forschungsheft **648**(88), 1–36 (1988)
7. K. Yamagiwa, A. Ito, Y. Kato, M. Yoshida, A. Ohkawa, Effects of liquid property on air entrainment and oxygen transfer rates of a plunging jet reactor. J. Chem. Eng. Jpn. **34**(4), 506–512 (2001)
8. A. Baylar, M.E. Emiroglu, An experimental study of air entrainment and oxygen transfer at a water jet from a nozzle with air holes. Water Environ. Res. **76**(3), 231–237 (2004)
9. S.M. Leung, J.C. Little, T. Holst, N.G. Love, Air/water oxygen transfer in a biological aerated filter. J. Environ. Eng. **132**(2), 181–189 (2006)
10. S. Deswal, D.V.S. Verma, Air-water oxygen transfer with multiple plunging jets. Water Qual. Res. J. Can. **42**(4), 295–302 (2007)
11. S. Deswal, Oxygen transfer by multiple incliend plunging water jets. Int. J. Eng. Appl. Sci. **4**(8), 57–63 (2008)
12. S. Deswal, Oxygenation by hollow plunging water jet. J. Institute of Eng. **7**(1), 1–8 (2009)
13. E. van de Sande, J.M. Smith, Mass transfer from plunging water jets. Chem. Eng. J. Netherlands **10**, 225–233 (1975)
14. K. Tojo, K. Miyanami, Oxygen transfer in jet mixers. Chem. Eng. J. Netherlands. **24**, 89–97 (1982)
15. P.D. Cummings, H. Chanson, Air entrainment in the developing flow region of plunging jets—Part 1: Theoretical Development. J. Fluids Eng. **119**(3), 597–602 (1997)
16. T. Bagatur, A. Baylar, N. Sekardag, The effect of nozzle type on air entrainment by plunging water jets. Water Qual. Res. J. Canada **37**, 599–612 (2002)
17. H. Chanson, S. Aoki, A. Hoque, Physical modelling and similitude of air bubble entrainment at vertical circular plunging jets. Chem. Eng. Sc. **59**, 747–758 (2004)
18. M.E. Emiroglu, A. Baylar, Study of the influence of air holes along length of convergent divergent passage of a venture device on aeration. J. Hyd. Res. **41**, 513–520 (2003)
19. S. Deswal, D.V.S. Verma, Performance evaluation and modelling of a conical plunging jet aerator. Int. J. Mech., Aerospace, Industrial, Mechatronic Manuf. Eng. 1(11) (2007)
20. M. Kumar, S. Ranjan, N.K. Tiwari, R. Gupta, Plunging hollow jet aerators—oxygen transfer and modeling. ISH J. Hydraulic Eng. **24**(1), 61–67 (2017)
21. B.K. Shukla, A. Goel, Study on oxygen transfer by solid jet aerator with multiple openings. Eng. Sci. Tech., An Int. J. **21**(2), 255–260 (2018)
22. M. Kumar, N.K. Tiwari, S. Ranjan, Kernel function based regression approaches for estimating the oxygen transfer performance of plunging hollow jet aerator. J. Achievements Mat. Manuf. Eng. **2**(95), 74–84 (2019)

23. B.K. Shukla, P.K. Sharma, A. Goel, Study on oxygenation performance of solid jet aerator having circular opening corresponding to variable jet length and flow area. J. Phys: Conf. Ser. **1531**(012117), 1–7 (2020)
24. M. Kumar, N.K. Tiwari, S. Ranjan, Soft computing based predictive modelling of oxygen transfer performance of plunging hollow jets. ISH J. Hydraulic Eng., 1–11 (2020)

Recycled Waste Materials

Utilization of Different Supplementary Cementitious Materials and Recycled Concrete Aggregate for Stabilization of Pavement Base Layer

Tanna Manohar, Nemmadi Vasudeva Rao, and Jyoti Prakash Giri

1 Introduction

Based on the demand of rapid urbanization as well as the scarcity of dumping lands, the use of waste materials in the field of construction is increased worldwide including India. The continuous use of raw materials leads to depletion of the natural resources. To resolve this issue, researchers and engineers need an effective method of utilizing the wastes those are originated from daily life as substitute materials in the various construction processes.

One of the wastes is demolition concrete, are occurring from various sources such as old air terminal runways, bridges, old structures, and concrete roads. These obtained wastes are processed to make them suitable for construction activities, and these processed materials are termed as recycled concrete aggregates (RCAs). The usage of RCA can be observed in various layers of pavements in past few decades, and found that, it is a good replacement material to natural resources. From past studies, it was observed that, recycled asphalt pavements (RAPs) used in base and sub-base layer of the pavement with cement addition to different types of fiber offering similar performance in the form of bearing strength as well as durability compared to the layer compacted with natural aggregate [1–7].

Keeping view on this, the main objective of the study on the usage of RCA at base layer of pavement with cement, ground-granulated blast-furnace slag (GGBS), pond ash (PA) and comparing their performance with the conventional base layer. To

T. Manohar · N. V. Rao
Department of Civil Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh 532127, India

J. P. Giri (✉)
Department of Civil Engineering, Centurion University of Technology and Management, Bhubaneswar, India
e-mail: jyotiprakash.nitr@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_12

find the objective, the base layer mixture has prepared with coarse aggregate fraction of the natural aggregate (NA) and RCA with addition to 5% of binder like cement, GGBS, and PA. Further, the performance studies have conducted through California bearing ratio (CBR) test and an unconfined compressive (UCS) test.

2 Materials

2.1 Aggregate

The natural aggregates are collected from the nearby quarry of Rajam, Andhra Pradesh. The RCA is collected from the old building parts and laboratory tested sample prepared for different testing purpose in college campus. The physical properties of them are in the laboratory and represented in Table 1.

2.2 GGBS

The GGBS is collected from the steel plant at Vishakhapatnam. GGBS is a by-product, generated from iron ore mixed with lime stone and coke while burning in the blast furnace. The properties of the GGBS are found in the laboratory listed below in the Table 2.

Table 1 Physical properties of NA and RCA

Tests	Specification	NA	RCA	Recommended value [8]
Specific gravity	[9]	2.74	2.58	
Water absorption (%)		1.15	5.57	<2
Crushing value (%)		22.67	28.39	<30
Aggregate impact value (%)	[10]	16.83	22.75	<30
Los-Angeles abrasion (%)		27.86	33.46	<40

Table 2 Physical properties of GGBS

S. no	Tests	Experimental value
1	Consistency (%)	32
2	Soundness (mm)	4
3	Fineness modulus	0.14
4	Specific gravity	2.96

Table 3 Physical properties of pond ash

S. no	Tests	Experimental value
1	Fineness (m^2/kg)	246
2	Specific gravity	2.15

Table 4 Physical properties of cement

S. no	Tests	Experimental value
1	Specific gravity	3.15
2	Initial setting time (min)	40
3	Final setting time (min)	510
4	Consistency (%)	32

2.3 Pond Ash

The pond ash is collected from the NTPC Parawada, Vishakhapatnam. The pond ash is obtained from the coal-based thermal plants, and it is a mixture of fly ash and bottom ash which are dumped together in an ash pond. The properties of the pond ash are observed in the laboratory presented in Table 3.

2.4 Cement

Cement of grade 53 is collected from the local store. The physical properties of the cement found in laboratory are listed in Table 4.

2.5 Sample Preparation and Tests

The experimental work mainly aims at utilizing the RCA with cement and other types of cementitious materials like GGBS and pond ash in the base layer of the pavement. Six different proportions are considered for this study containing NA and RCA as main fraction addition to these three types of cementitious materials. The RCA mixed with the cement represented as RCAC; RCA mixed with GGBS represented as RCAG, and the RCA with pond ash is represented as RCAP. In similar way, NA with cement, GGBS, pond ash are represented as NAC, NAG, NAP, respectively. The compaction parameters and performance study are done using modified proctor test, California bearing ratio (CBR) test (both soaked and unsoaked condition), and unconfined compressive strength (UCS) test, respectively, with 5% of binding materials by total weight of sample for all six mixtures as shown in Figs. 1, 2, 3, and 4 [10–12].

(a) (b)

Fig. 1 Sample preparation **a** mixing **b** compaction

Fig. 2 CBR testing setup

3 Experimental Outcomes and Discussions

3.1 Compaction Parameters

The results of the compaction tests for the sample prepared with 5% binding materials are represented in Table 2. From Table 2, it is detected that, the OMC of the RCA increases, and the dry density for the same is decreased. This might be due to the presence of sand–cement coat on the surface of RCA, and it absorbed more percentage of water. However, it is reversed when the mixtures are prepared with natural aggregate, i.e., low OMC and high MDD compared to RCA mixtures (Table 5).

Fig. 3 Prepared UCS sample

Fig. 4 Curing of UCS sample

Table 5 Compaction parameters (OMC and MDD)

S. no	Sample	OMC (%)	MDD (g/cc)
1	NAC	8	2.34
2	NAG	10	2.22
3	NAP	11	2.19
4	RCAC	12	2.17
5	RCAG	11	2.19
6	RCAP	9	2.2

3.2 Strength Characteristics

The variation of CBR for the NA and the RCA samples is represented in Fig. 5. From Fig. 5, it is observed that, the NAG is the highest CBR value compared with the other mixtures considered in this study under unsoaked condition. Whereas, in soaked condition, the highest value is observed for sample NAC followed by RCAC. From Figs. 5 and 6, it is found that, the soaked CBR value is more as compared to unsoaked one. The reason behind this may be the hydration process happened under the presence of water with cementitious materials. However, addition of the GGBS and cement to the RCA offering a significant performance in the CBR values which is nearly similar to NA mixes.

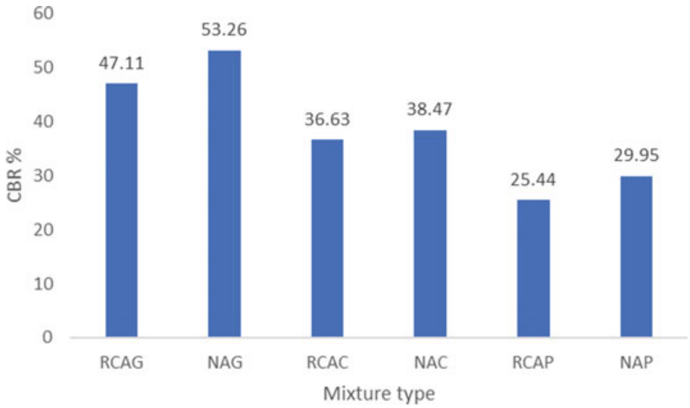


Fig. 5 Results of unsoaked CBR

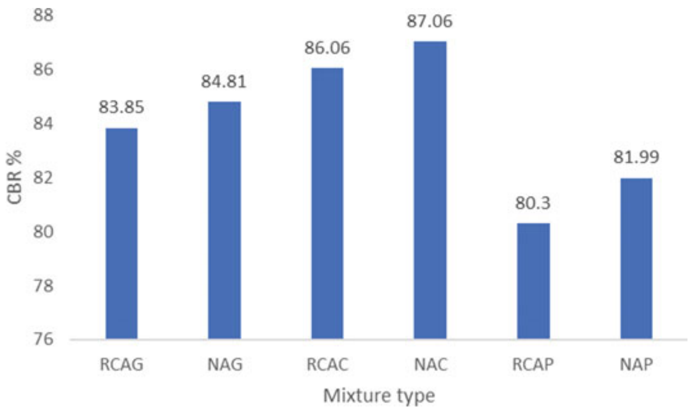


Fig. 6 Results of soaked CBR with different types of cementitious materials

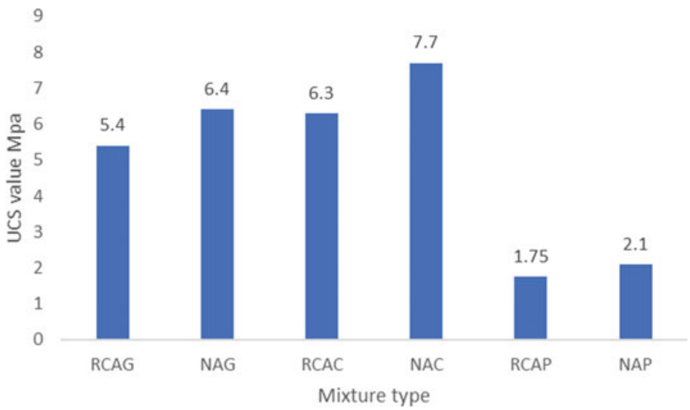


Fig. 7 Results of UCS with different types of cementitious materials

The unconfined compressive strength of all the mixtures considered is represented in Fig. 7. From this figure, it found that, the NA mixed with cement offering the highest UCS value followed by RCAC. Whereas, the lower values are found for the mixtures prepared with pond ash. The reason behind this may be due to the lack of binding quality of pond ash with course aggregate.

4 Conclusions

From this experimental investigation conducted on six different types of mixtures containing 5% of cement, GGBS, and pond ash, the following conclusions are drawn.

- The maximum dry density is found for the sample prepared with NAC, whereas the maximum dry density for sample compacted with RCAC.
- From the CBE test, maximum unsoaked CBR value is observed for NAG followed by RCAG compared to others in unsoaked condition. Whereas, in soaked condition, the maximum CBR value is found for NAC followed by RCAC.
- The maximum unconfined compressive strength is offered by the sample prepared with NAC followed by RCAC.

Based on the abovementioned experimental results, it may conclude that, the use of RCA and non-conventional cementitious materials in the base and sub-base layer pavement is possible as they are offering nearly similar result compared to conventional one. Hence, the uses of these waste materials in pavement construction conserve the natural resources as well as solve the dumping problem of them.

References

1. L.R. Hoyos, A.J. Puppala, C.A. Ordonez, Characterization of cement-fiber-treated re-claimed asphalt pavement aggregates: preliminary investigation. J. Mater. Civ. Eng. **23**(7), 977–989 (2011)
2. W.S. Guthrie, A.V. Brown, D.L. Eggett, Cement stabilization of aggregate base material blended with reclaimed asphalt pavement. Transp. Res. Rec. **2026**(1), 47–53 (2007)
3. H. Akbulut, C. Gürer, Use of aggregates produced from marble quarry waste in asphalt pavements. Build. Environ. **42**(5), 1921–1930 (2007)
4. A. Arulrajah, J. Piratheepan, M.M. Disfani, A reclaimed asphalt pavement and recycled concrete aggregate blends in pavement subbases: laboratory and field evaluation. J. Mater. Civ. Eng. **26**(2), 349–357 (2013)
5. D. Avirneni, S. Saride, Durability studies on fly ash stabilized reclaimed asphalt pavement materials. Geo-Chicago (2016)
6. M. Hoy, S. Horpibulsuk, A. Arulrajah, A. Mohajerani, Strength and microstructural study of recycled asphalt pavement: Slag geopolymer as a pavement base material. J. Mater. Civ. Eng. **30**(8), 04018177 (2018)
7. MORTH (Ministry of Road Transport& Highways) Specification for Road and Bridge Work 5th Revision (2013)
8. IS-2720-10(1991): methods of test for soils, part 10: Determination of unconfined com- pressive strength of soil
9. IS:2386 (Part-III)—1963 Method of test for aggregates for concrete
10. IS:2386 (Part IV)—1963 methods of test for aggregates for concrete mechanical properties
11. IS-2720 (Part 16) Methods of test for soils: Laboratory determination of CBR (second re-vision) (1987)
12. IS-2720 (Part-8) (Reaffirmed-May 2015) Methods of test for soils: Determination of wa- ter content - dry density relation using heavy compaction (1983)

Review on Fresh and Hardened Properties of Concrete Incorporating Silica Fume

Gurbej Singh, Kanish Kapoor, Paramveer Singh, and Mudasir Nazeer

1 Introduction

SCC development in the construction industry is an outstanding achievement in solving case problems. It is not affected by the skill of the team, but due to the high water content and resistance to discrimination, it can be pushed long distances if necessary. The term SCC was coined in 1986, but the model was first introduced in 1988 at the University of Kochi in Japan. During this time, SCC was designed to increase durability, shorten construction time and achieve better surface quality for concrete structures. The SCC exhaust does not require additional internal or external compression vibrations. It floats like a "treasure" and has a very smooth surface after insertion. In terms of structure, SCC has the same material as traditional vibrating concrete, namely, concrete, additives and water, as well as the addition of additional chemicals and minerals, in different numbers. The importance of determining the overall suitability of recycled materials has increased in recent years with a growing emphasis on sustainable construction.

1.1 Self-Compacting Concrete

Self-Compacting concrete (SCC) can also be defined as fresh concrete that flow under its own weight and does not require external vibrations for compression. It is used in construction where it is difficult to use a vibrator to compact concrete. Filling and passage capacity and partition strength are properties of self-installing concrete.

G. Singh (✉) · K. Kapoor · P. Singh · M. Nazeer
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India
e-mail: gurbejs.sc.19@nitj.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_13

SCC has superior fresh flow capacity that compacts and compresses the material without separation problems. The materials, tests and properties of self-hardening concrete are described in the following sections.

1.2 Need of Utilization of Silica Fume in Concrete

Silica fume (SF) is a byproduct of the smelting processes in the silicon and ferro-silicon industries. It is also called micro-silica, condensed silica smoke, vaporized silicate, or silica smoke. The color of premium silica fume is white or gray. Quartz smoke consists of very fine glass particles with a surface area of between 13,000 and 30,000 m^2/kg. The particles are about 100 times smaller than the average cement particle. Due to its fineness and high silica content, silica smoke is a very effective pozzolanic material. Silica is generally used in concrete to improve its properties. Silica fumes have been found to increase compressive strength, adhesion strength and abrasion resistance; reduced permeability; thus improving the corrosion protection of reinforced steel.

1.3 Advantages of Silica Fume in Concrete

- Silica fume is a type of inorganic neutral filler with very stable physical and chemical properties. It does not contain crystallized water, does not participate in the sedimentation reaction and does not interfere with the reaction mechanism.
- The particle size distribution of silica fume is reasonable, high compression, high hardness and wears resistance. It can greatly improve the tensile, compressive, impact and wear resistance of the hardened product, and the abrasion resistance can be increased 0.5–2.5 times.
- It can increase the thermal conductivity, change the viscosity of the adhesive and improve the fire resistance.
- The exothermic peak temperature of the epoxy resin curing reaction can be reduced, the linear expansion coefficient of the compressed product and the shrinkage rate of the solidified product can be reduced to relieve internal stress and avoid cracking.
- Due to the fine particle size and adequate distribution of silica dust, it can effectively reduce and eliminate precipitation and stratification.
- Pure silicone powder, small impurities, stable physical and chemical properties, so that the hardened material has good insulating properties and good arc resistance.
- Low bulk density, 0.2–0.8 or 1–2.2. As a polymer filler, it can reduce the cost by reducing the amount of loading and the amount of polymer.
- Good frost resistance and relatively fast elastic modulus of micro-silica after 300–500 fast closing/opening is 10–20%, and the elastic modulus of concrete of 30–73% is usually 25–50 cycles. Therefore, the frost resistance can be improved.

2 Findings of Silica Fume

- Strength properties like compressive strength are evaluated and compared with test results for concrete and traditional concrete, and different percentages of quartz dust are adjusted for the burden of the concrete after 7, 14 and 28 days of testing.
- Silica fume is one such industrial byproduct, which is getting used and experimented upon to get a stronger and sturdy concrete.
- The use of SCC is seen as an answer to boost filling that's not easily accessible with traditional cubic methods.
- By creating a mix of blends with this product, we found that the resistance to the GGBS blend increased by 20% and therefore the instinctive fire by 4.23%, so it decreased.
- The use of silica in concrete has technical possibilities and economic advantages.
- The high water absorption and porous structure of the RCA are the most challenges when using the RCA in SCC, which needs high flow power and good technical strength.
- The substitution of 50% CRCA and 25% FRCA within the SCC mixture showed a small decrease within the nature of the hard SCC compared to the SCC created by the positive and negative addition.
- The output capacity of SCC has been significantly reduced by over 50% for RCA use.
- Slump flow, V-funnel, column segregation, sieve segregation, segregation probe, U-shaped box, and VSI tests are utilized in the study.
- Power reduction is eighteen when 100% total recycling is integrated.
- The significant decrease in compressive strength was no quite 43% to 100% of the speed of the glass waste.
- After the primary day of preparation of the concrete, a rapid absorption of water is observed, this gradually fades over time.

3 Objectives of the Study

- For understand the utilization of self-compacting Concrete within the industry.
- To compare natural materials with recycled concrete aggregate.
- For determine the properties of Self-compacting concrete at fresh and hard stage of concrete.
- To understand the various mechanical and durability properties of SCC containing silica fume and its effects on the properties.

4 Effect of Silica Fume on the Fresh Properties of Concrete

4.1 Workability Test

Except for SF30, all of the fresh specimen has a slump flow diameter conform to AFGC and EFNARC recommendation, VMA 0.25 and VMA 0.30 which concluded a slump flow diameter of less than 60 cm. These results represent that the introduction of silica fume as a partial replacement by weight of cement ended to a decrease in slump flow diameter values. The fact that the silica fume has fineness and Pozzolanic properties due to which, it is very reactive in nature and which leads to increase the inter-particles friction. The VMA increases fixing of free water and cohesion, and which result in decrease of the slump flow [1].

When silica fume is added in concrete, it is found the concrete already required more water/cement ratio to obtain same workability as normal concrete. The higher amount of water requirement is may be because of higher surface area of silica fume particles [2].

5 Effect of Silica Fume on the Hardened Properties of Concrete

5.1 Compressive Strength

Influence of silica fume in concrete of grade M40 by using M-sand instead of river sand. They observed that 10% silica fume replacement with cement provides better results than 0% silica fume replacement concrete. High amount of calcium content and silica content concrete has shown more impact on the improvement of strength. They also use Metakaolin and GGBS as a replacement of cement and found that, up to 10% of replacement level, strength improves to 6% more compare to 0% replacement in both cases. They finally confirmed that out of all replacement, 10% silica fume replacement is more efficient in improving the compressive strength of concrete [3].

For the compressive strength test, they prepare cementations material containing the untreated silica fume and denoted as CL0. and that containing sonicate silica fume as CL1.Test was conducted as per BS 196–1.They reported an increment in the value of compressive strength compare to normal cement concrete For CL1, value obtained about 60 MPa, 86Mpa and 100Mpa and for CL0 52 MPa, 80 Mpa and 90 Mpa at the age of 3 days, 7 days and 28 days, respectively. It is because of the fine particles in CL1 results in large surface area. It gets compacted better in between fine grain cement [4].

There was an increase in compressive strength by replacing silica fume with 6, 8, 10, 12 and 14% by weight of cement. An increment of 14.7% in compressive strength was there when 10% silica fume added in the concrete. It was the highest among other replacement levels. Again, they start replacing Natural Courses Aggregate with Recycled Coarse Aggregate. Compare to control mix concrete they observed 2.18% increment on compressive strength when 40% Recycled Aggregate with 10% silica fume is replaced, which was more than other combinations. They concluded that 10% silica fume and 40% Recycled Aggregate will provide more significant strength then other replacement levels. The reason may be higher density of silica fume on concrete, they added [5].

They perform an experimental study on silica fume mix concrete. They tested compressive strength with different percentage combination of silica fume replacing cement. Tests were conducted at curing period of 7, 14 and 28 days and compared with absolute 0% silica fume mixed concrete. They observed an increment in compressive strength up to 10% of silica fume replacement. After that the strength decreases. They confirmed it with M25 and M30 grade concrete mix [6].

5.2 Flexural Strength

Author use M30 Grade concrete and there mix proportions were 10% of silica fume and GGBS used as 0, 40, 50 and 60% of cement weight. The water cement ratio maintained 0.45. The average flexural strength results of different specimens compared to normal cement concrete shows that there is a significant increase in flexural strength. At 50% replacement of GGBS and 10% of silica fume has the maximum flexural strength of 6.28 Mpa compare to all proportion, where controlled concrete provide strength of 5.2 Mpa [7].

Investigate the effect of silica fume in the flexural strength of concrete. They tested with M25 and M30 grade of concrete with partial replacement of silica fume (0, 2.5, 5, 7.5, 10, 15 and 20%). They concluded that with 10% replacement of silica fume with cement in concrete shows maximum flexural strength (5.02 N/mm^2) compare to other replacement levels [6].

Author studied the effects of carbon nano-tubes on the flexural strength of cement—silica fume carbon nano-tubes cement mortar. Silica fume is present 10% by weight of cement. Water /Binder ratio of 0.5 was used for all mortar mixes. They found that mortar with silica fume has higher strength and when carbon nano-tubes were introduced on the mortar, it further increases the flexural strength [8].

Author reported that for a constant water/cement ratio and percentage of silica fume increase the yield stress and plastic viscosity in concrete. They further concluded that Silica fume also influence the flexural strength to a certain point in concrete. According to their test results, flexural strength exceeds to 9.2 Mpa for 30% replacement of cement which was the highest strength compare to other replacement combinations [1].

5.3 Split Tensile Strength

Observed that there is a decrease in the split tensile strength as the percentage of silica fume is increasing in the concrete. For 28 days of curing period, controlled specimen has more strength then rest of the proportions. The test results show split tensile strength of 3.41Mpa for 50% replacement, which was the maximum value for silica fume mixed concrete [7].

A comparative study to fine out the effect of silica fume, metakaolin and GGBS on the split tensile strength. They took M-sand instead of river sand. And partially replaced cement with all pozzolanic materials by varying percentage (5, 10 and 15) one by one. Test was conducted after a curing period of 7 and 28 days. Comparing all values, silica fume with 10% replacement provides the maximum split tensile strength (5.6 N/mm^2) then Metakaolin (5.53 N/mm^2) and GGBS (5.29 N/mm^2) [3].

Author prepared a composite mineral admixture by grinding a mixture of silica fume and steel slag. They took 92:8 or 84:16 as the steel slag/ silica fume ratio proportion by mass. They confirmed that a proper percentage of cement replacement with this admixture will add strength to the concrete. It also helps to reduce drying shrinkage of concrete. They found an increment of 9.2% in split tensile strength compare to plain cement concrete when admixture was added to 30% by weight of cement [9].

Use recycled Aggregate rejected by precast elements having compressive strength 75Mpa instead of natural Aggregate to find the mechanical properties of high-performance concrete prepared from precast industry. They introduced silica fume as a replacement of cement by 0%, 5% and 10%. And test is conducted at 28 days of curing period in cylindrical specimen with 150 mm dia and 300 mm height. The author found decrease in strength with increase in replacement of natural Aggregate with recycled Aggregate [8].

The effect of silica fume on the fresh and hardened properties of fly ash-based self-compacting geo-polymer concrete (SCGC). They kept the water to geo-polymer ratio 0.33 by mass. The percentage silica fume that replaced fly ash was taken as 5, 10 and 15%. They found that, at a replacement value of 10% silica fume, concrete provides maximum tensile strength to be 4.40 and 4.67 N/mm2 at 7 and 28 days of curing, respectively [10].

5.4 Permeability

Investigate the effect of silica fume replacing cement by 5–20% by weight of cement on the permeability of concrete. He took the water cement ratio as 0.4 and 0.5. According to his test results, there was a change in permeability after introducing silica fume in it as compare to normal concrete. As the percentage of silica fume increases, the permeability decreases gradually [11].

Author considers the water cement ratio as 0.4. He confirmed that water cement ratio, silica fume percentage and degree of hydration are the major influencer for concrete against permeability. As silica fume percentage increases in concrete, the permeability of bulk past decreases [12].

They increase the density of silica fume by producing silica fume granules mixed with a solid super plasticizer and tested for the permeability in concrete. They choose 7.5% of silica fume replacement level with cement as an optimum dose and water cement ratio as 0.35 and 0.4. They found that adding silica fume to the concrete decrease the permeability. At the age of 90 day, they got the value of water penetration are 4.3 and 6.1 for normal silica fume concrete and granular silica fume concrete, respectively [13].

By mixing of silica fume and polypropylene in some definite proportion can reduced the permeability of chloride in by 75%. They also identified decrement in diffusion of chloride by 98% when silica fume and glass fiber is added in cement mortar. It is because; silica fume produces calcium silicates and calcium aluminates by some chemical reactions which leads to increase the density of mortar and residue the capillary porosity of mortar [14].

Author investigated on clay sample with silica fume in different proportion of 0%, 5%, 10%, 15%, 20%, 25%, 30% and 50%. They tested 5 different samples for each proportion. The permeability values were calculated for 48 h. They found an improvement on the permeability as compared to normal specimens. They identify low permeability in the samples of 25% and more silica fume contents [15].

5.5 Sulfate Resistance

Author investigated on cement containing 10.7% of C3A according to ASTM C 1012. He uses silica fume as a replacement of cement by 0%, 10% and 20% by mass. Super plasticizer was used in 20% silica fume bars. After a one-year period, it was observed that there is a less expansion on silica fume mortar compare to normal mortar. Also, in 1.7-year, normal mortar crosses the limit of expansion, i.e., 0.10% expansion but silica fume mortar never exceeds the limit even after 5 years [16].

On concrete with partial replacing cement with silica fume by 5% and 10%. The paper concluded that silica fume plays an important role in sulfate resistance in concrete. The concrete specimens were examined for a period of 1 year by exposing them in 5% sodium sulfate solution. He found no sign of spalling there in whole period in the silica fume concrete [17].

They confirmed that the replacement of cement with fly ash and silica fume can increase the sulfate resistance in mortar. Further, they observed that under a very low pH of 2% H2SO4 solution, the replacement of silica fume or fly ash by cement will not effective. Test results shows that in exposure to 10% NA2SO4, mortar having silica fume percentage of 5% reduced the sulfate attack easily whereas fly ash cement mortar provided better results only when the percentage of fly ash was more than 30% [18].

6 Future Recommendations

The use of self-compacting concrete is increasing day by day due to many attractive properties in the construction industry. Superior freshness and hardening properties are used to produce SCC in the construction industry. Better freshness and hardness properties are achieved through the incorporation of minerals and various chemical mixtures and additives. Although the review was conducted in accordance with the study title and this review work presents a wealth of information, there are still many research gaps that could be further explored in this area of research. In order to focus the application of SCC in the construction sector, it is recommended to study the effect of the application of SF and SP on other mechanical properties such as adhesive strength, impact resistance and abrasion resistance. In addition to these mechanical properties; it is recommended to investigate time-dependent mechanical properties such as creep shrinkage and SCC, with particular attention to the title of the research. While the addition of SF and SP is a mineral and chemical additive and increases the permeability and usability of SCC, other types of mineral and chemical additives are also encouraged to study their effect on fresh and chemical properties.

7 Conclusion and Summary

Due to high fineness value and high content of amorphous silicon, it is very reactive pozzolanic material and has a great impact on the improvement of strength of concrete. It can be used as a partial replacement of cement for high performance concrete. The workability of concrete generally depends on the particle size, specific surface area, particle shape and replacement level of silica fume.

As, smaller the particle size and higher the specific surface of mineral admixture increases the water demands of concrete. It is clear that concrete having partial replacement of 10% silica fume with cement provides more compressive strength compare to normal cement concrete. Also, this study concluded that silica fume can improve the flexural strength to a certain level.

For split tensile strength, there is not a big gap between results of normal and silica fume cement concrete. Although, it shows very less but important amount of growth in split tensile strength. Due to the small particles of silica fume, it is very efficient to reduce the permeability of concrete. And result shows that it reduces the permeability significantly compare to normal cement concrete. It is also very successful to improve sulfate resistance for concrete. It can save the structure from heavy damages.

As a whole, it can be summarized that silica fume is an ideal replacement of cement for a certain value. It will improve the quality of construction and provide more durability to the structure. As a byproduct or waste material, it is very necessary to reuse it, so that our environment will be pollution free.

References

1. A. Suryavanshi, S. Nigam, S.K. Mittal, R. Bharosh, An experimental study on partial replacement of cement in concrete by using silica fume. Int. Res. J. Eng. Technol. (IRJET) **5**(2), 1450–1454 (2018)
2. M. Benaicha, et al. Influence of silica fume and viscosity modifying agent on the mechanical and rheological behavior of self-compacting concrete. Constr. Build. Mat. **84**, 103–110 (2015)
3. T.C. Holland, Silica fume–User's manual, US Department of transportation. Federal Highway Administration. Silica Fume Association (SFA), Washington (2005)
4. R.D. Hooton, Influence of silica fume replacement of cement on physical properties and resistance to sulfate attack, freezing and thawing, and alkali-silica reactivity. Mat. J. **90**(2), 143–151
5. E. Kalkan, S. Akbulut, The positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. Eng. Geol. **73**(1–2), 145–156 (2004)
6. S. Karein, M. Motahari et al., A new approach for application of silica fume in concrete: Wet granulation. Construction Build. Mat. **157**, 573–581 (2017)
7. J. Liu, D. Wang, Influence of steel slag-silica fume composite mineral admixture on the properties of concrete. Powder Technol. **320**, 230–238 (2017)
8. P.S. Mangat, J.M. Khatib, Influence of fly ash, silica fume, and slag on sulfate resistance of concrete. Fuel and Energy Abstracts 6(37) (1996)
9. F.A. Memon, M.F. Nuruddin, N. Shafiq, Effect of silica fume on the fresh and hardened properties of fly ash-based self-compacting geopolymer concrete. Int. J. Minerals, Metallurgy, Mat. **20**(2), 205–213 (2013)
10. A. Mohan, M.T. Hayat, Characterization of mechanical properties by preferential supplant of cement with GGBS and silica fume in concrete. Mat. Today: Proc. **43**, 1179–1189 (2021)
11. G. Naga Venkat, K. Chandramouli, E. Ahmed, V. Nagendra Babu, Comparative study on mechanical properties and quality of concrete by part replacement of cement with silica fume, metakaolin and GGBS by using M−Sand as fine aggregate. Materials Today: Proceedings (2020). https://doi.org/10.1016/j.matpr.2020.10.819
12. D. Pedro, J. De Brito, L. Evangelista, Mechanical characterization of high performance concrete prepared with recycled aggregates and silica fume from precast industry. J. Clean. Prod. **164**, 939–949 (2017)
13. D. Perraton, P.C. Aiticin, D. Vezina, Permeabilities of silica fume concrete. Special Publication **108**, 63–84 (1988)
14. M.A. Sanjuán, J.C.G. Cristina Argiz, A. Moragues, Effect of silica fume fineness on the improvement of Portland cement strength performance. Constr. Build. Mat. **96**, 55–64 (2015)
15. H.-W. Song, J.-C. Jang, V. Saraswathy, K.-J. Byun, An estimation of the diffusivity of silica fume concrete. Build. Environ. **42**(3), 1358–1367 (2007)
16. K. Torii, M. Kawamura, Effects of fly ash and silica fume on the resistance of mortar to sulfuric acid and sulfate attack. Cem. Concr. Res. **24**(2), 361–370 (1994)
17. Y. Venkatasiva, P. Lakshmaiah Chowdary, An experimental investigation on the properties of concrete with partial replacement of cement by silica fume and coarse aggregate by recycled aggregate
18. T.H. Wee, A.K. Suryavanshi, S.F. Wong, A.K.M.A. Rahman, Sulfate resistance of concrete containing mineral admixtures. Materials J. **97**(5), 536–549 (2000)

Comparative Study of Internal Curing Techniques for Concrete

Narinder Verma and Sanjeev Naval

1 Introduction

The curing of concrete is an important process during the first hours after casting to maintain optimal conditions for cement hydration and for assuring the required durability and strength of the hardened concrete, thus enabling a high performance of the structure with lower maintenance cost during its longer service life. Therefore, to maximize the degree of hydration of cement and possibly that of the supplementary cementitious materials (SCM) and to reduce early shrinkage cracking (autogenous shrinkage, plastic shrinkage, and drying shrinkage), effective curing for extended period of time is a must. Common curing techniques consider an external water supply to maintain a high internal relative humidity (RH) by water spraying or fogging, watering, use of wet coverings, or ponding of the concrete element.

In these types of concretes with a low water cement ratio (less than 0.42), there is insufficient water to allow complete hydration of Portland cement under sealed conditions, resulting in rapid water consumption and a rapid decline in the mixture's internal humidity. Unhydrated cementitious components operate as inert filler when high degrees of hydration are not achieved, decreasing both the deep percolation of the weak structure and the concrete's potential durability [1].

The introduction of additional water from within the impervious concrete matrix was presented as a solution to the problem of insufficient hydration. Internal curing is a process that operates on the premise of dispersing water reservoirs throughout the concrete.

N. Verma (✉)
Punjab Technical University, Kapurthala, Punjab, India
e-mail: amrevr@gmail.com

S. Naval
DAV Institute of Technology, Jalandhar, Punjab, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_14

2 Problems of Cracking

Concrete cracks result in a shorter service life, higher maintenance costs, and faster corrosion, all of which raise the life cycle cost of the structure. When concrete loses moisture or the temperature drops, it loses volume. Concrete will shrink if volume loss is not controlled, and there will be no impact. In practice, however, the ground, columns, and walls, among other constraining components, prohibit the structure from decreasing freely. Tensile stresses come into play, when the concrete is kept from shrinking, and when these stresses reach a certain level, cracking occurs.

Sustained stress develops in concrete under restraint displacement, which, as the viscoelastic material in concrete ages, relaxes, taking the stresses out of the system by sliding C-S-H sheets over one another, introducing creep and micro-cracking, and resulting in a lower overall state of stress in the system. As a result, the amount of stress created is directly proportional to shrinkage, elastic modulus, and hydration, while viscoelasticity and aging have an inverse relationship. Reduce shrinkage cracking through improving concrete strength, making the system more resistant to cracking by using low water–cement ratio concretes, or simply stiffening the concrete and lowering its viscoelastic performance. However, taking the aforesaid technique to improving strength entails raising elastic modulus, increasing built-in stresses and diminishing the viscoelastic effect in the system, all of which pushes the age of cracking forward. Thus, stronger concrete leads to stiffer and less relaxing concrete pier by worsening the problem of cracking. Also, L Hermite graphical representation made it clear that shrinkage is a paste property. So, the key to reducing shrinkage is to reduce water–cement ratio because aggregates are volumetrically stable.

Le Chatelier reported that in a cement paste the volume of reactants is greater than the volume of products. This difference is called the chemical shrinkage and is an indicator of how much reaction occurs in the system. Power's model of cement hydration also concluded that chemical shrinkage is proportional to reacted cement and is about 8 to 10% in ordinary cement and is more in cementitious materials [2].

Autogenous shrinkage refers to the macroscopic volume reduction that occurs during the hydration of cement problem materials after setting. Volume variations caused by substance loss or gain, temperature changes, or the application of external force are not included internally, aggregates limit it, while externally, neighboring structural components limit it, resulting in cracking and even failure. Because the system is in a fluid state and collapses on itself when shrinking, this attachment shrinkage is equal to chemical shrinkage before setting. Enough hydration products have generated at the moment of setting to establish a self-supporting skeletal skeleton in the paste matrix. Water-filled capillary holes exist within this solid framework. The spaces fill when water is consumed by the hydration process, and capillary tensions are formed, resulting in a volumetric change. The matrix's solidification prevents the bulk system from shrinking at the same rate as the chemical system. Attachment shrinkage is a volume change that occurs without any moisture transfer to the environment or a change in temperature. This shrinkage causes a decrease in fluid pressure, which finally cavitates the vapor-filled space in the pore system. These spaces develop and penetrate smaller and smaller pores as hydration progresses. The relative humidity in the capillary pores decreases as a result of this. Self-desiccation is the occurrence of a decrease in relative humidity in hardening cement paste due to the consumption of capillary water during the cement hydration process. External curing is used to maintain the capillary post-saturated; however, if the water–cement ratio is low, water will not permeate from the outside even when curing is applied due to the material's limited permeability. Self-desiccation has a negative impact on the performance of high-performance concrete (HPC), especially when the water–cement ratio is low. It causes a decrease in hydration rate due to a drop in relative humidity to the point where hydration stops when relative humidity falls below roughly 75%. Another result is a significant rise in autogenous shrinkage, which causes concrete to crack, compromising both mechanical and durability qualities [3].

3 Internal Curing

Internal water reservoirs must be introduced to combat autogenous shrinkage and, as a result, early age cracking. These reservoirs can alleviate the capillary tension induced by self-desiccation, as well as diminish autogenous shrinkage and early age cracking. Cold internal curing is the method of delivering water from the inside of the concrete to decrease autogenous shrinkage, reduce early age cracking, and promote the hydration process. According to ACI committee, internal curing refers to the process by which hydration of cement occurs because of the availability of additional internal water that is not a part of mixing water [4].

4 Internal Curing Agents

Internal curing agents act is nucleus of water holding sites which relieves them when negative pressure develops during low relative humidity. Two most commonly used agents are lightweight aggregates and superabsorbent polymers. Behavior of these agents is governed by the factors:

- Ability of absorption of water
- Ability of desorption of water
- Distribution of the agents.

Methods of providing internal water reservoir is to act as internal curing inclusions are.

1. Lightweight aggregates (LWA)
2. Superabsorbent polymers (SAP).

5 Choosing Internal Curing Agents

The porous internal curing agents' poor mechanical qualities can have a negative impact on the concrete's mechanical properties. As a result, according to the protected paste volume concept, it is required to optimize the size and amount of internal curing agents. This concept proposes that the internal curing agent particle size can be reduced so that all of the cement paste is within a small enough distance from the internal curing agent particle surface for the internal curing water to enter. Internal curing has been shown to have negative consequences on early age strength. The impact of internal curing on material concrete strength, on the other hand, is varied and relies on the type of concrete used. Internal curing has a varying effect on material concrete strength, depending on the agent type and content, the presence of chemical admixtures, and aggregate content. Even when strength was not diminished, there was a significant fall in elasticity modulus. Internal curing has only a minor impact on creep. To minimize the negative effects of internal curing and maximize their good effects, a design approach that optimizes the IC agent concentration, size, kind, and so on is necessary. It may not be essential to completely eliminate autogenous shrinkage. Only the amount of IC agent required to reduce the danger of cracking due to controlled autogenous shrinkage to acceptable levels should be utilized. This will be cost-effective and will reduce unwanted side effects such as a negative impact on concrete's rheological, mechanical, and durability properties.

The term "protected paste volume" comes from a study of the efficiency of air entrainment in providing frost resistance. The volume of cement paste shielded against frost damage by a system of air voids in the cement paste is known as the protected paste volume. It has been demonstrated by numerous researches that for normal-strength concrete spacing, factor below 200 μm guarantees frost durability [5].

Bentz and Snyder extended this notion to internal curing in 1999. It is expected that if the cement paste is placed within a sufficiently small distance from the IC agent's surface, the cement paste will be shielded from self-desiccation and autogenous shrinkage will be reduced. The size of internal curing agent particles controls the spacing factor for IC or the spatial proximity of internal curing water-to-cement paste. Water transmission is also stated to be successfully confined to distances of the order of 100–200 μm as the capillary pore space in the cement paste depercolates during curing. It was also discovered that a well-dispersed system of small saturated LWFA particles would be most beneficial to the curing of field concrete, similar to the case of air voids protecting concrete from freezing and thawing damage, which is in agreement with the protected paste volume concept for air voids, which suggested that a finally dispersed system of small air voids would be superior to onsite curing.

The influence of LWA size on IC efficiency was investigated by Lura et al., who discovered that fine LWA performed better. The grain size of the LWA utilized as a curing agent was lowered in this study in order to lessen the paste–aggregate closeness or the distance to which the IC water should diffuse. The reduction in grain size to 4–2 mm was shown to be advantageous, but any further reduction resulted in a drop in curing efficiency. It was also discovered that LWA with the lowest absorption and the smallest spacing resulted in the greatest autogenous shrinkage.

As a result, other elements must be addressed in addition to the spacing notion, which may overcome the spacing factor's influence. Internal curing water is one such element. The gradient of capillary pressure between the water in the LWA and the water in the surrounding paste matrix dominates the migration of the internal curing water in the case of LWA. Smaller LWA particles have lower absorption, implying a tiny pore structure off the IC reservoir, and as a result, the driving power for water to permeate from the IC reservoir into the surrounding paste matrix is reduced. As a result, when the particle size of LWA is reduced, two competing mechanisms occur. First, the spacing factors should be reduced, which should improve efficiency, and second, the pore structure of LWA should be refined, which should also improve efficiency [5].

In the case of SAP as an IC agent, the tendency was toward larger SAP particles, which caused more initial swelling and less autogenous shrinking afterward. Water is held in SAP by Vander Waal forces rather than capillary pressure as it is in LWA. The water will quickly evaporate from the particle at first, but the rate of evaporation will slow as water must diffuse through more side chains, which interact with the water molecules due to their ionic composition. Furthermore, larger SAP particles have a better water absorption capacity. As a result, water will release more readily from larger SAP particles than from smaller ones, resulting in two competing processes when the SAP size is reduced: higher IC efficiency due to smaller spacing and lower efficiency due to a tendency for tighter water hold. Because the larger SAP particles have a higher efficiency, it appears that the SAP particle structure, rather than the spacing factor, is the most important element [4].

After modeling frost resistance, the protected paste volume concept was developed, and the value of the required spacing factor of 200 m was calculated from there. However, a survey of the literature reveals that the order of magnitude of the spacing factor required for internal curing is several millimeters [5].

By assuming that the percentage of protected paste volume is about equal to the percentage of autogenous shrinkage decrease, indirect measurements can help estimate this spacing parameter (Figs. 1 and 2).

Size fractions of pumice lightweight aggregate containing 20 kg of pre-saturated internal curing water per cubic meter of concrete:

2.36–4.75 mm (Pumice2),

1.18–2.36 mm (Pumice1), and 0.6–1.18 mm (Pumice0).

WSAREF-reference mix without Pumice.

The autogenous shrinkage calculation is based on determining the shrinkage after the initial peak of expansion, which often happens in IC systems within the first day and close to the final setting time. This section of the length change curve represents a realistic estimate of the processes caused by self-desiccation, which begins shortly after the cementitious matrix is set. Although the length change in the paste around the IC agent may not be uniform, the value of the autogenous shrinkage recorded may provide a weighted average approximation. On this basis, derived curves of the proximity of the paste matrix, i.e., the proportion located within a particular distance

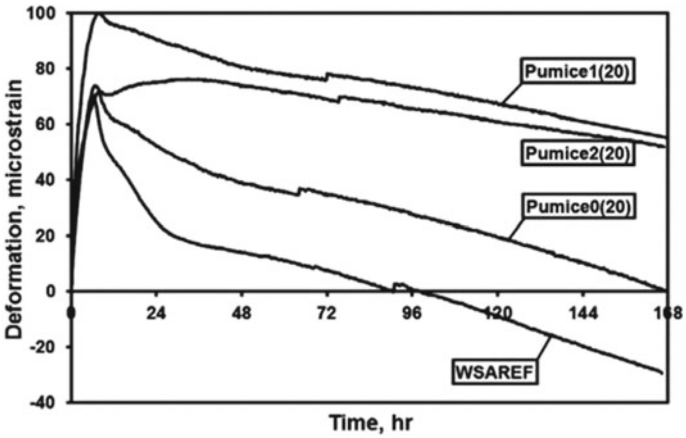


Fig. 1 Effect of grain size on free shrinkage of mixes with w/c ratio 0.33 containing amount of pumice required to counteract self-desiccation

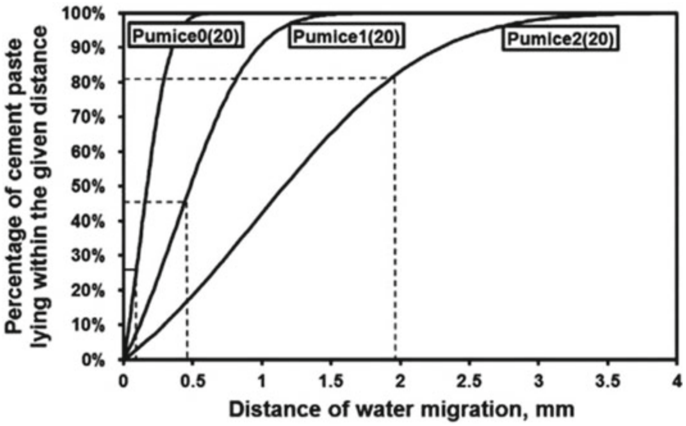


Fig. 2 Assessment of distance of water migration for mixes containing different pumice fractions with w/c ratio of 0.33

from the IC reservoir, can be used to calculate the distance of water migration. The estimated distance offers a range where there is no shrinkage and beyond that the autogenous shrinkage is uniform. This is an implied assumption in this way of calculation. As a result, the calculated value can be regarded as an approximation of the "effective value." The range of values produced by recent direct measuring techniques of water migration from the IC agent is pretty similar to this estimate of the effective value. Based on the values of the relative autogenous shrinkage decrease, an estimate of the effective distance of water migration is given (which is assumed to be equal to the percent of protected paste volume, i.e., the paste lying within sufficiently small distance from the IC reservoir to allow it to be fully migrated by water). The graphs below show the relationship between the spacing factor and shrinkage reduction and water absorption (Figs. 3 and 4).

While the correlation between the two figures reveals that as the LWA's water absorption capacity rises, so does the spacing factor and as the spacing factor increases, so does the shrinkage decreases [5].

Water traveled a distance of 2–4 mm, according to direct measurements such as X-ray absorption, neutron and X-ray tomography, and neutron radiography. The direct ink penetration test can also estimate water transport distances of up to a millimeter. As a result of the protected paste volume idea, it is concluded that the larger the void, the larger the spacing factor, and that the spacing factor has a limit, which is 200 μm for frost resistance and around 1 mm for internal curing.

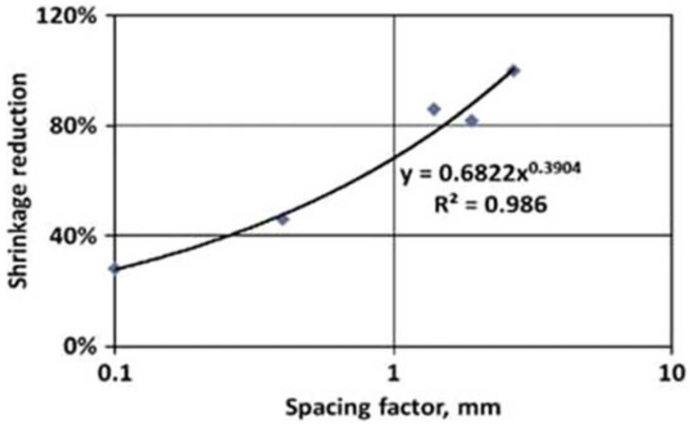


Fig. 3 Correlation of spacing factor and shrinkage reduction

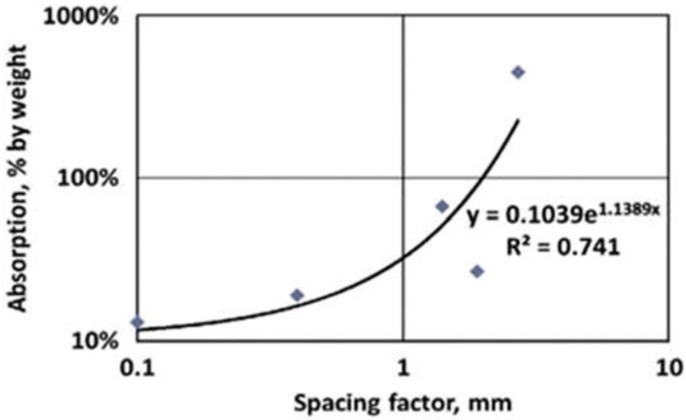


Fig. 4 Correlation of spacing factor and water absorption of LWA

SAPs are cross-linked hydrophilic networks that can swell when exposed to water, with osmotic pressure acting as the main driving factor. As a result, SAPs take moisture from their surroundings and keep it without dissolving it. As a result, SAP improves the number of internal water sources available for internal curing and shrinkage reduction. The presence of SAP in concrete can have an impact on both its fresh and hardened properties. The use of 0.6 percent SAP by mass of cement in concrete with a high *w/c* (>0.45) resulted in no influence on degree of hydration but a reduction in compressive strength due to an increased volume of voids. However, in the case of low *w/c* (0.45) mixtures, even a minor amount of SAP addition (0.4% by mass of cement) resulted in a drop in compressive strength. In addition, compared to a combination with 0.3% SAP, the addition of 0.6 percent SAP by mass of cement in concrete can enhance total porosity by approximately 2% by total volume. When compared to mixes with dry SAP powder, adding pre-soaked SAP to high-strength concrete enhances its early age dimensional stability and results in reduced strength reduction [4].

The addition of SAP may result in a greater number of bigger pores and a decrease in the number of smaller holes that are thought to be filled by hydration products. The SAP functions as an entrainment agent for the air. These encased air spaces might have a negative impact on the concrete's strength and modulus of elasticity.

The use of SAP differs from that of LWA in a few ways. Because it absorbs water during the mixing process, SAP can be used as a dry concrete additive. The use of SAP provides for complete control over the pore form and size distributions of the hardening concrete; nevertheless, the pores introduced by SAP should be in the 50–300 m range. Changes in setting and rheology, agglomeration of SAP particles, and crushing of SAP particles during mixing by aggregate particles are all potential issues with SAP addition. As a result, the SAP that will be used must be carefully selected.

Akcay and Tasdemir [6] investigated the effects of spatial distribution of lightweight aggregates (LWAs) on internal curing of concrete. As replacements for normal aggregates, different sizes and amounts of natural pumice LWAs were used as water reservoirs to provide internal curing in mitigating autogenous deformation. Water in the pre-soaked LWAs flows into cement paste during hydration and provides internal curing to counteract the RH loss due to self-desiccation of binding paste. The results show that variations in the autogenous strain of concrete can be evaluated in terms of LWA–LWA proximity. The protected paste volume approach, previously used for air-entrained concrete, is applied to calculate the internally cured volume of paste. The results show that the experimental rate of mitigation of autogenous strain for different series of concrete specimens, with respect to the reference concrete, gave the best-fitted values at water flow distance of 1 mm. The results indicate that the protected paste volume in internal curing can be determined by calculating the water-entrained volume using image analysis [6].

Wei et al. [7] investigated the microstructure and the desorption properties of sintered fly ash and expanded shale LWFAs. The influences of these two types of LWFAs on autogenous shrinkage and internal RH development were experimentally evaluated in concrete with w/c of 0.3 and 0.4. The internal curing efficiency, defined as the relative volume ratio of LWFAs in paste matrix as compared to that used for completely mitigating autogenous shrinkage, is a function of particle size and spacing of LWFAs. The results show that 100% internal curing efficiency (no autogenous shrinkage at the age of 28 days) can be achieved if the ratio of the LWFA particle/paste proximity and the particle size (2L/R) approaches (1.1) [7].

Mousa et al. [8] carried out a study to compare among concretes without or with silica fume (SF) along with chemical type of shrinkage reducing admixture, polyethylene-glycol (Ch), and pre-soaked lightweight aggregate (leca) as self-curing agents for water retention even at elevated temperature (50 °C) and their durability.

Silica fume concrete either without or with Ch gave the best results under all curing regimes: significant water retention and good durability properties [8].

Mousa et al. [9] during his investigation used pre-soaked lightweight aggregate (Leca) and polyethylene-glycol (Ch.); self-curing agents concluded that the use of self-curing agent (Ch.) in concrete effectively improves the physical properties compared with conventional concrete. On the other hand, up to 15% saturated, leca was effective while 20% saturated leca was effective for permeability and mass loss but adversely affects the sorptivity and volumetric water absorption. Self-curing agent Ch. was more effective than self-curing agent leca. In all cases, both 2% Ch. and 15% leca were the optimum values. Higher cement content and/or lower water–cement ratio leads to more effective results of self-curing agents in concrete. Incorporation of silica fume into concrete mixtures enhances all physical properties [9].

Shen et al. [8] conducted a study to determine the effect of internal curing with SAPs on the IRH of early age concrete under sealed and unsealed conditions. Test results showed that (1) the IRH of concrete that was internally cured with SAPs increased with an increase in the content of internal curing water 28 days after casting under sealed and unsealed conditions. (2) The degree of decrease in the IRH of internally cured concrete was lower under sealed conditions than under unsealed conditions 28 days after casting. (3) The critical time of the IRH of internally cured concrete increased with increases in the content of internal curing water under both sealed and unsealed conditions. (4) The decrease rate of the IRH in early age concrete that was internally cured with SAPs dropped with an increase in the content of internal curing water under sealed and unsealed conditions [8].

Liu et al. [10] investigated the water-absorbing mechanism of internal curing on SAP and LWA. The impact of these two types of internal curing materials on the shrinkage of high-performance cement-based materials is investigated. The use of internal curing materials delays the reduction in internal RH and minimizes autogenous shrinkage while increasing chemical shrinkage. The addition of additional water to internal curing ingredients enhances drying shrinkage [10].

Al Saffar et al. [11] This paper examines research findings on the development of an internal curing method for high-performance concrete (HPC). Common ingredients were utilized to provide the internal curing necessary to prevent self-desiccation in cement paste, which will lessen the likelihood of cracking in hardened concrete. Furthermore, this research focuses on HPC behavior, such as density, strength (com pressive, splitting tensile, and flexural), shrinkage (autogenous and drying), and the microstructure of hydrated cement paste. Internal curing is more successful in splitting tensile and flexural strength than compressive strength at a late stage, according to the findings. Internal curing has made the interfacial transition zone more compact and denser, boosting strength [11].

Li et al. [9] explored the potential for internal curing of saturated recycled fine aggregate (RFA) in mortar. Water release from saturated RFAs at various relative humidity (RH) values was investigated using desorption isotherms. Capillary pressure measurements and autogenous shrinkage tests for mortar ($w/c = 0.30$) with RFA at an early age were used to evaluate water release. The influences of the RFA particle size, water absorption capacity, and dosage were analyzed. Desorption isotherms of the RFAs showed that only 16–36% of the water they absorbed in 24 h was released at RH > 93%. Retardation of self-desiccation and reduction of early autogenous shrinkage of mortar were observed with saturated RFAs. RFAs with finer particle sizes and higher water absorption capacities gave greater reductions in autogenous shrinkages at the first three days, which could be attributed to the RFA pore structure. Internal curing with the RFA was observed clearly in a mixture with a high aggregate content [9].

Yang et al. [12] gave an overview of factors affecting the effectiveness of internal curing in cement-based materials from three aspects: the amount of internal curing water, characteristics of internal curing materials, and migration distance of internal curing water. It was found that (i) the equation developed to calculate the requirement of internal curing water for concretes with different water-to-cement ratios (w/c) based on Power's model that includes silica fume and to get a maximum degree of hydration by prewetted lightweight (LWA) could not completely reduce autogenous shrinkage, the water release characteristics of internal curing materials (e.g., the time to release and the distance to migrate) under uniformly distributed conditions may over-ride the influence of the spacing factor, and (iii) unexpected effects resulting from internal curing on the properties of concrete may occur if the characteristics of internal curing materials do not match the pore structure of concrete mixture [12].

Paul et al. [13] identified the moisture transport mechanisms within an LWA that governs IC performance. Results on LWA of different internal structures (natural, manufactured), and different size distributions (fine, coarse), pre-soaked with either pure water or water containing shrinkage reducing admixtures (SRA), indicate that there are different mechanisms involved in water uptake and release: one controlled by capillary action and one controlled by air diffusion into the pore water. It is concluded that it is the internal structure, geometry, and particle size distribution of the LWA that determine the effect of SRA and the overall LWA impact on the IC performance. By using 3D micro-CT images, LWAs are studied in order to determine which characteristics (pore size, pore connectivity, pore distribution) are better suited for improving IC. This contribution to understanding water transport in LWAs may help to engineer the characteristics of LWA optimized for IC applications [13].

Studies have been conducted to investigate the potential of using crushed clay brick as an alternate aggregate. The main advantages of using crushed brick aggregates as alternative aggregates are reducing concrete density, reducing natural aggregate consumption, and being considered environmentally friendly approach. The properties that force to investigate its usage as internal curing agent are:

1. Over burnt bricks have a higher strength than the conventional bricks and al-so greater than other LWAs tested.
2. Over burnt bricks have more water absorption capacity than the conventional sand.
3. Cost-effective.
4. Ease of availability.

6 Conclusion

Based on the research work mentioned above, the following conclusions can be drawn:

- The addition of LWA reduces the autogenous deformation. The efficiency of the partial replacement of fine aggregates by different contents of LWA is very dependent of the size, the amount, the saturation degree, and the porosity of the LWA particles. The addition of fully saturated LWA substantially reduces autogenous deformation and hence mitigates the risk of early age cracking.
- SAP can be used as a means for introducing internal water reservoirs to eliminate autogenous shrinkage, but the SAP that will be used must be carefully chosen. The reduction of the autogenous deformation using SAP was much less than the reduction from the LWA.
- Increasing the amount of LWA or SAP can lead to a reduction of compressive strength (especially with higher amounts).
- The early age expansion occurred prior to the first day for the internally cured concrete, and the maximum expansion increased with the increase of internal curing water;
- The autogenous shrinkage and its rate of internally cured concrete decreased with the increase of the amount of internal curing water.

References

1. G. Espinoza-Hijazin, Á. Paul, M. Lopez, Concrete containing natural pozzolans: new challenges for internal curing. J. Mat. Civil Eng. **24**(8), 981–988 (2012)
2. R. Henkensiefken, D. Bentz, T. Nantung, J. Weiss, Volume change and cracking in internally cured mixtures made with saturated lightweight aggregate under sealed and unsealed conditions. Cement Concr. Compos. **31**(7), 427–437 (2009)

3. S. Zhutovsky, K. Kovler, Hydration kinetics of high-performance cementitious systems under different curing conditions. Mater. Struct. **46**(10), 1599–1611 (2013)
4. G.R. de Sensale, A.F. Goncalves, Effects of fine LWA and SAP as internal water curing agents. Int. J. Con. Stru. Mat. **8**(3), 229–238 (2014)
5. S. Zhutovsky, K. Kovler, A. Bentur, Revisiting the protected paste volume concept for internal curing of high-strength concretes. Cem. Concr. Res. **41**(9), 981–986 (2011)
6. B. Akcay, M.A. Tasdemir, Effects of distribution of lightweight aggregates on internal curing of concrete. Cement Concr. Compos. **32**(8), 611–616 (2010)
7. W. Ya, X. Yaping, Z. Qianqian, Internal curing efficiency of Prewetted LWFAs on concrete humidity and autogenous shrinkage development. J. Mater. Civ. Eng. **26**(5), 947–954 (2014)
8. M.I. Mousa, M.G. Mahdy, A.H. Abdel-Reheem, A.Z. Yehia, Self-curing concrete types; water retention and durability. Alexandria Engineering J. **54**(3), 565–575 (2015)
9. M.I. Mousa, M.G. Mahdy, A.H. Abdel-Reheem, A.Z. Yehia, Physical properties of self-curing concrete (SCUC). HBRC J. **11**(2), 167–175 (2015)
10. J. Liu, C. Shi, X. Ma, K. Khayat, J. Zhang, D. Wang, An overview on the effect of internal curing on shrinkage of high-performance cement-based materials. Constr. Build. Mater. **146**, 702–712 (2017)
11. D. Al Saffar, A. Alsaad, B. Tayeh, Effect of internal curing on behavior of high-performance concrete: an overview. Case Stud. Constr. Mat. **10**, Feb (2019)
12. D. Shen, T. Wang, Y. Chen, M. Wang, G. Jiang, Effect of internal curing with super absorbent polymers on the relative humidity of early-age concrete. Constr. Build. Mater. **99**, 246–253 (2015)
13. Z. Li, J. Liu, J. Xiao, P. Zhong, Internal curing effect of saturated recycled fine aggregates in early-age mortar. Cement Concr. Compos. **108**, 103444 (2020)
14. L. Yang, C. Shi, J. Liu, Z. Wu, Factors affecting the effectiveness of internal curing: A review. Constr. Build. Mater. **267**, 121017 (2021)
15. A. Paul, S. Murgadas, J. Delpiano, P.A. Moreno-Casas, M. Walczak, M. Lopez, The role of moisture transport mechanisms on the performance of lightweight aggregates in internal curing. Constr. Build. Mater. **268**, 121191 (2021)

Recycling of Used Foundry Sand and Fly Ash in Concrete as a Partial Replacement for Conventional Ingredients

Ranjeet Sabale, Usharani Karande, Atul Kolhe, Amruta Kulkarni, and Anand Tapase

1 Introduction

The global population is increasing with tremendous rate, and according to United Nations department of home affairs, it will be 9.5 billion in 2050 [1]. So, to fulfill the infrastructure demand for such hasty population, reinforced cement concrete (RCC) has gained very importance due to its numerous advantages. Natural fine aggregate (NFA), commonly known as sand, is an important component of concrete; however, fine aggregate is in short supply at the moment due to its excessive use; also, local authorities have outlawed the extraction of fine aggregate from water bodies to protect the ecosystem. As a result, it is critical to consider a new supply or substitute material for natural fine aggregate. By keeping this objective, the current study was designed to replace a specific percentage of natural fine aggregate with foundry sand. The usage of industrial waste materials generated by various industrial activities has grown in importance, and there is a growing research interest in controlling those waste materials for economic, environmental, and technological reasons. Therefore,

R. Sabale (✉) · A. Kolhe · A. Kulkarni
Department of Civil Engineering, Dr. D. Y. Patil Institute of Engineering, Management & Research, Akurdi, Pune, Maharashtra, India
e-mail: ranjeetsabale123@gmail.com

A. Kolhe
e-mail: atul.kolhe@dypiemr.ac.in

A. Kulkarni
e-mail: hodcivil@dypiemr.ac.in

U. Karande · A. Tapase
Civil Engineering Department, Rayat Shikshan Sanstha's, Karmaveer Bhaurao Patil College of Engineering, Satara, India
e-mail: usharani.karande@kbpcoes.edu.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_15

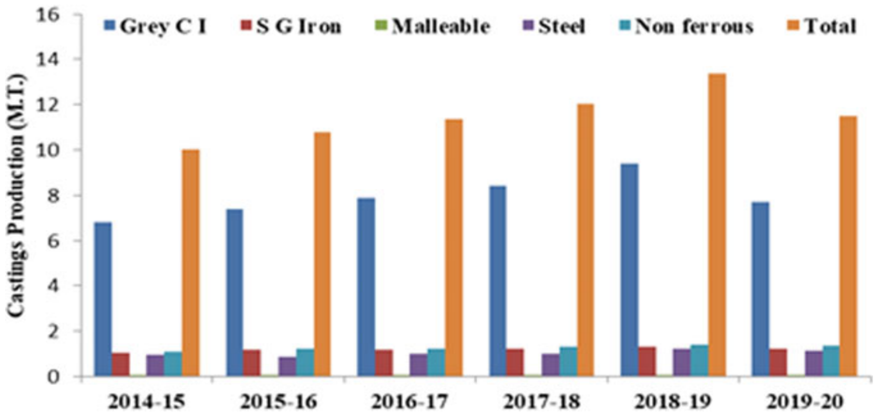


Fig. 1 Castings production in India in Million Tones (M.T.)

in present study, the emphases were given on recycling of used foundry sand and fly ash in production of concrete.

In India, most industrial operations produce large amounts of by-product materials like used foundry sand, fly ash, demolition waste, and plastic waste. The disposal of such by-product waste materials from numerous sectors has become a serious concern for institutions and researchers in the current context.

Figure 1 depicts the status of foundry industry in India; from this, it is observed that only India produces about 12 Million Tones (M.T) of metal casting in (2019–2020) [2]. So, it reveals that throughout the world approximately 100 M.T. of foundry sand has been used for industrial processes. Also, American foundry sector produces around 9.4 M.T. of UFS in year [3]. The continuous attempt has been made to utilize industry and demolition waste materials in the production of concrete. Such efforts may lead to reduction in total construction costs as well as it is a solution to waste disposal issues. Such a sustainable approach is helpful to alleviate the scarcity of natural sand and to conserve the ecosystem.

Researchers and industry personnel are working on finding acceptable substitute materials for natural fine aggregates on a constant basis. A few case studies showed that, used aggregate is best alternate material to natural aggregate [4]. Khatib et al. [5] carried an experimental study; authors have replaced the natural fine aggregate with waste foundry sand (WFS). The replacement proportion was used from (0–100%) the outcomes of study revealed that, the compressive strength and slump of modified concrete have declining trend when the conventional materials have replaced with UFS more than 40%. The disposal of fly ash (FA) produced by coal-fired power plants and sugar industries is one of the most serious environmental challenge. If the amount of FA increases and the capacity of landfill area decreases, the problems become more difficult to solve. As a result, to intervene this waste disposal scenario, research has been conducted to see if high-volume fly ash (HVFA) may be used as a cement substitute in construction materials. Rashad [6] carried a review work; author has presented the previous work regarding the partial replacement of fly ash in concrete. Few researchers have carried out work to establish the effects of used foundry sand (UFS) and fly ash (FA) in partial of full-scale replacement to concrete ingredient [7–9]. The research was carried out to create precast concrete using foundry sand and fly ash [7]. The demolition waste can be used as partial replacement or alternate to natural fine aggregate [10]; authors have replaced the natural fine aggregate with recycled fine aggregates in the proportions 10–40%. The result of work shows that, up to 30% replacement, the strength of concrete has increased, but above this proportion strength follows decline trend. The sustainable initiative was taken by Neslihan [11]; the author has used waste foundry sand in production of building material. The geopolymer material was produced using waste foundry sand, and the study concluded that, geopolymer material is suitable for building construction. The experimental work was undertaken to develop flowable slurry mixtures utilizing foundry sand; the results of work show that, the 28-day strength varying between 40 and 90 psi [12]. Siddique and Khatib [13] carried an experimental study to check feasibility of fly ash in concrete. The authors have replaced the natural fine aggregates with class F fly ash in proportions 35%, 45%, and 55%. The findings of study show that, the values of abrasion resistance of concrete were raised when fly ash was replaced with sand at all ages. Yao et al. [14] conducted a review study on the experimentation work regarding the recycling and partial replacement of conventional material with waste material. Some studies were carried out to produce the pervious concrete; the authors have used fly ash for partial replacement (10–20%) of cement. The study concludes that, with reduction in total voids, the abrasion also reduced [15].

The substantial substitution of cement with fly ash aids to environmental conservation. As production of one ton of Portland cement requires approximately 2.5 tons of raw materials and such attempts will produce approximately one ton of greenhouse gases [16]. Venkatakrishnaiah and Sakthivel [16] conducted a study in which the authors employed fly ash as a partial substitute material for cement, resulting in a sustainable approach to reducing greenhouse gas emissions. To have a successful alternate material to cement or natural fine aggregate, only, strength tests are not sufficient; in addition to that, tests on carbonation and alkalinity are more important. Medeiros et al. [17] conducted an experimental work; the study was planned for partial replacement of cement (10–30%) with fly ash. The authors have conducted XRD tests; after experimentation, it was concluded that, by adding/replacing of fly ash in cement mass, rate of carbonation increases, while alkaline reserves lowers down.

The current study aims to recycle industry waste, such as used foundry sand and fly ash, by adding it into concrete as a partial replacement for natural fine sand and cement mass. This attempt may help to alleviate the natural sand scarcity issue, to conserve the ecosystem, to solve the issue of waste disposal and greenhouse emissions and produces sustainable concrete mix with optimum cost.

Table 1 Physical properties of OPC and PPC

Details of Properties	OPC	PPC	Standards limits
Specific gravity	2.98	2.80	–
Fineness (%)	1.40	1.72	≤10%
Standard consistency (%)	27	30	–
Initial setting time (min)	90	50	≥30 min
Final setting time (min)	350	175	≤600 min

2 Test Program

2.1 Material Used

The following materials were employed in the present study: ordinary Portland cement (OPC), Portland Pozzolana cement (PPC), natural coarse aggregates (NCA), natural fine aggregates (NFA), i.e., river sand, used foundry sand (UFS), fly ash (FA), and water. The detailed qualities of various materials are explained as follows,

2.1.1 Cement

Ordinary Portland cement (OPC) of grade 43 and Portland Pozzolana cement (PPC) were employed in this study. The OPC was tested according to the IS: (8112–1989) guidelines [18]. Moreover, PPC that met the requirements of IS: 1489–1991 (Part 1) [19] was used to test the scenarios. Table 1 lists the results of the extensive physical and mechanical testing performed on cement.

2.1.2 Aggregates

The locally available crushed coarse aggregate with a maximum aggregate size of 20 mm was used in this study. Table 2 shows the results of various experiments performed to identify the properties of NCA according to conventional standards [20]. The grain size distribution of the natural coarse aggregates employed in this study is shown in Fig. 2. The Pavana River's fine sand passing through 4.75 mm sieve and retained on 150 μ sieve was used for concrete production. The sand sample falls under grading zone II (IS: 383-1970) [21]. The physical properties of fine sand used in this study are given in Table 3.

2.1.3 Used Foundry Sand and Fly Ash

Foundry sand used in this work was obtained from Shanti foundry, Chinchwad, Pune, Maharashtra. The methodology adopted in this work, the used foundry sand was

Table 2 Properties of coarse aggregates (CA)

Test carried for	Observed values
Fineness modulus	6.86
Specific gravity	2.85
Water absorption (%)	0.65
Bulk density (Kg/m^3)	1622
Aggregate impact value (%)	20.8
Aggregate crushing value (%)	24.85

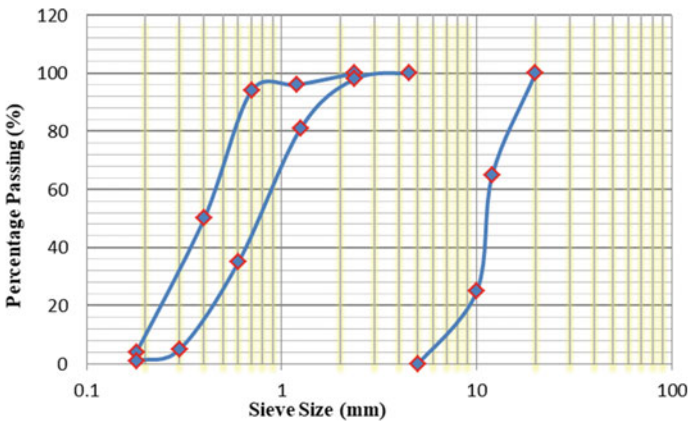


Fig. 2 Grain size distribution of aggregates

Table 3 Physical properties of natural fine aggregate (NFA) and UFS

Details of Properties	Experimental values	
	NFA	UFS
Fineness modulus	2.65	2.56
Specific gravity	2.64	2.55
Grading zone	II	II
Water absorption (%)	1.0	0.45

used as partial replacement to NFA in the proportions 15%, 25%, and 35%. Table 3 explicates the physical properties of UFS. The coal-fired fly ash was used in this work to partially replace the cement. The cement was replaced in the proportions 15%, 25%, and 35% with fly ash. The detailed properties of fly ash are given in Table 4.

Table 4 Chemical properties of fly ash (FA)

Items	Observed values
Al_2O_3 (%)	23.1
SiO_2 (%)	50.5
Loss on ignition	2.51
CaO (%)	10.72
MgO (%)	2.88
Specific gravity	2.45
Initial setting time (min)	45
Final setting time (min)	250
Standard consistency (%)	34

2.1.4 Water

In the current work, for preparing concrete, regular tap water was used. The pH of the water used in this experiment is 7.32.

The guidelines provided in IS: 456-2000 [22] were referred while selecting water sample. The guidelines suggest that, possibly, pH value should be in the range (6.5–8.5).

2.2 Concrete Mix Design

In this work, M20 concrete has been used for analysis. The water–cement (w/c) ratio of 0.54 was employed in the mix design. Moreover, the proportions of the constituent ingredients for different concrete mixes were estimated using the guidelines provided in IS: 10262-2009 [23]. The NFA and cement were partially replaced with used foundry sand (UFS) and fly ash (FA) in the proportions as cited earlier. The mixes with (100%) NFA and cement were considered as reference/control mixes. The graphs depict the comparison with mixes having 100% conventional ingredient versus mixes with partial replacement.

2.3 Testing of Concrete

The modified concrete composed with partial replacement of conventional concrete ingredients with recycled materials like fly ash and UFS was tested to estimate its compressive strength, splitting tensile strength, and flexural strength. For the compressive strength test, the cubes were used of size (150 × 150 × 150) mm; for splitting tension test, the cylinders with the diameter (150 mm) and height (300 mm) were used. Moreover, to determine the flexural strength of concrete, the beams having dimensions (100 × 100 × 500) mm were cast. In the laboratory premises, the concrete specimens after demolding were kept in normal water at room temperature for curing purposes. According to guidelines [24, 25], the concrete specimens were tested after 7 and 28 days of moist curing.

3 Results and Discussion

3.1 Compressive Strength

The compressive strength of formulated concrete mixes depicts the feasibility and the maximum limit up to which concrete ingredients should be replaced with recycled material (Figuwerrw 5). In this experimental work, the concrete specimens were tested after 7 days and 28 days to estimate the compressive strength (Figs. 3 and 4). From the results, it is observed that, the compressive strength, in the case of replacement of NFA with UFS, up to 25% increases, but above 25% it declines. Also, for replacement of cement with fly ash, the results show increasing trend up to 25% (Figs. 5 and 6).

The concrete mixes consisting 25% replacement showed the higher compressive strength than control mixes. Moreover, after 28 days of curing, the samples give the increased strength by 8, 17.72, and 4.10% when replacement proportion of NFA by UFS was 15%, 25%, & 35%, respectively. Overall, the strength statistics depicts the increasing trend after 28 days.

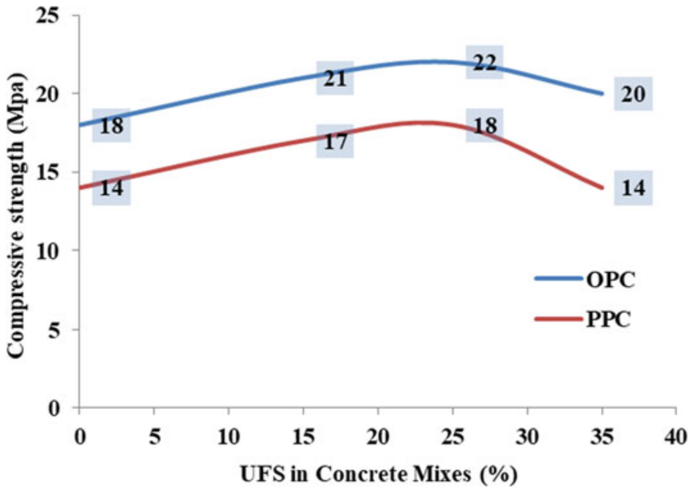


Fig. 3 Compressive strength of concrete mixes after 7 days of curing

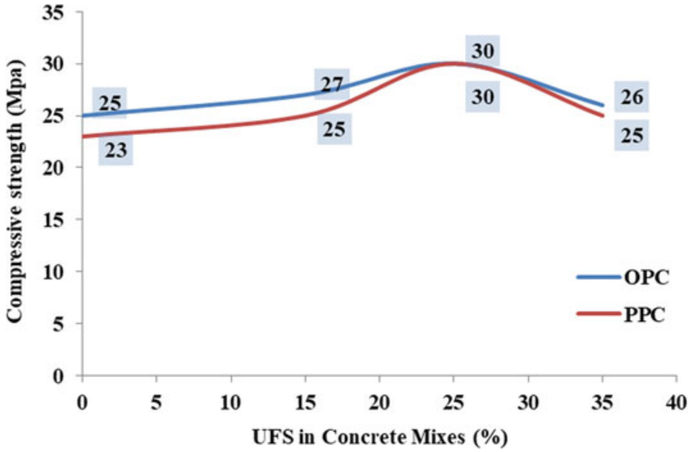


Fig. 4 Compressive strength (28 days)

Fig. 5 Testing of concrete specimens in laboratory

3.2 *Flexural Strength*

The flexural strength indicates the stress in material before it yields. The flexural strength variation of various concrete mixtures after 7 and 28 days is shown by Figs. 7 and 8, respectively. It also grew until the FS content in mixes reached 25%, after which it began to decline. Mixes consisting replacement of NFA with UFS up to 25% showed the higher strength than control mixes.

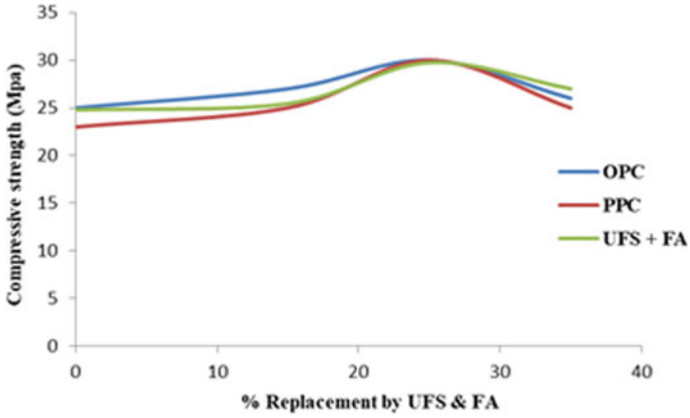


Fig. 6 Compressive strength (UFS + FA)

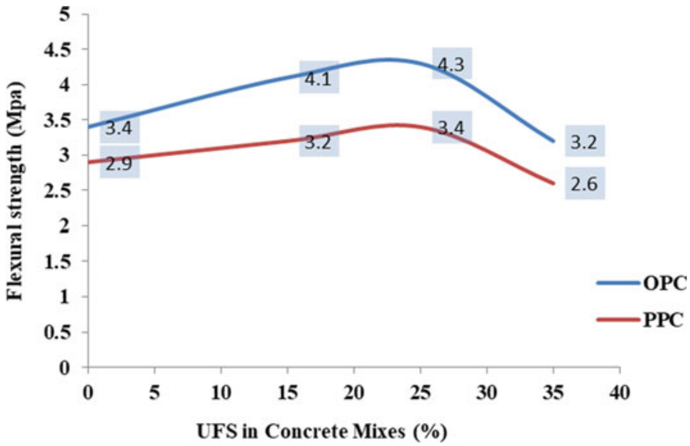


Fig. 7 Flexural strength (7 days)

After 28 days, the specimens showed, for OPC mixes while replacement proportion 15%, 25%, and 35%, the flexural strength was more than control mix by 5.67%, 10.72% and lower by 2%. Moreover, for PPC mixes, the flexural strength was 8.17%, 13.47%, and 6.25% more as compared to control mixes.

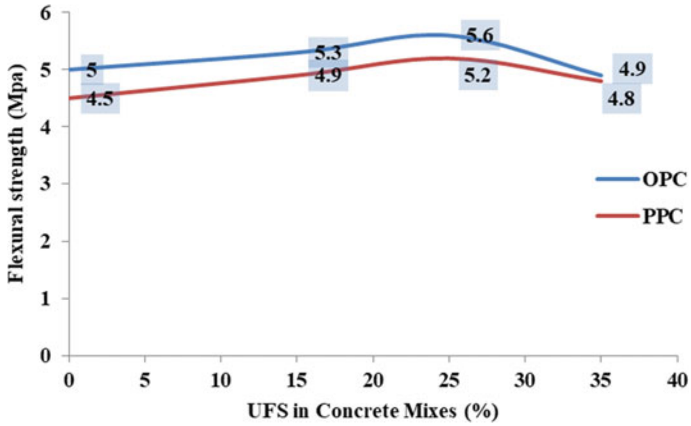


Fig. 8 Flexural strength (28 days)

3.3 Slump

In the current investigation, it was discovered that as the percentage of conventional concrete material replaced with recycled material is increased, the slump of the concrete decreases (Fig. 9).

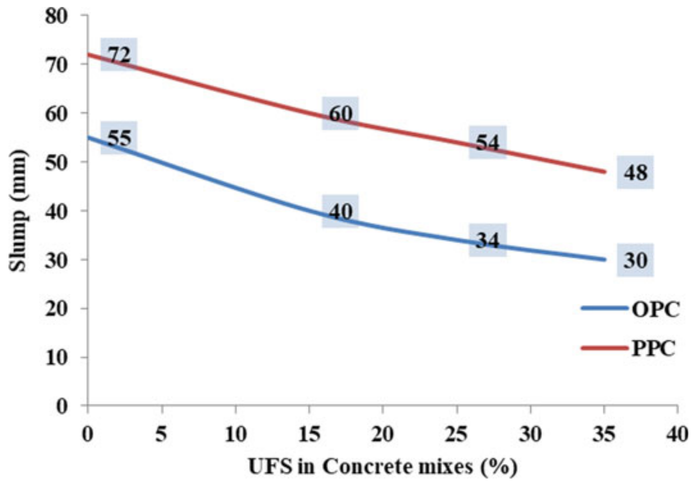


Fig. 9 Slump of concrete mixes

3.4 Splitting Tensile Strength

From experimentation, it was observed that, the splitting tensile strength of concrete using UFS was increased up to 25% replacement; however, the mixes showed lower strength than control mixes above this proportions (Fig. 10). In present investigation, after 28 days, while replacement of NFA with UFS by 15% and 25%, the splitting tensile strength for concrete mixes showed 8.34% and 12% increased values, respectively, while for 35% replacement, the concrete shows lower strength by 10% (Fig. 11).

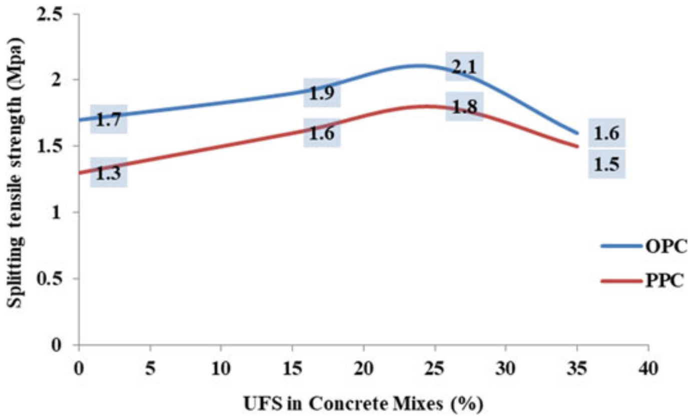


Fig. 10 Splitting tensile strength (7 days)

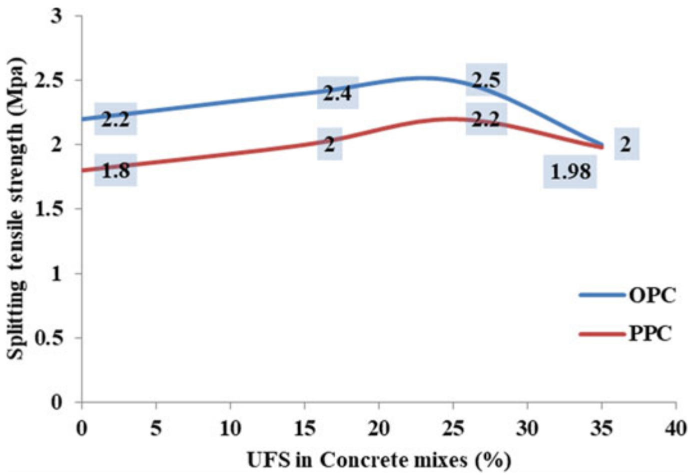


Fig. 11 Splitting tensile strength of concrete mixes after 28 days of curing

4 Conclusions

This study shows and investigates the use of foundry sand as a partial alternative for NFA, i.e., sand, in concrete mixtures. From this study, the following conclusions can be drawn.

- For both OPC and PPC-based concrete mixes, workability declines as the level of UFS in the concrete mix rises.
- It was observed that up to 25% substitution of NFA by UFS and 25% substitution of cement by fly ash, there was an increasing trend in strength of different mixes for both OPC- and PPC-based concrete mixes, but after this proportion, there was a declining tendency for strength was observed.
- Economical and efficient replacement proportion of recycled material was observed up to 25% without hampering the design guidelines.

Overall, foundry sand can be substituted for natural fine aggregates in the creation of high-quality concrete mixes without sacrificing strength. This effort may result in the preservation of natural resources such as fine aggregate, as well as trash reduction and ecosystem protection.

References

1. https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html (Accessed on 17/4/2021)
2. http://foundryinfo-india.org/profile_of_indian.aspx (Accessed on 2/8/2021)
3. S. Saha, C. Rajasekaran et al., Use of foundry sand as partial replacement of natural fine aggregate for the production of concrete. Sustain. Constr. Build. Mat. Lecture Notes in Civil Engineering **25**, 61–71 (2019). https://doi.org/10.1007/978-981-13-3317-0_6
4. S. Saha, C. Rajasekaran, Mechanical properties of recycled aggregate concrete produced with Portland Pozzolana Cement. Adv. Conc. Constr. Int. J. **4**(1), 27–35 (2016). https://doi.org/10.12989/acc.2016.4.1.027
5. J.M. Khatib, S. Baig, A. Bougara, C. Booth, Foundry sand utilization in concrete production. Proceedings of Second International Conference on Sustainable Construction Materials and Technologies, June 28–30, 2010, Università Politecnica delle Marche, Ancona, Italy (2010)
6. A.M. Rashad, A brief on high-volume Class F fly ash as cement re- placement—a guide for Civil Engineer. Int. J. Sustain. Built Environ. (2015). https://doi.org/10.1016/j.ijsbe.2015.10.002
7. T.R. Naik, R.N. Kraus, B.W. Ramme, F. Canpolat, Effects of fly ash and foundry Sand on performance of architectural precast concrete. J. Mat. Civil Eng. **24**(7). https://doi.org/10.1061/(ASCE)MT.1943-5533.0000432
8. M. Elchalakani, H. Basarir, A. Karrech, Green concrete with high-volume fly ash and slag with recycled aggregate and recycled water to build future sustainable cities. J. Mater. Civ. Eng. (2016). https://doi.org/10.1061/(ASCE)MT.1943-5533.0001748
9. S.A. Basha, P. Pavithra, B.S. Reddy, Compressive strength of fly ash based cement concrete. Int. J. Inno. Eng. Tech. (IJIET). **4**(4), 141–156 (2014)
10. S. Saha, C. Rajasekaran, K. Vinay, Use of concrete wastes as the partial replacement of natural fine aggregates in the production of concrete. GCEC 2017. Lecture Notes in Civil Engineering **9**, 407–416 (2019). https://doi.org/10.1007/978-981-10-8016-6_32

11. D. Neslihan, Waste foundry sand usage for building material production: a First Geopolymer Record in Material Reuse. Adv. Civil Eng. https://doi.org/10.1155/2018/1927135
12. T.R. Naik, V. Patel, P. Dhaval, M. Tharaniyil, Flowable slurry containing foundry sands. Report no. Cbu-1992-23 (1992)
13. R. Siddique, J.M. Khatib, Abrasion resistance and mechanical properties of high-volume fly ash concrete. Mat. Struct., pp 709–718. https://doi.org/10.1617/s11527-009-9523-x
14. Z.T. Yao, X.S. Ji, P.K. Sarker, J.H. Tang, L.Q. Ge, M.S. Xia, Y.Q. Xi, A comprehensive review on the applications of coal fly ash. Earth-Science Revi. **141**, 105–121. http://dx.doi.org/10.1016/j.earscirev.2014.11.016
15. U.M. Muthaiyan, S. Thirumalai, Studies on the properties of per- vious flyash–cement concrete as a pavement material. Cogent Engineering **4**, 1318802 (2017). https://doi.org/10.1080/23311916.2017.1318802
16. R. Venkatakrishnaiah, G. Sakthivel, Bulk utilization of flyash in self compacting concrete. KSCE J. Civil Eng. (2017). https://doi.org/10.1007/s12205-015-0706-4
17. M. Medeiros, J.W. Raisdorfer, J.H. Filho, A. Ronaldo, Partial replacement and addition of fly ash in Portland cement: influences on carbonation and alkaline reserve. J. Build. Rehabil. (2017). https://doi.org/10.1007/s41024-017-0023-z
18. IS: 8112-1989. 43 Grade of ordinary portland cement—Specification. Bureau of Indian Standards, New Delhi
19. IS: 1489-1991 (Part 1). Portland pozzolana cement—Specification. Bureau of IndianStandards, New Delhi
20. IS: 2386-1963. Methods of tests for aggregates for concrete. Bureau of Indian Standards, New Delhi
21. IS: 383-1970. Specifications for coarse and fine aggregates from natural sources of concrete. Bureau of Indian Standards, New Delhi
22. IS: 456-2000. Code of practice for plain and reinforced concrete. Bureau of Indian Standards, New Delhi
23. IS: 10262-2009. Concrete mix proportioning—Guidelines. Bureau of Indian Standards, New Delhi
24. IS: 516-1959. Methods of test for strength of concrete. Bureau of Indian Standards, New Delhi
25. IS: 5816-1970. Splitting tensile strength of concrete—Method of test. Bureau of Indian Standards, New Delhi

A Review on Influence of Replacing Industrial Wastes with Fine Aggregate in Concrete

S. Varadharajan, S. V. Kirthanashri, Mohammad Samim, Bishnu Kant Shukla, and Gaurav Bharti

1 Introduction

Concrete utilization has risen dramatically in the last decade due to rapid urbanization and industrialization worldwide, with annual production reaching 12 billion tons [1]. The enormous manufacturing of concrete has boosted the production of concrete ingredients like cement, sand, and coarse aggregate. Globally, about 27 billion tons of trash will be produced by 2025 [2]. So, this waste may be used to substitute fine and coarse aggregate in concrete. In India, about 8.5 tons of municipal solid waste is produced yearly [3]. This review article is focused towards the use of industrial wastes in manufacture of concrete. Industrial waste from marble and granite grinding, waste glass, jarosite, and imperial smelting furnace (ISF) slag may be used as a partial replacement of fine aggregate in concrete [4]. All major developing nations produce huge amounts of marble dust which is difficult to eliminate. India, for example, generates massive quantity of marble waste powder slurry each year. Similarly, 90,000 tons of granite are mined and processed annually, with about 65% of the granite is discarded [5]. ISF slag is an amorphous waste product of hydrometallurgical zinc and lead extraction from sulfide ore. Rajasthan, India, produces enormous quantity of ISF slag every year which is difficult to dispose due to environmental hazards [6]. Walez slag is a waste product produced during zinc recovery in an electrical furnace. Walez slag disposal is difficult and environmentally hazardous. Globally, huge quantity of Walez slag is produced annually [7]. The presence of metals such as lead,

S. Varadharajan (✉) · M. Samim · B. K. Shukla · G. Bharti
JSS Academy of Technical Education, Noida, India
e-mail: svrajan82@gmail.com

G. Bharti
e-mail: gauravbharti@jssaten.ac.in

S. V. Kirthanashri
AIMMSCR, Amity University Noida, Noida, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_16

chromium, and zinc in industrial waste products makes disposal difficult and storage problematic. Every year, India produces about 10 million metric tons of foundry sand [8]. Foundry sand is widely utilized in steel production and is often recycled. Energy processing of waste foundry sand involves hazardous chemicals like phenols, which must be properly disposed [8]. Glass is another massively generated waste in in all developed and developing nations [9]. Glass contains silica and may be used as a fine aggregate in concrete [9]. This should help with waste glass storage and disposal. The recycling of glass requires highly specialized labor and equipment. Figure 1 shows the production of industrial waste concrete and Fig. 2 shows the dispersion of ISF slag generation in India which shows that Rajasthan is the state which results in generation in of ISF in massive scale in comparison to other states.

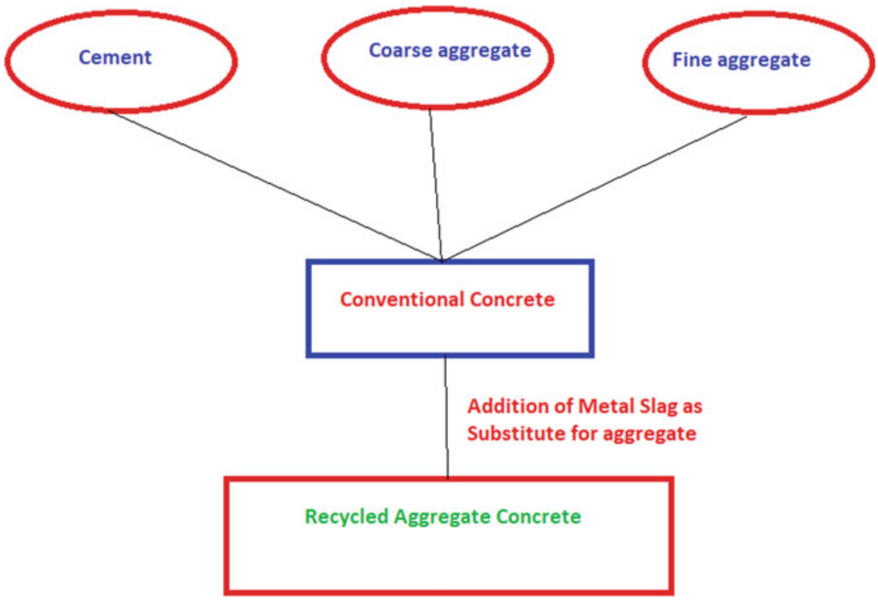


Fig. 1 Manufacturing process of concrete with industrial wastes

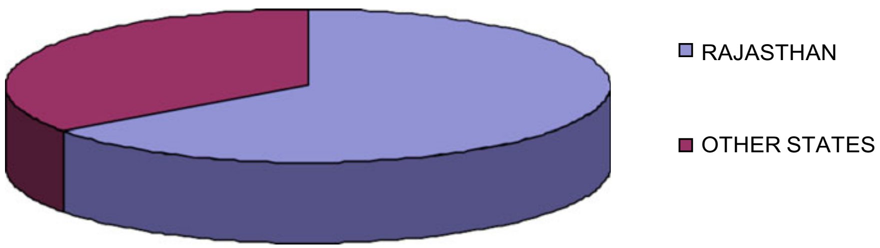


Fig. 2 Distribution of imperial smelting furnace slag generation in India

This research study aims in exploring the research works pertaining to the utilization of different alternatives for substitution of fine aggregate. The different types of substitutions available has been critically examined and its impact on parameters like cost effectiveness, environmental benefits, etc., has been explored in detail.

2 Properties of Industrial Wastes

According to previous research studies, the grain size distribution of industrial waste has been given in this study. The outcome of this gradation analysis indicates that the grain size of industrial wastes are consistent with the particle size distribution of fine aggregate. Researchers Vijaylakshmi et al. [10] & Singh and Siddique [8] found that industrial wastes have a smaller particle size than fine aggregate and may be utilized successfully in concrete without significantly degrading the strength and durability properties. More recently, Mehra et al. [11] revealed that Jarosite may be utilized successfully as a fine aggregate replacement in concrete without having a significant impact on the strength characteristics of the concrete. Using waste foundry sand with very small particle size, Singh and Siddique [8] were able to achieve enormous strength enhancement in concrete. A study by Ashish [12] who used marble waste powder in concrete, while other studies [13–15] showed the positive benefits of utilizing marble waste powder owing to the micro filling capability of marble waste powder. In addition, Ghannam et al. [5] have shown that granite waste may be used to substitute fine aggregate in concrete. Basar and Aksoy [16] used waste foundry sand as a replacement for fine aggregate in concrete and conducted a study to see how mechanical characteristics changed when waste foundry sand was substituted for fine aggregate. Using high percentage of ISF slag, Morrison et al. [4] replaced fine aggregate in concrete with ISF slag. As noted by the author, the ISF slag included concrete exhibits strength characteristics that are comparable to those of conventional concrete when the replacement level is 30% of the original level. But when fine aggregate is replaced with ISF slag in large proportions, only a little decrease in the strength characteristics was observed. Walez slag was utilized in concrete as a fine aggregate substitute. When Walez slag was used, the authors found that it was helpful [7]. Glass powder has been utilized as a fine aggregate replacement in concrete by Kim et al. [9], Chen et al. [17], observed advantageous characteristics of the concrete when compared to the conventional concrete. Basar and Aksoy [16], have used waste foundry sand in concrete and observed superior characteristics when compared to the ordinary concrete. According to Fig 3, shows various industrial wastes used in concrete. Morrisson's ISF slag composition is shown in Fig. 4 (2005).

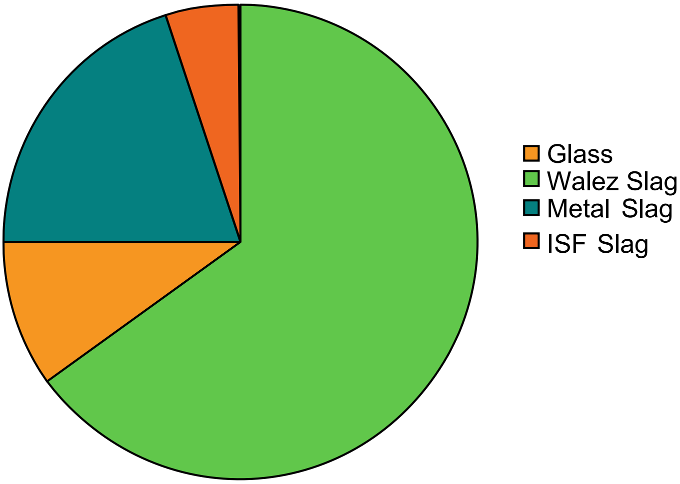


Fig. 3 Research works using different industrial wastes

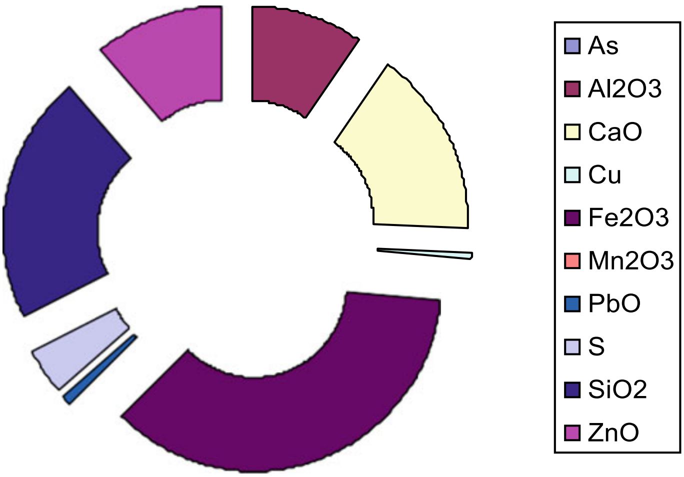


Fig. 4 Composition of ISF slag adopted by Morrisson (2005)

3 Conclusions

The primary goal of this research work was to investigate the characteristics of several types of concrete made from industrial waste, such as marble waste powder, quartz waste powder, jarosite, waste foundry sand, Walez Slag, and other similar materials, in order to develop a better understanding of their properties. If fine aggregate and cement were substituted with industrial wastes, the researchers observed that properties like as compressive strength, split tensile strength and flexural strength were significantly improved at low to medium percentages of replacement. When the percentage of replacement is high, however, the mechanical properties of the concrete reduces as a consequence of the reduction in mechanical properties [1–20]. Environmental benefits of using industrial products in concrete include a reduction in carbon dioxide gas emissions, particulate emissions, a reduction in land degradation, and an overall improvement in the quality of ecosystems and human life as a result of their usage.

References

1. M.S. Savadkoohi, M. Reisi, Environmental protection based sustainable development by utilization of granite waste in reactive powder concrete. J. Clean. Prod. **266**, 121973 (2020)
2. A. Laurent, I. Bakas, J. Clavreul, A. Bernstad, M. Niero, E. Gentil, M.Z. Hauschild, T.H. Christensen, Review of LCA studies of solid waste management systems-part I: lessons learned and perspectives. Waste Manage. **34**(3), 573–588 (2014)
3. I.S. Mir, P.P.S. Cheema, S.P. Singh, Implementation analysis of solid waste management in Ludhiana city of Punjab. Environ. Challenges **2**, 100023 (2021)
4. C. Morrison, R. Hooper, K. Lardnera, The use of ferro-silicate slag from ISF zinc production as a sand replacement in concrete. Cem. Concr. Res. **33**(12), 2085–2089 (2003)
5. S. Ghannam, H. Najm, R. Vasconez, Experimental study of concrete made with granite and iron powders as partial replacement of sand. Sustain. Mater. Technol. **9**, 1–9 (2016)
6. B. Tripathi, A. Misra, S. Chaudhary, Strength and abrasion characteristics of ISF slag concrete. J. Mater. Civil Eng. **25**, 1611–1618 (2013)
7. S. Sorilini, C. Collivignarelli, G. Plizzari, M.D. Foglie, Reuse ofWaelz slag as recycled aggregate for structural concrete, in *Conference proceedings on Use of Recycled Materials in Buildings and Structures* (RILEM, Barcelona, Spain, 2004), pp. 1086–1094
8. G. Singh, R. Siddique, Effect of waste foundry sand (WFS) as partial replacement of sand on the strength, ultrasonic pulse velocity and permeability of concrete. Constr. Build. Mater. **26**, 416–422 (2012)
9. S. Kim, S.Y. Choi, E.I. Yang, Evaluation of durability of concrete substituted heavyweight waste glass as fine aggregate. Constr. Build. Mater. **184**, 269–277 (2018)
10. M. Vijaylakshmi, A.S.S. Sekar, G.G. Prabhu, Strength and durability properties of concrete made with granite industry waste. Constr. Build. Mater. **46**, 1–7 (2013)
11. P. Mehra, R.C. Gupta, B.S. Thomas, Assessment of durability characteristics of cement concrete containing jarosite. J. Clean. Prod. (2016). https://doi.org/10.1016/j.jclepro.2016.01.055
12. B. Tripathi, S. Chaudhary, Performance based evaluation of ISF slag as a substitute of natural sand in concrete. J. Clean. Prod. **112**(1), 672–683 (2016)
13. H. Heboub, H. Aoun, M. Belachia, H. Houari, E. Ghorbel, Use of waste marble aggregates in concrete. Constr. Build. Mater. **25**, 1167–1171 (2011)
14. F. Gameiro, D.J. Brito, D.C. Silva, Durability performance of structural concrete containing fine aggregates from waste generated by marble quarrying industry. Eng. Struct. **59**, 654–662 (2014)
15. A.A. Aliabdo, M.A. Elmoaty, E.M. Auda, Re-use of waste marbledust in the production of cement and concrete. Construction and Building Materials, 50, 28–41 (2014); S. Singh, S. Khan, R. Khandelwal, A. Chugh, R. Nagar, Performance of sustainable concrete containing granite cutting waste. J. Clean. Prod. (2016). https://doi.org/10.1016/j.jclepro.2016.02.008
16. H.M. Basar, N.D. Aksoy, The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete. Constr. Build. Mater. **35**, 508–515 (2012)

17. C.H. Chen, R. Huang, J.K. Wu, C.C. Yang, Waste E- particles used in cementitious mixtures. Cem. Concr. Res. **36**, 449–456 (2006)
18. P. Mehra, R.C. Gupta, B.S. Thomas, Properties of concrete containing jarosite as a partial substitute for fine aggregate. J. Clean. Prod. (2016). https://doi.org/10.1016/j.jclepro.2016.01.015
19. N. Gurumoorthy, K. Arunachalam, Micro and mechanical behaviour of treated used foundry sand concrete. Constr. Build. Mater. **123**, 184–190 (2016)
20. D.K. Ashish, Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth. J. Build. Eng. **15**, 236–242 (2018)

Utilization of Fly Ash in Concrete: A State-of-the-Art Review

S. Varadharajan, S. V. Kirthanashri, Neha Maurya, Prasad Bishetti, Bishnu Kant Shukla, and Gaurav Bharti

1 Introduction

The basic impact of cement on concrete creep is the binding strength. When loaded at an early age, concrete exhibits poor resistance to creep. The concrete creep reduces with the increasing strength [1]. The greater initial concrete strength, reduces the creep comprehensively. The aggregate's impermeability and high elastic modulus also prevents creep. Concrete with sandstone aggregate has around 250% more creep than lime stone aggregate, which has the greatest elastic modulus in all circumstances. Because cement paste is the main component of concrete that controls creep and the water–cement ratio used is the most important factor affecting creep [1–6]. The greater gap between cement particles and aggregates increases creep. The surrounding temperature and humidity also have a significant impact on creep in addition to Concrete's viscosity and elastic modulus which decrease with increasing temperature. Creep is disregarded when the volume surface area ratio is higher than 0.9 [6]. Creep is inversely related to surface area and previous research studies have shown that the volumetric surface area ratio of components affects concrete creep significantly [7]. Admixtures are extremely efficient in reducing creep and they are often used to improve workability, frost resistance, cement usage reduction, and placement time to meet realistic project needs. Flyash (FA) is being increasingly

S. Varadharajan (✉) · N. Maurya · P. Bishetti · B. K. Shukla · G. Bharti
JSS Academy of Technical Education, Noida, India
e-mail: s.varadharajan@jssaten.ac.in

P. Bishetti
e-mail: prasadbishetti@jssaten.ac.in

G. Bharti
e-mail: gauravbharti@jssaten.ac.in

S. V. Kirthanashri
AIMMSCR, Amity University Noida, Noida, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_17

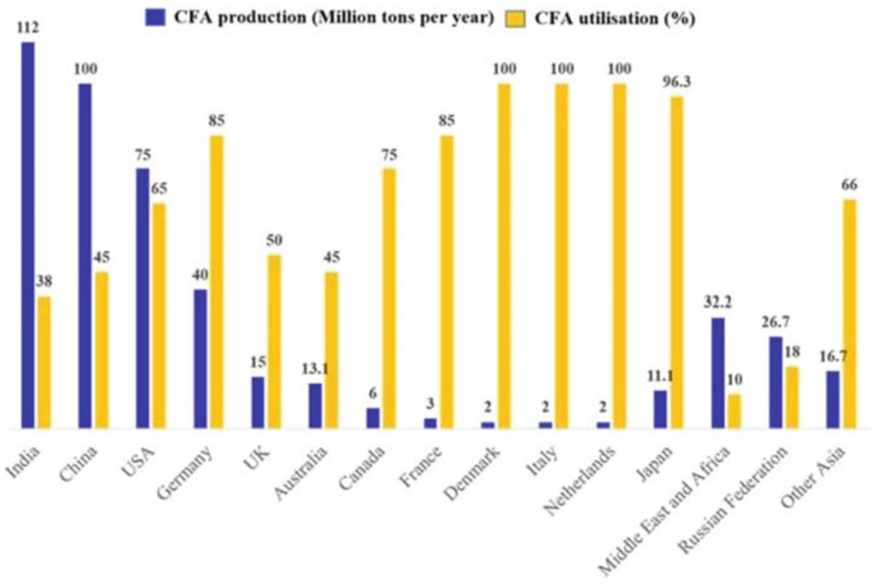


Fig. 1 Production and utilization of fly ash across the globe [as reported in 25]

used to replace cement as shown in Figs. 1 and 2. Fly ash significantly increases concrete slip. Although concrete with fly ash has lower early strength than concrete without fly ash, its late strength is higher. As a result, early age loading is preferable for reducing concrete creep. The early creep of concrete with fly ash increases with the amount of fly ash content. At, concrete with fly ash creeps less than concrete without flyash [8]. Fly ash is a popular mineral additive with a wealth of experimental data on its effect on concrete creep. The research study shows that using fly ash at a percentage of 12 or 30% reduces concrete creep shrinkage compared to using pure cement [9]. Many researchers have utilized fly ash asses the creep behavior of recycled concrete. Completely recycled concrete has a greater creep degree than regular concrete. Adding fly ash combined with mineral powder reduces the total creep and initial creep of the recycled concrete. Some Authors [10] have investigated the effect of development operative material on the creep effectiveness of ferrocement tubes and observed that creep decreases with concrete grade [11]. Self-compacting concrete creeps more than ordinary concrete [12]. Chindaprasirt [13] found that fly-ash concentration and water–cement ratio increased creep. Because limestone contains more tricalcium aluminate, Hemalatha and Dwivedi [14, 15] reported concrete creep to reduce with concrete strength. This research work aims in a detailed review of literature works pertaining to the utilization of fly ash in concrete. The recent advancements and a comprehensive review of recent literature works have been presented [16–25]. Furthermore, effectiveness of fly ash utilization in constructions considering the aspect of enhancement of properties, environmental benefits, cost-effectiveness has also been presented.

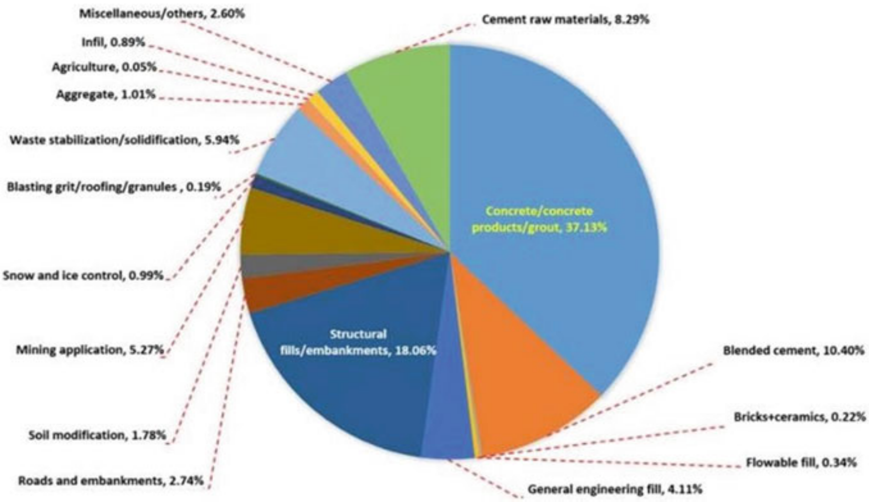


Fig. 2 Potential percentage utilization of fly ash [as reported in 25]

2 Necessity of Utilizing Fly Ash in Geopolymer

FAA-GPCC concrete has been explored in this research work due to its high environmental impact. A number of FAA-GPCC tests revealed that the material's strength was on par with that of OPC concrete in several instances. Using FAA-GPCC technology may result in further economic and environmental advantages. However, if FAA-GPCC is to be considered the best long-term treatment, its impact on the long-term characteristics of GPCC must be considered. A large number of papers have addressed the uses of FA and their impact on the technical characteristics of GPCC systems. Another section of this paper has an in-depth discussion of the different uses of FA is one of the by-products of coal combustion is fly ash, which is a fine powder generated by the burning of pulverized coal [7, 8, 17]. It is a by-product of the burning of coal. After the pulverized coal is burned in the boiler, molten mineral residue is left behind. After the flue gas has been collected and cooled in the boiler tubes, the waste solidifies and becomes ash. The larger ash particles are pushed to the bottom of the combustion chamber, referred to as "bottom ash" or "slag," depending on their size. Evaporators and filter baghouses are used to recover FA from flue gas prior to exhaustion. If unburned colloidal particles do not burn, they nevertheless have an impact on the characteristics of the fuel. The mineral composition of the coal used to generate FA varies depending on the kind of coal utilized. Some of the most important variables to consider are coal supply, pulverization level, combustion conditions, as well as ash collection and processing techniques in addition to the disposal methods [15, 17]. In recognition of the fact that each power plant is unique, the FA produced changes from plant to plant. The kind of FA generated in a plant is influenced by the circumstances under which it is burned.

3 Environmental Impact of Using Fly Ash in Concrete

Toxic metals (including mercury and arsenic) produced during coal burning endanger human and environmental health. FA disposal has many negative health and environmental effects. FA has traditionally been released directly into the atmosphere, causing considerable harm to human and environmental health. Therefore, FA should be treated before it is released to control the pollution. FA is often stored in coal based-power plants and dumped in landfills globally. FA is a pollutant because it includes acidic, toxic, and radioactive components [22, 23]. FA contains hazardous metals such as lead, arsenic, mercury, cadmium, and uranium [15]. Cancer and other respiratory diseases such as asthma are increased by significant FA exposure. FA exposure has been related to brain issues including cognitive deficits and developmental issues, as well as lung, renal, and gastrointestinal issues. In open landfills or wet ponds, FA may pollute groundwater and damage the environment. Wet ponds hold around one-fifth of total FA disposal, and uncontrolled leaching and leakage may be a significant environmental issue. When FA is exposed to dampness, the dangerous components break down and pollute the groundwater. Contaminated water is dangerous to human health and may cause cancer if ingested.

4 Conclusions

Production of Portland cement is rising, owing to increasing construction, industrialization, and population expansion causing CO_2 emissions in cement plants, leading to global warming and finding innovative eco-friendly materials is vital to mitigate this pollution [1–26]. FA is a fine powder generated by power stations burning pulverized coal. FA is an organic waste that causes dumping issues but in combination with water, it produces a cementitious material. Due to heavy volume of FA produced and shortage of disposal in landfills, a sustainable FA consumption solution is needed. Utilization of FA as a substitute of cement in concrete may guarantee safe waste disposal, minimize health hazards, reduce pollution from cement plants along with reduced CO_2 emissions in addition to mitigation of cement production costs. Although FAA-GPCC has superior strength than conventional concrete, its durability is still an issue. According to current research, FA particle refining decreasing permeability. In addition, curing temperature influences GPCC absorption. Despite having more porosity than OPC concrete, FAA-GPCC exhibited better resistance to chloride attack by reducing chloride penetration thereby increasing the NaOH ratio in geopolymers. It also reduced chloride dispersal and permeability in comparison to OPC concrete. The introduction of Na_2-SiO_3 solution did not enhance the freeze-thaw endurance of FAA-GPCC. FAA-GPCC is less susceptible to attack from atmosphearic agencies than OPC concrete. The FAA-GPCCs also have superior fire resistance and strength properties than OPC concrete by producing a denser concrete with smaller voids.

References

1. F. Xi, S.J. Davis, P. Ciais, D. Crawford-brown, D. Guan, C. Pade, T. Shi, M. Syddall, J. Lv, L. Ji, L. Bing, J. Wang, W. Wei, Substantial global carbon uptake by cement carbonation, 1 (2016). https://doi.org/10.1038/NGEO2840
2. P.J.M. Monteiro, S.A. Miller, A. Horvath, Towards sustainable concrete. Nat. Publ. Gr. **16**, 698–699 (2017). https://doi.org/10.1038/nmat4930
3. S.A. Miller, F.C. Moore, Climate and health damages from global concrete production. Nat. Clim. Change (2020). https://doi.org/10.1038/s41558-020-0733-0
4. S.A. Miller, A. Horvath, P.J.M. Monteiro, Readily implementable techniques can cut annual CO2 emissions from the production of concrete by over 20%. Environ. Res. Lett. **11**, 074029 (2016)
5. R. Siddique, Utilization of silica fume in concrete: review of hardened properties. Resour. Conserv. Recycl. **55**, 923–932 (2011). https://doi.org/10.1016/j.resconrec.2011.06.012
6. H. Zhao, W. Sun, X. Wu, B. Gao, The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures. J. Clean. Prod. **95**, 66–74 (2015). https://doi.org/10.1016/j.jclepro.2015.02.050
7. Y.H.M. Amran, R. Alyousef, H. Alabduljabbar, M. El-Zeadani, Clean production and properties of geopolymer concrete; a review. J. Clean. Prod. (2020). https://doi.org/10.1016/j.jclepro.2019.119679
8. A.R.K. Gollakota, V. Volli, C.M. Shu, Progressive utilisation prospects of coal fly ash: a review. Sci. Total Environ. (2019). https://doi.org/10.1016/j.scitotenv.2019.03.337
9. J.L. Provis, Cement and concrete research alkali-activated materials. Cem. Concr. Res. **114**, 40–48 (2018). https://doi.org/10.1016/j.cemconres.2017.02.009
10. L.N. Assi, K. Carter, E. Deaver, P. Ziehl, Review of availability of source materials for geopolymer/sustainable concrete. J. Clean. Prod., 121477 (2020). https://doi.org/10.1016/j.jclepro.2020.121477
11. P. Nuaklong, P. Jongvivatsakul, T. Pothisiri, V. Sata, Influence of rice husk ash on mechanical properties and fire resistance of recycled aggregate high-calcium fly ash geopolymer concrete. J. Clean. Prod. **252**, 119797 (2020). https://doi.org/10.1016/j.jclepro.2019.119797
12. J.L. Provis, R.J. Myers, C.E. White, V. Rose, J.S.J. Van Deventer, X-ray microtomography shows pore structure and tortuosity in alkali-activated binders. Cem. Concr. Res. (2012). https://doi.org/10.1016/j.cemconres.2012.03.004
13. P. Chindaprasirt, P. De Silva, Effect of SiO_2 and Al_2O_3 on the setting and hardening of high calcium fly ash-based geopolymer systems. J. Mater. Sci. 4876–4883 (2012). https://doi.org/10.1007/s10853-012-6353-y
14. T. Hemalatha, A. Ramaswamy, A review on fly ash characteristics—towards promoting high volume utilization in developing sustainable concrete. J. Clean. Prod. **147**, 546–559 (2017). https://doi.org/10.1016/j.jclepro.2017.01.114
15. A. Dwivedi, M.K. Jain, Fly ash—waste management and overview: a review. Recent Res. Sci. Technol. (2014)
16. A. Danish, M.A. Mosaberpanah, Formation mechanism and applications of cenospheres: a review. J. Mater. Sci. (2020). https://doi.org/10.1007/s10853-019-04341-7
17. A. Bhatt, S. Priyadarshini, A. Acharath Mohanakrishnan, A. Abri, M. Sattler, S. Techapaphawit, Physical, chemical, and geotechnical properties of coal fly ash: a global review, Case Stud. Constr. Mater. (2019). https://doi.org/10.1016/j.cscm.2019.e00263
18. X.Y. Zhuang, L. Chen, S. Komarneni, C.H. Zhou, D.S. Tong, H.M. Yang,
19. W.H. Yu, H. Wang, Fly ash-based geopolymer: clean production, properties and applications. J. Clean. Prod. (2016). https://doi.org/10.1016/j.jclepro.2016.03.019
20. M.-I.M. Chou, Fly ash fly ash. Encycl. Sustain. Sci. Technol. (2012). https://doi.org/10.1007/978-1-4419-0851-3_121
21. M. Amin, B.A. Abdelsalam, Efficiency of rice husk ash and fly ash as reactivity materials in sustainable concrete. Sustain. Environ. Res. (2019). https://doi.org/10.1186/s42834-019-0035-2

22. M.E. Munawer, Human health and environmental impacts of coal combustion and post-combustion wastes. J. Sustain. Min. (2018). https://doi.org/10.1016/j.jsm.2017.12.007
23. Z.T. Yao, X.S. Ji, P.K. Sarker, J.H. Tang, L.Q. Ge, M.S. Xia, Y.Q. Xi, A comprehensive review on the applications of coal fly ash. Earth-Sci. Rev. (2015). https://doi.org/10.1016/j.earscirev.2014.11.016
24. K. Tzanakos, A. Mimilidou, K. Anastasiadou, A. Stratakis, E. Gidarakos, Solidification/stabilization of ash from medical waste incineration into geopolymers. Waste Manage. (2014). https://doi.org/10.1016/j.wasman.2014.03.021
25. R.K. Gollakota, R.K. Anjani, V. Volli, C.-M. Shu, Progressive utilisation prospects of coal fly ash: a review. *Science of the Total Environment* **672**, 951–989 (2019).
26. L. Assi, K. Carter, E. Eddie, R. Anay, P. Ziehl, Sustainable concrete: building a greener future. J. Clean. Prod. **198**, 1641–1651 (2018). https://doi.org/10.1016/j.jclepro.2018.07.123

Use of Waste Marble Dust and Waste Glass Powder and Bacterial Solution for Manufacture of Ecofriendly Concrete

S. Varadharajan, S. V. Kirthanashri, Abhishek Tiwari, Animesh Jaiswal, and Bishnu Kant Shukla

1 Introduction

The cement utilization has vastly amplified in previous years due to increased construction activities which has resulted in enormous enhancement in emission of particulate matter and greenhouse gas. The use of concrete ingredients consumption can be mitigated by substitution of WGP and WMD in concrete. WMD gains property of binding in contact with water. WGP shows similarity in property to fine aggregate. The WMD and WGP are available in abundance and processed economically. WMD can pose serious threat if not disposed as (a) It can stick to sides of drain pipes and cause blockage (b) Result in filling of soil pores and can render land infertile. (c) Can result in respiratory diseases. Utilization of WMD results in strength enhancement in concrete [1–6]. Ulubeyli et al. observed rise in concrete durability due to substitution of WMD. Mishra et al. observed enhancement in concrete strength due to mitigation in air void content [7]. Kelestemur et al. observed betterment in thermal properties due to WMD utilization in concrete [8]. However, some observers reported negligible effect of WMD on concrete properties, and low alumina content was reported as the main cause [9–11]. The adoption of WMD (replacing cement) and WGP (replacing fine aggregate) along with inclusion of Bacillus Pasteri and hooked steel fibers could aggravate the strength properties in addition to environmental benefits. The combination of materials adopted in this work is not reported in previous research works to best of author's knowledge. Also, a detailed study on

S. Varadharajan (✉) · A. Tiwari · B. K. Shukla
Department of Civil Engineering, JSS Academy of Technical Education, Noida 201301, India
e-mail: svrajan82@gmail.com

S. V. Kirthanashri (✉) · A. Jaiswal
AIMMSCR, Amity University Noida, Noida, India
e-mail: kirthanasv@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_18

strength and environmental properties for the combination of materials has not been deliberated in previous literature studies to best of author's knowledge [6].

2 Materials and Methods

This research work adopts Portland Pozzolana cement (PPC) as per BIS: 8112-2013 [12] to act as a binding agent in concrete. The preliminary tests on PPC cement have been demonstrated in Table 1. Crushed gravels of size 20 and 10 mm have been utilized as coarse aggregates. The chemical characteristics of WMD and WGP are elucidated in Table 2. The fine aggregates are composed of natural sand as per BIS 383 [13]. The particle size distribution (fine aggregate and WMP) is shown in Fig. 1 and Table 3. The dolomite is the major crystalline compound as depicted by the chemical analysis of WMP along with small quantities of calcium carbonate and silicon dioxide. Chemical scrutiny of WGP shows silica as the main constituent. The hooked steel fibers have been included in ingredients of concrete (1, 2, 3% by cement weight) as per author's previous research works [14, 15]. The properties of hooked steel fibers have been presented in Table 4. The Indian standard provisions have been followed for determination of. Proportions of cement: fine aggregate: coarse aggregate and it has been evaluated as 465 kg: 625 kg: 1130 kg for 1 cum of concrete. The detailed mix proportions used in this research paper have been elucidated in Table 5. Bacillus pasteurii is adopted as a bacterial solution to enhance the properties of concrete. The purification and isolation has been done following Metwally et al. [16]. The inclusion of WMD increases concrete strength in compression [15, 17].

Table 1 PPC test results

Tests	Experimental value	Standards as per is 8112–1980
Normal consistency	28%	–
Initial setting time (min)	132	Not less than 30 min
Final setting time (min)	95	Not greater than 600 min
Fineness (m^2/kg)	351.65	
Specific gravity	3.01	–
Compressive strength in Mpa		
3 days	30.62	
7 days	41.54	
28 days	46.45	

Table 2 Chemical composition of cement and WMD and WGP

Chemical composition	Cement	WGP	WMD
Calcium oxide	48.8	11.02	42.32
Silicon dioxide	31	73.0	5.6
Aluminum oxide	9.3	2.50	0.4
Iron oxide	5.2	0.30	0.80
Sulfur trioxide	2.6	0.35	0.187
Magnesium oxide	2.2	1.55	14.34
Potassium oxide	0.5	11.18	0.076
Sodium oxide	0.4	0.10	0.065

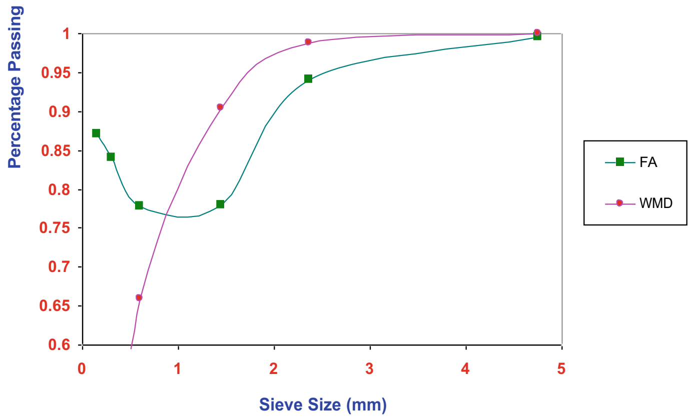


Fig. 1 Sieve analysis of WMD and fine aggregate

Table 3 Properties of coarse and fine aggregate

Property	Coarse aggregates		Fine aggregates	
	20 mm	10 mm		
Specific gravity	2.69	2.76	2.57	2.67
Water absorption	0.885	0.94	1.64	1.85
Fineness modulus	6.89	6.51	2.55	2.48

3 Results and Discussion

(a) **Compressive strength**

The strength of concrete in compression is evaluated as per provisions of Indian standard code. Figure 2 depicts mean compressive strength results of concrete cubes at age of 28 days. The 28 day strength in compression for C1, C2, and C3 mix

Table 4 Properties of hooked steel fibers

Property name	Value
Wire diameter (d)	0.75 mm (±0.04 mm)
Fiber length (L)	60.0 mm (±2 mm)
Hook length (l and l')	1–4 mm
Hook depth (h and h')	1.80 mm (±1 mm)
Bending angle	45 (min. 30)
Aspect ratio (L/d)	80
Tensile strength of drawn wire	1200 N/mm^2

Table 5 Details of mixes

Mix number	WMD (%)	WGP	Bacterial concentration
C0	0	0	Not present
C1	3	10%	Not present
C2	6	10%	Not present
C3	9	10%	Not present
D1	3	10%	10^6 per 'ml'
D2	6	10%	10^6 per 'ml'
D3	9	10%	10^6 per 'ml'

increases by 11.56, 13.35, and 16.48% with respect to C0 mix. The addition of bacterial solution increases the strength in compression by 13.34, 15.23, and 18.11% for D1, D2, and D3 mix as compared to D0 mix. This observation is in correlation with results reported in previous research works. This happens because of better filling of voids in the concrete matrix by WMD. Also, capacity of binding of cementitious matrix increases due to chemical reaction (between C3A and WMD) leads to production of carbano–aluminates [14, 18, 19]. Mixing of steel fibers in concrete by 1, 2, and 3% by weight of cement augments the compressive strength by 22.69, 29.13, and 33.49% because of crack bridging by steel fibers. D3 mix was observed to gain maximum compressive strength in comparison to all mixes and this result is in correlation with previous studies [9, 14, 15]. Mishra et al. obtained a 53.83% enhanced strength in compression due to substitution of fine aggregate with WMD [10]. Khyaliya et al. reported an enormous increase of 150% in cement mortar due to substitution of fine aggregate with WMD [20]. Similar conclusions have been reported in previous research works [18, 21, 22]. But, reverse observations were reported by other researchers due to addition of WMD [11, 23].

(b) **Split Tensile strength**

The concrete strength in tension is determined as per procedures suggested in Indian standard code. Figure 3 elucidates 28 day concrete strength in tension enhances by 11.01, 15.23, and 18.21% for C1, C2, and C3 mix as compared to C0 mix. The addition of bacterial solution further enhances by 14.12, 18.65, and 22.67% in comparison

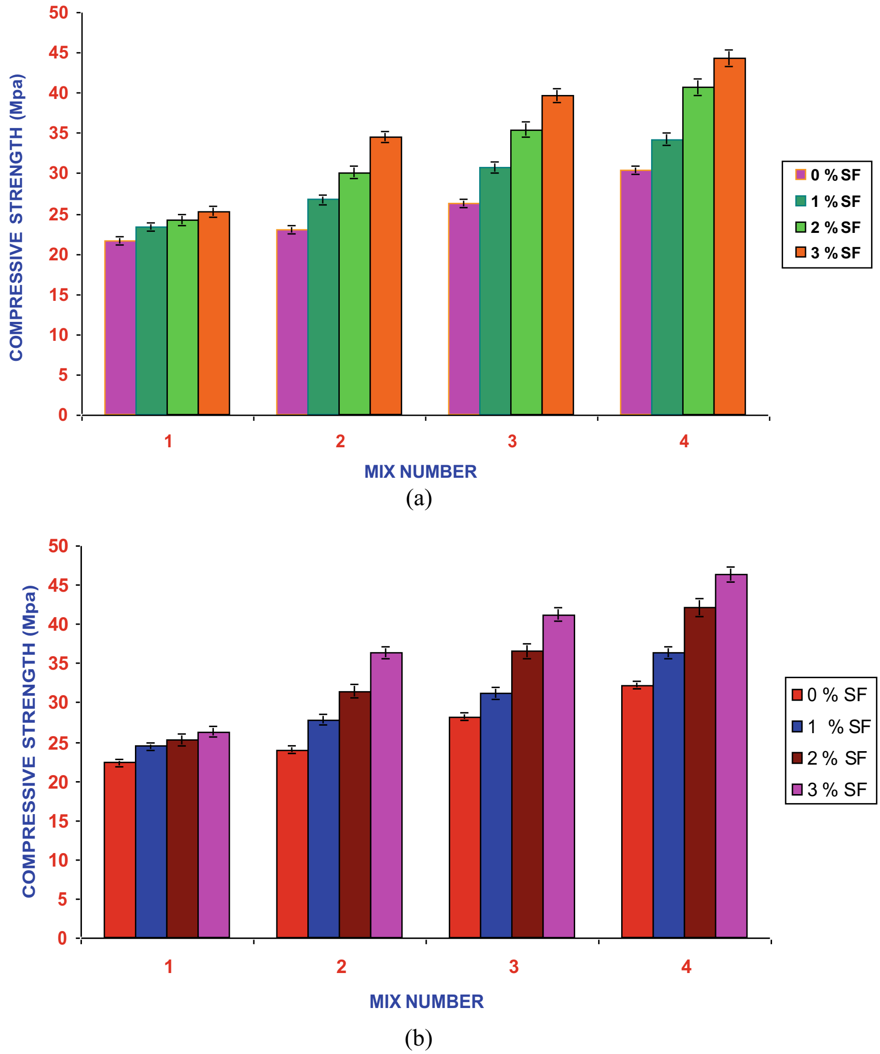


Fig. 2 Mean 28 day compressive strength for concrete **a** with bacterial solution, **b** without bacterial solution (mix 1 denotes C0 mix, mix 2: C1, mix 3: C2, mix 4: C3. SF represents steel fiber percentage)

to C0 mix (Fig. 3). The development of carbano–aluminates causes cement matrix to get dense and improves interfacial transition zone [24]. A 33 % enhanced strength in tension was reported by Hebhoub et al. to substitution of WMD with fine aggregate [25]. Similar findings were concluded by Kabeer et al. for cement mortar cubes [9]. Contradicting observations have been reported by previous researchers due to addition of WMD in concrete [11, 23]. The strength in tension increases by addition of steel fibers due to increased ductility and densification of interfacial transition

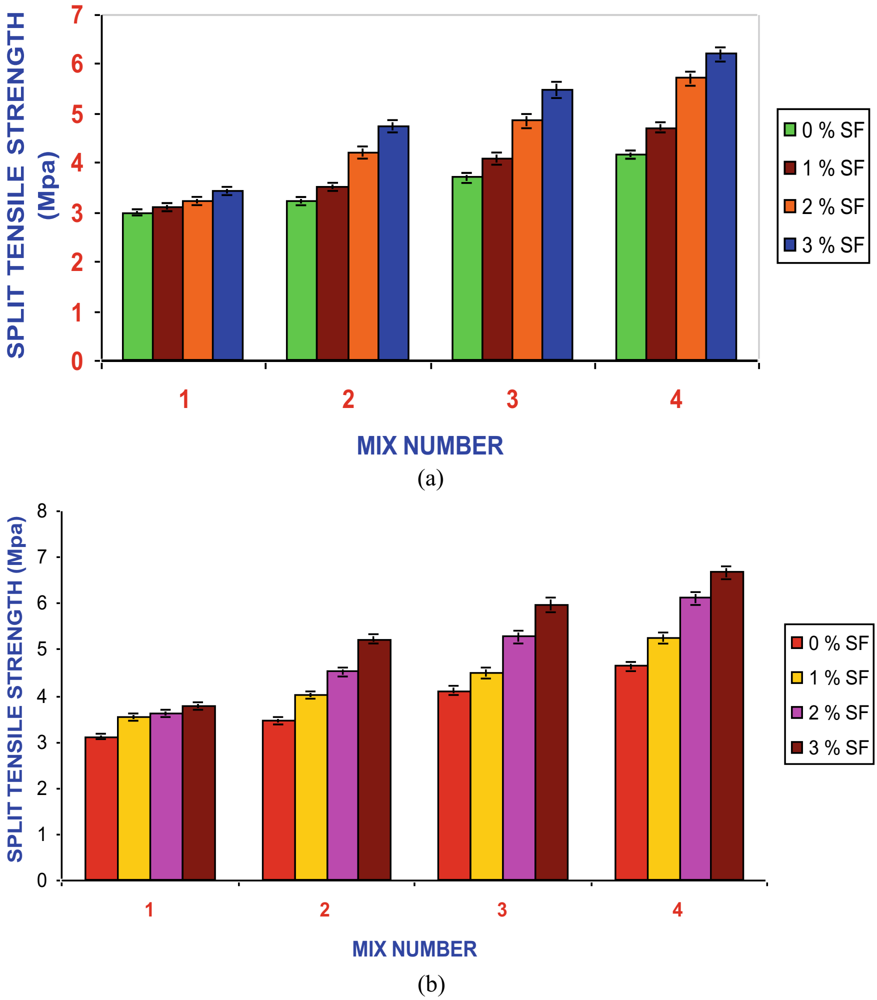


Fig. 3 Mean 28 day split tensile for concrete **a** with bacterial solution, **b** without bacterial solution (mix 1 denotes C0 mix, mix 2: C1, mix 3: C2, mix 4: C3. SF represents steel fiber percentage)

zone [24, 26–28]. A 76% increment in strength was reported by Libre et al. [29]. Gao et al. reported similar results [30]. A 38.7% increase in concrete strength in tension was observed by Siddiqui et al. due to inclusion of steel fibers [31]. El-Dieb reported an enormous enhancement of 52% in concrete tensile strength due to the substitution of 0.52% steel fibers [32]. Sahmaran and Yaman, Khaloo and Gencel also reported increased split tensile strength by addition of steel fibers [33–35].

The experimental data are utilized to propose alternate rules to estimate strength of concrete in tension and compression as

$$fcc = 0.601a + 301.14b + 17.12c + 11.34d - 16.34 \quad (1)$$

$$ftt = 0.03843a + 20.12b + 3.42c + 2.13d - 1.723 \quad (2)$$

where $f$cc is compressive strength, ft tis split tensile strength, a is no. of days, b is percentage of steel fibers, c is percentage of WMD, d is percentage of WGP.

The above proposed rules showed excellent correlation with reference to experimental results and results reported in previous literature (Fig. 4). The addition of WMP to concrete has beneficial effect in concrete [1–10, 14–22, 24– 45].

(iii) **Environmental impact assessment**

ISO 14040 [44] guidelines are used for assessment of environmental benefits of manufactured concrete. The determination of environmental benefit considers concrete life cycle from manufacturing to disposal. OPEN LCA software [46] has been utilized for life cycle assessment study. The inventory data are taken from Mendoza et al. [45]. The recipe midpoint and endpoint parameters have been adopted in accordance with previous research works [14, 15]. Figure 5 depicts the results of environmental impact assessment due to addition of WMD and WGP in concrete. From Fig. 5, it could be clearly seen that addition of WMD and WGP in concrete leads to decrement of CO2 emission by 14 %.

The parameters considered in recipe midpoint and endpoint analysis have been considered as per author's previous research works [14, 15]. The results of recipe midpoint and endpoint analysis have been depicted in Fig. 5 elucidate that due to incorporation of WMD and WGP the greenhouse gas emission is decreased by 14% which is quite substantial in reduction of global warming. The particulate matter emission observes a decrease of 45% due to inclusion of WMD and WGP which is quite useful considering environmental pollution and respiratory diseases caused because of WMD and WGP. In addition, the magnitude of emitted chlorofluro carbons is inhibited by 18% which is quite useful in reducing the rate of ozone depletion. It is because, reduction in amount of WMD and WGP diminishes the quantity of cement and fine aggregate required. The dredging of fine aggregate is one of the most discussed environmental concerns, especially in India as dredging promotes floods which is one of the worst forms of socioeconomic disasters. The parameters considered for endpoint analysis are (a) Ecosystem quality (b) Resources utilized (c) Aspect of human health. It is clearly evident from Figs. 6 and 7 that the inclusion of WMD and WGP results in significant improvement of the environmental parameters leading to the sustainable development. The Bacillus pasteurii inclusion leads to marginal improvement of environmental parameters.

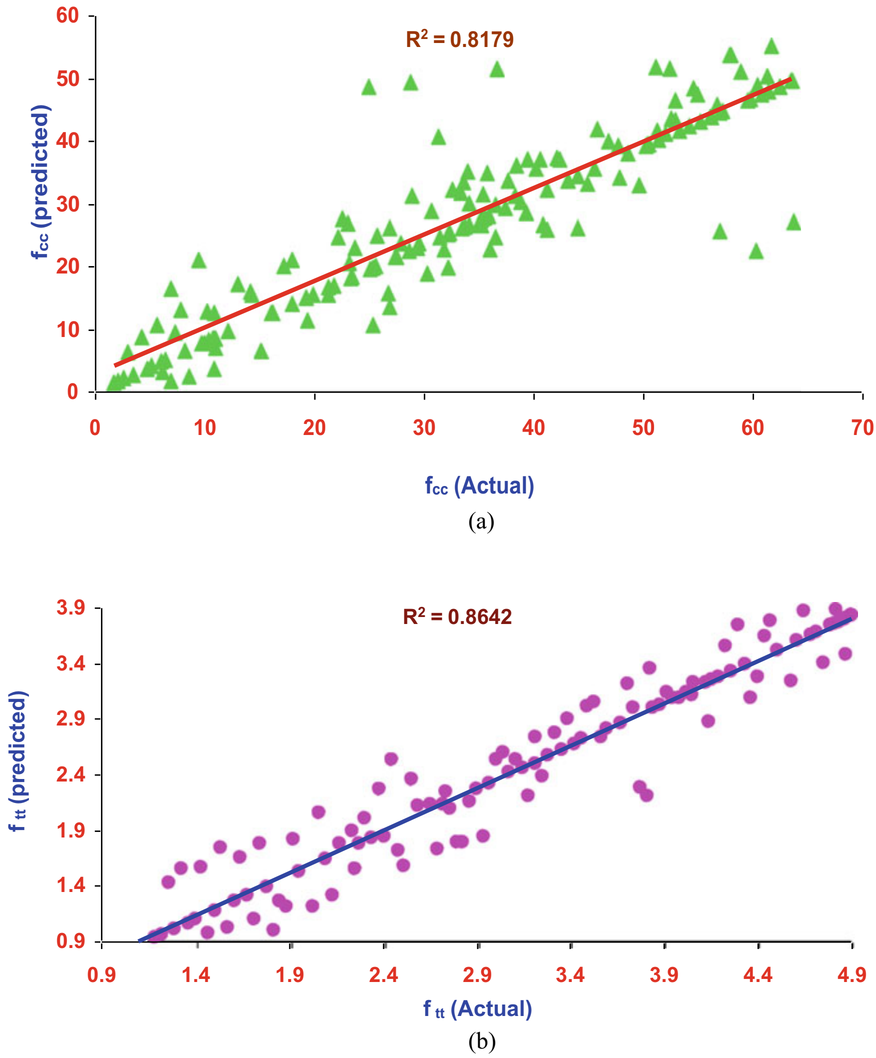


Fig. 4 **a** Comparison between actual and predicted compressive strength. **b** Comparison between actual and predicted split tensile strength

4 Conclusions

This work aims to incorporate industrial wastes like WMD and WGP in concrete to derive better strength properties and environmental benefits. In this research work, cement is substituted by WMD in percentages of 3, 6, 9%, and fine aggregate is substituted by 10% WGP. In addition, Bacillus pasteurii and steel fibers have been included in concrete to enhance strength properties of manufactured concrete. The

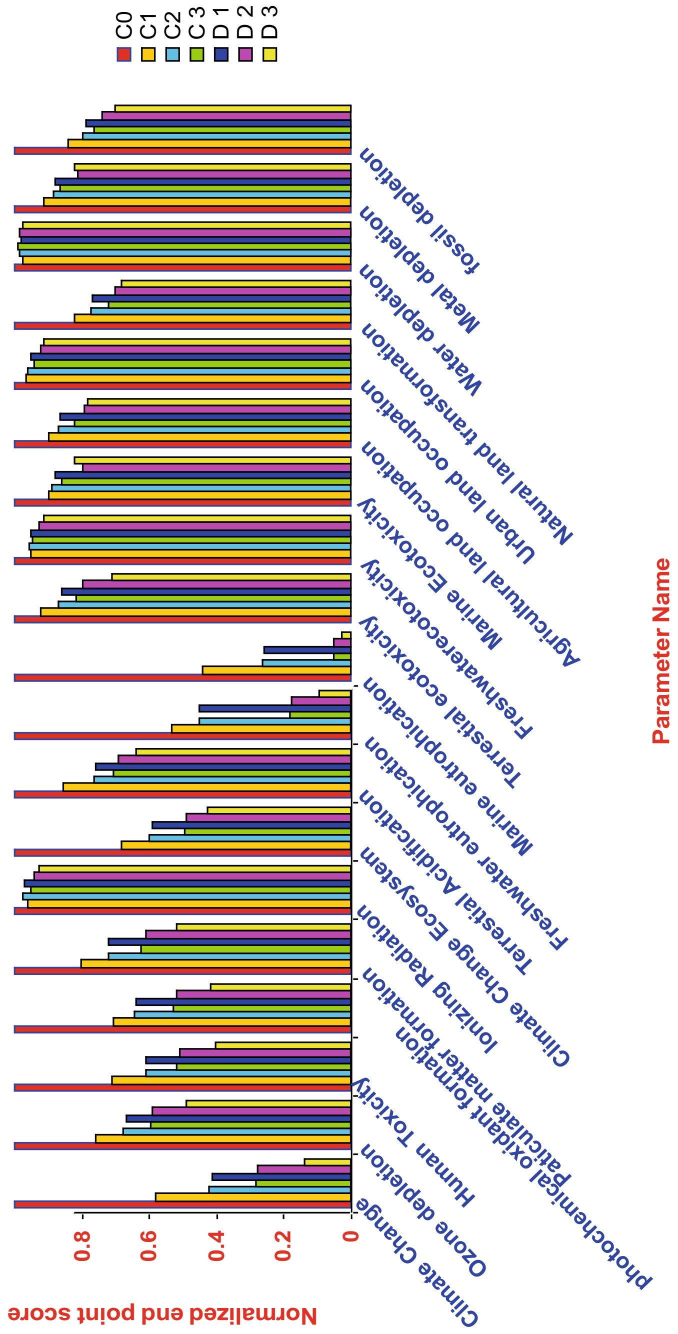


Fig. 5 Recipe midpoint analysis for mixtures considered in the analytical study

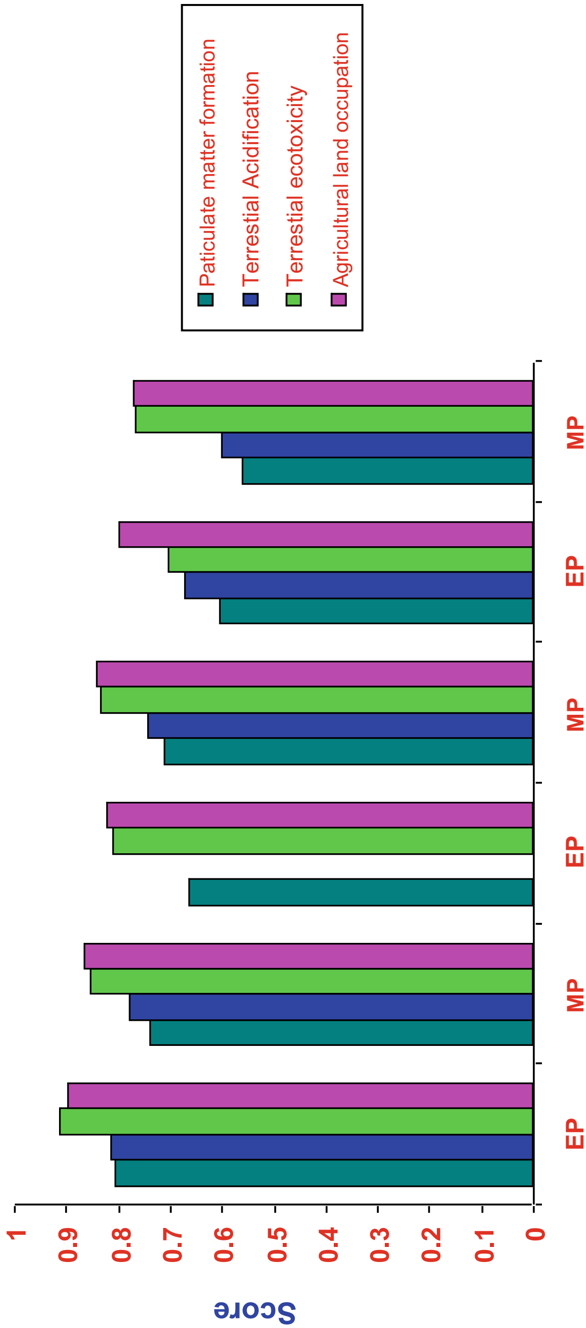


Fig. 6 Comparison of parameters between midpoint and endpoint analysis

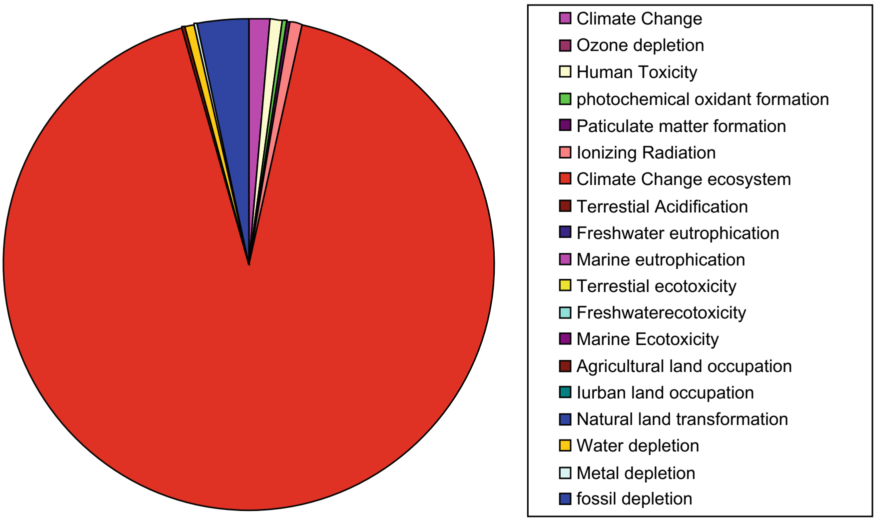


Fig. 7 Effect of WMD and WGP on environment

results elucidate that addition of WMD, WGP, Bacillus pasteuri, and hooked steel fibers increases the strength properties of concrete significantly, and formation of carbano–aluminates also results in significant strength enhancement. This is because of micro-filling ability of WGP and WMD which fill the pores of concrete effectively. The mix D3 gained the maximum strength as it contained percentage of WMD, WGP, and bacterial solution and hooked steel fibers. In this research work, alternate equations have been proposed to determine the mechanical properties. The proposed rules were observed to be more accurate as indicated by a high value of correlation coefficient. The environmental benefits were assessed by OPEN LCA software which showed comprehensive reduction in percentage of particulate emission and carbon dioxide emission due to incorporation of WGP and WMD.

References

1. J. Costa, C. Pinelo, A. Rodriguez, Characterization of the Estremoz, Borba and Vila Viçosa region marble quarrying dump ins NPR/GERO. Natl Lab Civ Eng Lisbon Port (1991), p. 246
2. H.Ş Arel, Recyclability of waste marble in concrete production. J. Clean. Prod. **10**(131), 179–188 (2016)
3. B. Demirel, The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete. Int. J. Phys. Sci. **5**(9), 1372–1380 (2010)
4. V. Corinaldesi, G. Moriconi, T.R. Naik, Characterization of marble powder for its use in mortar and concrete. Constr. Build. Mater. **24**(1), 113–117 (2010)
5. N. Ural, C. Karakurt, A.T. Cömert, Influence of marble wastes on soil improvement and concrete production. J. Mater. Cycles Waste Manage. **16**(3), 500–508 (2014)

6. F. Gameiro, J. De Brito, D.C. da Silva, Durability performance of structural concrete containing fine aggregates from waste generated by marble quarrying industry. Eng. Struct. **1**(59), 654–662 (2014)
7. G.C. Ulubeyli, T. Bilir, R. Artir, Durability properties of concrete produced by marble waste as aggregate or mineral additives. Procedia Eng. **1**(161), 543–548 (2016)
8. O. Keleştemur, E. Arıcı, S. Yıldız, B. Gökçer, Performance evaluation of cement mortars containing marble dust and glass fiber exposed to high temperature by using Taguchi method. Constr. Build. Mater. **16**(60), 17–24 (2014)
9. K.S. Kabeer, A.K. Vyas, Utilization of marble powder as fine aggregate in mortar mixes. Constr. Build. Mater. **20**(165), 321–332 (2018)
10. A. Mishra, A. Pandey, P. Maheshwari, A. Chouhan, S. Suresh, S. Das, Green cement for sustainable concrete using marble dust. Int. J. Chem. Technol. Res. **5**(2), 616–622 (2013)
11. R. Rodrigues, J. De Brito, M. Sardinha, Mechanical properties of structural concrete containing very fine aggregates from marble cutting sludge. Constr. Build. Mater. **15**(77), 349–356 (2015)
12. BIS 8112. Ordinary Portland cement, 43 grade-specification. New Delhi: Bur. Indian Stan. (2013)
13. BIS 383. Coarse and fine aggregate for concrete—specification. Bur. Indian Stand (1997)
14. S. Varadharajan, Determination of mechanical properties and environmental impact due to inclusion of flyash and marble waste powder in concrete, in *Structures*, vol. 25 (Elsevier, 2020), pp. 613–630
15. S. Varadharajan, A. Jaiswal, S. Verma, Assessment of mechanical properties and environmental benefits of using rice husk ash and marble dust in concrete, in *Structures*, vol. 28 (Elsevier, 2020) pp. 389–406)
16. G.A. Metwally, M. Mahdy, A.E.R.H. Abd El, Performance of bio concrete by using Bacillus Pasteurii bacteria. Civil Eng. J. **6**(8), 1443–1456 (2020)
17. A. André, J. de Brito, A. Rosa, D. Pedro, Durability performance of concrete incorporatingcoarse aggregates from marble industry waste. J. Cleaner Prod. **15**(65), 389–396 (2014)
18. V.L. Bonavetti, V.F. Rahhal, E.F. Irassar, Studies on the carboaluminate formation in limestone filler-blended cements. Cem. Concr. Res. **31**(6), 853–859 (2001)
19. K. Vardhan, R. Siddique, S. Goyal, Strength, permeation and micro-structural characteristics of concrete incorporating waste marble. Constr. Build. Mater. **10**(203), 45–55 (2019)
20. R.K. Khyaliya, K.S. Kabeer, A.K. Vyas, Evaluation of strength and durability of lean mortar mixes containing marble waste. Constr. Build. Mater. **30**(147), 598–607 (2017)
21. M. Singh, K. Choudhary, A. Srivastava, K.S. Sangwan, D. Bhunia, A study on environmental and economic impacts of using waste marble powder in concrete. J. Build. Eng. **1**(13), 87–95 (2017)
22. Buyuksagis, I. Sedat, T. Uygunoglu, E. Tatar, Investigation on the usage of waste marble powder in cement-based adhesive mortar. Construct. Build. Mater. **154**, 734–742 (2017)
23. D. Silva, F. Gameiro, J. de Brito, Mechanical properties of structural concrete containing fine aggregates from waste generated by the marble quarrying industry. J. Mater. Civ. Eng. **26**(6), 04014008 (2013)
24. G. Campione, C. Cucchiara, L. La Mendola, M. Papia, Steel–concrete bond in lightweight fiber reinforced concrete under monotonic and cyclic actions. Eng. Struct. **27**(6), 881–890 (2005)
25. H. Hebhoub, H. Aoun, M. Belachia, H. Houari, E. Ghorbel, Use of waste marble aggregates in concrete. Constr. Build. Mater. **25**(3), 1167–1171 (2011)
26. O.A. Düzgün, R. Gül, A.C. Aydin, Effect of steel fibers on the mechanical properties of natural lightweight aggregate concrete. Mater. Lett. **59**(27), 3357–3363 (2005)
27. M.M. Kamal, M.A. Safan, Z.A. Etman, B.M. Kasem, Mechanical properties of self-compacted fiber concrete mixes. HBRC J. **10**(1), 25–34 (2014)
28. A.C. Aydin, Self compactability of high volume hybrid fiber reinforced concrete. Constr. Build. Mater. **21**(6), 1149–1154 (2007)
29. N.A. Libre, M. Shekarchi, M. Mahoutian, P. Soroushian, Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice. Constr. Build. Mater. **25**(5), 2458–2464 (2011)

30. J. Gao, W. Sun, K. Morino, Mechanical properties of steel fiber-reinforced, highstrength, lightweight concrete. Cem. Concr. Compos. **19**(4), 307–313 (1997)
31. R. Siddique, G. Kaur, Strength and permeation properties of self-compacting concrete containing fly ash and hooked steel fibres. Constr. Build. Mater. **30**(103), 15–22 (2016)
32. A.S. El-Dieb, Mechanical, durability and microstructural characteristics of ultra-highstrength self-compacting concrete incorporating steel fibers. Mater. Des. **30**(10), 4286–4292 (2009)
33. O. Gencel, W. Brostow, T. Datashvili, M. Thedford, Workability and mechanical performance of steel fiber-reinforced self-compacting concrete with fly ash. Compos. Interfaces **18**(2), 169–184 (2011)
34. M. Sahmaran, I.O. Yaman, Hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash. Constr. Build. Mater. **21**(1), 150–156 (2007)
35. A. Khaloo, E.M. Raisi, P. Hosseini, H. Tahsiri, Mechanical performance of self-compacting concrete reinforced with steel fibers. Constr. Build. Mater. **31**(51), 179–186 (2014)
36. M.J. Munir, S.M. Kazmi, Y.F. Wu, Efficiency of waste marble powder in controlling alkali–silica reaction of concrete: a sustainable approach. Constr. Build. Mater. **15**(154), 590–599 (2017)
37. A. Khodabakhshian, J. De Brito, M. Ghalehnovi, E.A. Shamsabadi, Mechanical, environmental and economic performance of structural concrete containing silica fume and marble industry waste powder. Constr. Build. Mater. **169**, 237–251 (2018)
38. V.M. Cunha, Steel fibre reinforced self-compacting concrete (from micromechanics to composite behavior) [Doctoral dissertation] (2010)
39. B. Chen, J. Liu, Properties of lightweight expanded polystyrene concrete reinforced with steel fiber. Cem. Concr. Res. **34**(7), 1259–1263 (2004)
40. M. Hassanpour, P. Shafigh, H.B. Mahmud, Mechanical properties of structural lightweight aggregate concrete containing low volume steel fiber. Arabian J. Sci. Eng. **39**(5), 3579–3590 (2014)
41. A.D. Sakalkale, G.D. Dhawale, R.S. Kedar, Experimental study on use of waste marble dust in concrete. Int. J. Eng. Res. Appl. **4**(10), 44–50 (2014)
42. A.E. Naaman, High performance fiber reinforced cement composites: classification and applications. CBM-CI international workshop Karachi, Pakistan (2007), pp. 389–401
43. A. Bentur, S. Diamond, S.J. Mindess, The microstructure of the steel fibre-cement interface. J. Mater. Sci. **20**(10), 3610–3620 (1985)
44. ISO14040/44, Environmental, management Life cycle assessment. Principles and framework/Requirements and guidelines International Organization of Standardization (2006)
45. J.M. Mendoza, M. Feced, G. Feijoo, A. Josa, X. Gabarrell, J. Rieradevall, Life cycle inventory analysis of granite production from cradle to gate. Int. J. Life Cycle Assess. **19**(1), 153–165 (2014)
46. V. OpenLCA software (GreenDelta TC), Germany (2018)

Study on Suitability of Sawdust as an Alternate for Fine Aggregate in Concrete

Prasad Bishetti, S. Varadharajan, Bishnu Kant Shukla, and Gaurav Bharti

Abbreviations

CA	Coarse aggregate
FA	Fine aggregate
FST	Final setting time
IST	Initial setting time
NCC	Normal consistency of cement
OPC	Ordinary Portland cement
SD	Sawdust

1 Introduction

Concrete is a composite material made from a specific ratio of water, fine aggregate, coarse aggregate, and cement. The cement acts as a binder that binds all the fine and coarse aggregates together, hence forming one solid mass. Concrete is an essential construction material, due to its ease of workability and good compressive properties, although its tensile and flexural properties are very poor. According to some resources, mechanical strength characteristics of concrete perhaps enhanced through

S. Varadharajan · B. K. Shukla · G. Bharti
Department of Civil Engineering, JSS Academy of Technical Education, Noida 201301, India
e-mail: bishnukantshukla@gmail.com

G. Bharti
e-mail: gauravbharti000@gmail.com

P. Bishetti (✉)
School of Civil Engineering, KLE Technological University, Hubballi 580031, India
e-mail: prasadnb55@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_19

the addition of reinforcement materials and admixtures. Agricultural (organic) materials are usually used to replace synthetic materials, during the production of green concrete. Within the past two decades, there has been intensive campaign for green concrete, due to the climate change and environmental issues of synthetic materials. Applications of these green concretes are widely acceptable in several constructional works, due to their environmental friendliness, lightweight, cost-effectiveness, and their appreciable structural properties. Availability of agricultural materials is widespread in the rural areas where they are produced, and proper disposal of their waste products often becomes a problem. Several researches had incorporated natural materials in the production of hybridized green concretes.

Generally concrete is a material which is used next to water all over globe. As India is a developing country in which construction activities like infrastructure development, housing projects are rapidly increasing. So, one can presume the quantum of concrete for the completion of these projects without any shortage of resources. Based on the type of concrete application, 25–35% of total volume will be fine aggregate. The main reason for using natural sand as a fine aggregate in concrete compared to the other materials is because of its superior shape, size, and bonding characteristics. And, because of its low-cost and widespread availability, river sand is a popular building material. River sand has a spherical particle shape and a smooth texture due to long Term abrasion by water against the sand particle [1]. It also has a very low amount of silt and clay since it has been washed for years. India is a developing country with a yearly growth in the construction sector, particularly in structural and infrastructural constructions. As a result, demand for river sand has increased to keep up with the growth of the construction sector. On the other side, overuse of river sand resulted in a significant depletion of river sand. The removal of river sand from the riverbed has caused several environmental problems, including bank erosion, the loss of water-retaining sand strata, aquatic life disturbance, the lowering of the underground water table near the stream, and the loss of vegetation along the riverbank, all of which have an impact on the habitat above and below ground.

Sawdust is an unpopular material that is hardly employed in the construction as a building material, but it is commonly discarded as waste from furniture manufacturing industries and sawmill and because it is plentiful and has no practical value. From the literature studied, India produces approximately 30,000–33,000 T sawdust annually [2–6]. As a result, the study's objective is to achieve the optimum dosage of sawdust to use as a partial replacement for fine aggregate in concrete. In addition to the above, a novel approach is made by treating the sawdust and making it moisture free; meanwhile, binder material has been also replaced with supplementary cementitious material, i.e., fly ash.

Table 1 Physical properties of OPC-43

NCC	32.0%
Compressive strength (28 days)	47.5 N/mm^2

2 Materials

2.1 Cement

OPC-43 was used for the concrete production (Table 1).

2.2 Fly ash

Class-F fly ash is utilized for a fractional substitution of cement by 81 weight in concrete.

2.3 Water

Ground water of pH 7.3 is used for the concrete manufacturing.

2.4 Fine Aggregate

Locally available normal-graded natural sand (Zone-II)

Properties tested natural sand sawdust

Fineness modulus 3.04 2.21

Confirming to Zones II and III (Table 2).

Table 2 Physical attributes of FA and SD

Sp.gr	2.58	1.7

Fig. 1 Sawdust

2.5 Coarse Aggregate

20 mm downsize crushed granite was used for the concrete production.

2.6 Sawdust Preparation

Preparation of sawdust: used in this investigation collected from local furniture manufacturing cum sawmill in Noida. To completely dry the sawdust, it is oven dried at a temperature of 50 °C for 24 h before being ground into smaller pieces, making it easier to mix with regular concrete. In order to determine the gradation and zone of sawdust sieve, analysis test was conducted as per BS 882:1992. Sawdust passing through 4.75 mm sieve and retained on 75 µm sieve is selected for replacement of natural sand in concrete (Fig. 1).

3 Method

3.1 Particle Size Grading

The sieves analysis of the fine aggregates was determined in compliance with Indian Standard procedures.

3.2 Mix Ratio

A conventional mix ratio of 1:1.5:3 (C: FA: CA: 0.55) and water-to-cement ratio of 0.55 were adopted for the concrete production. During the course of the concrete production, the natural sand was replaced with 2.5, 5.0, 7.50, 10.0, and 12.5% of sawdust.

3.3 Concrete Preparation

Two sets of concrete were produced during the course of this study; one set was incorporated with fly ash (10% of the cement weight), while the other set was produced without fly ash. The constituent materials (fly ash, sand, gravel, cement, and water) were thoroughly mixed by using the mechanical mixing method. The fly ash was dissolved in appropriate amount water (water-to-cement ratio), to be used for the concrete production to form a starch solution. After obtaining a near homogenous material, the freshly mixed concrete was filled into a standard mold (150 mm × 150 m × 150 mm), in three layers. Each layer was then rammed thirty-five times. Then, the cast concrete cubes were covered and left under a shady for 24 h, before they were removed from the molds. All the concrete cubes produced were cured by total immersion in water. The compressive strength and split tensile strength test have been conducted as per IS provisions.

3.4 For Sawdust Experimental Work

The experimental activity entails completing a gradation analysis of SD in accordance with the BS 882:1992 standard grading and using the results to design a mix to meet the needed strength and quality of concrete. After that, the concrete is checked for its workability parameters in fresh state using the slump test and then concrete cubes and prism are cast for further examination of hardened properties. A total of 36 cubical specimens were casted and called M0, M1, M2, M3, M4, and M5 in order to conduct the strength tests.

For each combination, a total of six concrete cubes were cast and testing has been done at the same age of 7D and 28D for all blends. Prisms for each mix were casted and tested for 28 days only. The ratio of water-to-cement was set at 0.55. The casted cube and prism concrete specimens were kept for curing in a tank situated in laboratory and then tested their compressive strength and flexural strength at different ages as mentioned above (Table 3).

Table 3 Mix proportion

Mix	Cement (Kg/m^3)	Fly ash (Kg/m^3)	FA (Kg/m^3)	SD (Kg/m^3)	CA (Kg/m^3)	Water
M0	360	40	600	0	1200	220
M1	360	40	585	15	1200	220
M2	360	40	570	30	1200	220
M3	360	40	555	45	1200	220
M4	360	40	540	60	1200	220
M5	360	40	525	75	1200	220

4 Results and Discussion

4.1 Particle Size Grading

The result revealed that the sand was well graded and met the BIS 87:2000 recommended. Indian Standard states that if sand had uniformity coefficient (Cu) higher, i.e., greater than 6 (Cu > 6), and also fine particles 160 content less than 5% (fines < 5%), the material or soil is considered as well graded and preferable for concrete production.

4.2 Workability (Slump Test)

The reason for the new substantial testing was to decide the functionality of each one of the six different blends. The slump test was utilized in this order to decide the consistency of the blend [7, 8]. The slump value obtained that for control mix was 90 mm, and shape of slump classed as true slump with high functionality according to the workability test results in Fig. 2. But the sawdust replaced mix has decreasing slump value; this may be due to water absorption characteristic of sawdust.

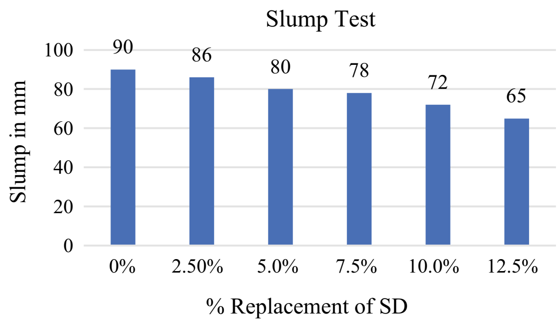


Fig. 2 Slump test

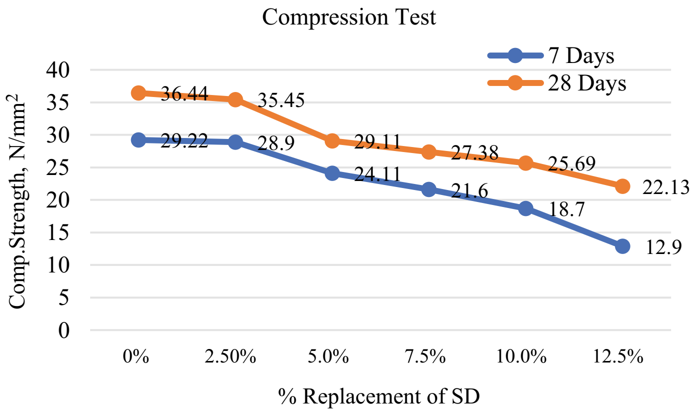


Fig. 3 Variation of compressive. Strength with age and percentage of SD

4.3 Compressive Strength

It was observed from the results that in (Fig. 3), the sawdust negatively affected the compressive strength of the concrete produced by higher replacements. At the age of 28D curing, one can observe steep decrease in the graph, as the sawdust volume increased from 2.5 to 12.5%. The results revealed that the compressive strength on the concrete decreased from 29.22 to 12.9 N/mm^2 for 7 days curing age and from 36.44 to 22.13 N/mm^2 for 28 days curing age, as the sawdust volume increased from 0 to 12.5%.

4.4 Flexural Strength

It was observed from the results that (Fig. 4), the sawdust had a negative effect on the flexural strength of the concrete produced [9, 10]. Test has been conducted on 28 days cured specimen, and the reduction in strength was observed from 6.43 to 4.82 N/mm^2 for 0–12.5% replacement of SD. But when compared to the percent of reduction in strength to that of flexural strength to compressive strength steep reduction is not observed in flexural strength. This may be due to the fibrous characteristic of the SD which is responsible for such trend.

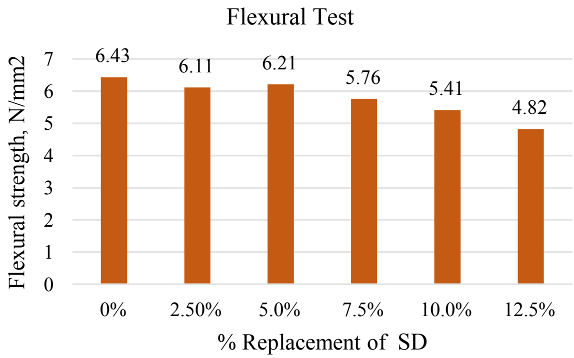


Fig. 4 Variation of flexural. Strength with age and percentage of SD

5 Conclusion

This research aim was to evaluate the effect of using sawdust as partial replacement of sand, in concrete manufacturing. Based on the confined observe achieved on the workability and strength test conducted on SD concrete, the subsequent conclusions are drawn.

- Sawdust a waste material can be considered for partial substitute of natural sand in the concrete mix through adopting some initial treatment like drying and grading practice.
- Study shows the aptness of sawdust in concrete and quantifies the variation in strength properties and potential changes.
- Results indicate approximate strength equal to the conventional mix of M20 (1:1.5:3) grade can be obtained by replacing up to 10% of natural sand by sawdust.
- Optimum replacement of SD can be limited to 10% of total volume of fine aggregate beyond which a there is noticeable decrease in both compressive and flexural strengths.
- Furthermore, using SD reduces the density of concrete, making it lighter and appropriate for use as a lightweight construction material in a variety of civil engineering applications.
- From the above conclusions, the workability and mechanical properties of concrete blend are inversely relative with the quantity of SD brought into the concrete. More the addition of SD, the lesser will be the workability and strength of the mix. This phenomenon is because of excessive water absorption characteristics of SD.

Therefore, there is no extensive scope for using SD as complete substitute to fine aggregate in concrete.

References

1. S.N.C. Deraman, M.A.D.A. Rashid, S.A. Saad, N.M. Husain, S.A. Masjuki, Effects of durian sawdust as a partial replacement of fine aggregate in concrete, in *IOP Conference Series: Materials Science and Engineering* (2021)
2. P. Dixson Jeson, S. Karthikeyan, G. Manikandan, Experimental study on properties of concrete by partial replacement of cement with silica powder and fine aggregate with saw dust ash. Int. J. Civil Eng. Technol. (IJCIET) **8**(3), 680–687 (2017). Article ID: 235 IJCIET_08_03_068
3. Sustainable Construction and Building Materials, Springer Science and Business Media LLC (2019)
4. D. Suji, Experimental study on partial replacement of fine aggregate with quarry dust and sawdust. Int. J. Advance. Eng. Technol. Manage. Appl. Sci. **3**(6) (2016)
5. A.M. Joy, A. Jyothi, Partial replacement of fine aggregate with sawdust for concrete. Int. J. Technol. Res. Eng. **3**(9) (2016)
6. D. Kumar, Low cost construction material for concrete as sawdust. Int. J. Current Eng. Technol. E-ISSN 2277-4106, P-ISSN 2347-5161
7. U. Tomas, Ganiron, Effect of sawdust as fine aggregate in concrete mixture for building construction. Int. J. Adv. Sci. Technol. **63**, 73–82 (2014)
8. O. Joseph Oyedepo, S. Daniel, Investigation of properties of concrete using sawdust as partial replacement for sand. Civil Environ. Res. ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online) **6**(2) (2014)
9. Abdullahi, Partial replacement of sand with sawdust in concrete production. Published in *3rd Biennial Engineering Conference* (Federal University of Technology, Minna, May, 2013)
10. A.K. Minocha, Amit Bhatnagar Immobilization of arsenate (As5+) ions in ordinary portland cement: influence on the setting time and compressive strength of cement. Res. J. Environ. Toxicol. (2007)

Study on Paving Blocks Using Plastic Waste

N. H. Parikshit, B. N. Manjunath, and Bishnu Kant Shukla

1 Introduction

Paver blocks are a popular decorative approach for laying out a pavement or hard surface. Pavers are available in a variety of styles, shapes, and colours. Block paving can be used to create a variety of various laying patterns. Manufactured and natural pavers are the two primary types of pavers. Concrete is the first type of produced paver. They are often strong and longlasting.

Plastics are becoming a more significant part of municipal solid waste. There is a lot of garbage plastic in the house, and it is becoming bigger. Although the amount of plastics in waste consumption is high, trash consumption differs by nation since it is unaffected by socioeconomic variables or garbage management programmes. We must make efficient use of it in order to address this issue.

This initiative recycles waste plastics and examines their characteristics as paving blocks. Because they are simple to lay and finish, paver blocks are perfect for constructing and completing paths and highways. The strength attributes of pavement blocks made of waste plastics are discussed, as well as design concerns for pavement blocks made of waste plastic bags. This initiative recycles waste plastics and examines their characteristics as paving blocks. Because they are simple to lay and finish, paver blocks are perfect for constructing and completing paths and highways [1, 2]. Plastic waste used in this work was brought from Ghazipur landfill site, Ghazipur dairy farm, New Delhi, and some in small quantity was brought from surrounding areas of Sector 62, Noida [3].

N. H. Parikshit · B. N. Manjunath · B. K. Shukla (✉)
Department of Civil Engineering, JSS Academy of Technical Education, Noida 201301, India
e-mail: bishnukantshukla@gmail.com

N. H. Parikshit
e-mail: pnhurukadli@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_20

Table 1 Experiment values of different properties

Properties of cement	Experimental values
Normal consistency	28%
Initial setting time	30 min
Final setting time	590 min
Specific gravity of cement	3.02

2 Materials and Methods

Ordinary Portland cement (53 grade), M-Sand, 10 mm coarse aggregate, PVC powder, and water are the ingredients to be utilised in the concrete mix [4].

2.1 Cement

Cement is a binder, a chemical that binds materials together in building by setting, hardening, and sticking to them. Rather of being utilised on its own, cement is generally employed to bind sand and gravel (aggregate) together. Masonry mortar is manufactured from cement and fine aggregate, whereas concrete is made from sand and gravel. Cement is the most frequently used material on the globe, coming in second only to water as the most utilised resource.

Inorganic cements, such as lime or calcium silicate, are widely employed in construction and are categorised as hydraulic or non-hydraulic based on their capabilities.

In this project, ordinary Portland cement with a grade of 53 is employed. Table 1 shows the physical characteristics of OPC as determined. The cement's physical characteristics were examined in the laboratory [4].

2.2 Fine Aggregate

The particles of fine aggregate—sand—are small, and their appearances are rarely. For this experiment, manufacturing sand was utilised. To remove toxic and large particles, the fine aggregate was sieved using a 4.75 mm sieve. 2.71 was discovered to be the specific gravity. The experiment values of different properties of cement are shown in Table 1, and particle size distribution curve is shown in Fig. 1.

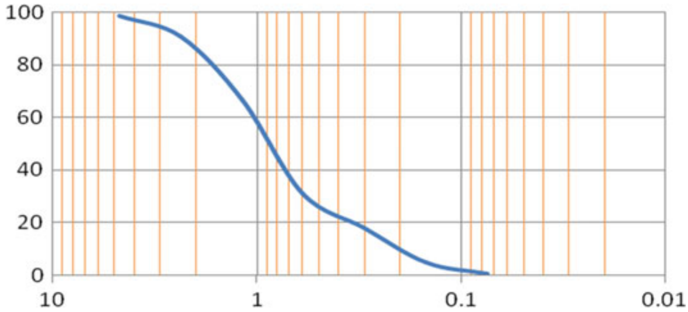


Fig. 1 Particle size distribution curve

2.3 Coarse Aggregate

Coarse aggregates are any particles greater than 0.19 in., but generally range between 3/8 and 1.5 in. in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder. The IS 15258:2006 describes that the maximum size of coarse aggregate should be 12 mm for paver design. Hence, 10 mm coarse aggregates are used in this work.

2.4 PVC

Polyvinyl chloride or PVC is most widely made synthetic plastic polymer, behind polyethylene and polypropylene. In 10, 20 and 30% of the cases, PVC plastic was crushed to a powder and replaced with sand accordingly, and it is shown in Fig. 2. The process of selecting acceptable mix components and determining their relative proportions in order to make concrete with the least amount of strength and durability while being as cost-effective as possible is referred to as mix design. Mix design can be accomplished in a variety of ways.

- The concrete mix for M30 grade was designed according to IS10262-1982. In percentages of 10, 20, and 30%, PVC plastic powder will be substituted in sand. The following techniques were used to manually compute the design:
- Calculate the volume of the mould.
- The concrete mix ratio must be calculated according to the IS codebook.
- The amount of materials needed to determine the mould volume.

Fig. 2 PVC powder

2.5 Test Data for Materials

- Specific gravity of cement 3.12
- Specific gravity of coarse aggregates 2.65
- Specific gravity of fine aggregate 2.71
- Fineness modulus of coarse aggregate 6.26
- Fineness modulus of fine aggregate 2.05.

Table 2 shows the mix proportions in detail. The proportions listed here are for a single paver mould. The concrete mix is determined by the number of paver moulds used and the needed quantity of concrete paver blocks [5]. The above-mentioned mix proportion can be used to determine it and also after casting the paver blocks made from plastic which is shown in Fig. 3 [6] (Table 3).

Table 2 Details of mix proportions

Materials (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregates (kg)	PVC powder (kg)
PB (0%)	0.78	1.33	1.471	0
PB (10%)	0.78	1.20	1.471	0.13
PB (20%)	0.78	1.07	1.471	0.26
PB (30%)	0.78	0.935	1.471	0.4

Fig. 3 Plastic waste paver block

Table 3 Compressive strength results of an ordinary paver block

Curing days	Compressive strength (Mpa)	Average (N/mm^2)
7	16.58	16.3
	16.02	
28	32.02	32.01
	32.0	

3 Experimental Result

Plastic concrete blocks must be examined under a compression testing machine (CTM) after adequate curing to determine their compressive strength applied a progressive compressive force to the specimen. The paver block was placed on the platform, and the load was imparted at a constant and uniform velocity on a smooth surface.

Taking note of the weight at which it did not succeed at and divided it by the cross-sectional area gave the compressive strength of the specimen determined by the paver block.

The strength of paver block after replacement of fine aggregate with the plastic is shown in Table 4, Table 5, and Table 6, respectively.

The average compressive strength of an ordinary paver block for 7 days is 15.15 N/mm^2, whereas that of a plastic paver block is 30.06 N/mm^2, which is slightly less than that of an ordinary block, indicating that plastic paver blocks can be used as an alternative as shown in Table 5. Paver blocks made using plastic waste, fine aggregates, and coarse aggregates have shown better results [7, 8]. Up to 20% of plastic, the property such a compressive strength was improved as shown in Table 5.

Table 4 PVC powder is used to replace 10% of the fine aggregate

Curing days	Applied load (KN)	Compressive strength (Mpa)	Average (N/mm^2)
7	409	14.98	15
	410	15.02	
28	819	29.98	29.96
	818	29.94	

Table 5 PVC powder replaced with 20% fine aggregate

Curing days	Applied load (KN)	Compressive strength (N/mm^2)	Average (N/mm^2)
7	412	15.09	15.15
	415	15.20	
28	820	30.03	30.06
	822	30.10	

Table 6 Thirty percentage replacement of PVC powder with fine aggregate

Curing days	Applied load (KN)	Compressive strength (N/mm^2)	Average (N/mm^2)
7	407	14.90	14.95
	410	15.01	
28	815	29.85	29.85
	815	29.85	

According to the above test results, the average compressive strength of a regular concrete paver block after 28 days of curing is 32.01 N/mm^2, while the average compressive strength of a plastic paver block is 29.85 N/mm^2. Hence, the paver blocks showed better results up to 20% replacement and further decreased as shown in Table 6. The bar chart depicting compressive strength results of 7 and 28 days is shown in Fig 4. The obtained results show that a plastic paver block has almost about the same strength as the regular one.

Based on the findings, it can be stated that plastic paver blocks may be used in parks, footpaths, and yards of both residential and commercial buildings since the compressive strength is adequate for user convenience [9].

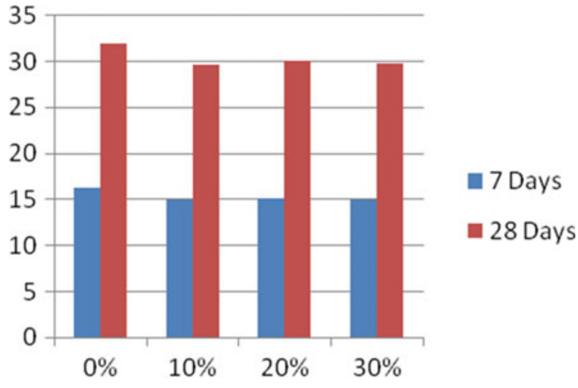


Fig. 4 Bar chart depicting compressive strength results of 7 and 28 days

4 Conclusion

- In our country, disposing of plastic garbage is a major issue. As a result, using waste plastic in paver block manufacture is a beneficial means of disposing of plastic trash since it lowers the quantity of plastic litter in the environment.
- Because plastic is a cheap material, replacing the fine aggregate with it lowered the cost of the paver blocks substantially. Hence, the paver blocks proved to be cheaper than the conventional blocks.
- Paver blocks using plastic waste showed to be more heat-resistant than the conventional blocks; this was due to the fact that the plastic is a heat-resistant material [10].
- It can be used in the places where there is light traffic and more pedestrians.
- Paver block made using plastic waste, fine aggregates, coarse aggregates have shown better results. Up to 20% of plastic, the compressive strength was improved.
- Waste plastic paver block can be used in non-traffic and traffic road.

References

1. P. Mathew, S. Varghese, T. Paul, E. Varghese, Recycled plastic as coarse aggregate for structural concrete. Int. J. Innov. Res. Sci. Eng. Technol. **2**(3) (2013)
2. R.L. Ramesh, K.M. Asharani, D.V.C. Katari, R. Sahana, Recycled plastics used as coarse aggregate forconstructional concrete. SJB Inst. Technol. Bangalore **2**(3) (2013)
3. Y. Ghernaouti, B. Rabehi, B. Safi, R. Chaid, Use of recycled plastic bag waste in the concrete. J. Int. Sci. Publ. Mat. Methods Technol. **8** (2015)
4. R. Atul, Use of plastic in a concrete to improve its properties. Int. J. Adv. Eng. Res. Stud. **1**(3), 109–111 (2012)
5. IS 15658, Precast concrete blocks for paving—specification, Bureau of Indian Standards, New Delhi (2006)
6. P. Suganthy, D. Chandrasekar, Utilization of pulverized plastic in cement concrete as fine aggregate.Int. J. Res. Sci. Eng. Technol. **2**(6) (2013)
7. A. Bhogayata, K.D. Shah, B.A. Vyas, N.K. Arora, Performance of concrete by using non recyclable plastic wastes as concrete constituent. Int. J. Eng. Res. Technol. (IJERT) **1**(4), (2012)
8. P.S. Patil, J.R. Mali, V. Ganesh, H.R. Kumavat, Innovative techniques of waste plastic used inconcrete mixture. Int. J. Res. Eng. Technol. **3**(9) (2014)
9. J. Ghuge, S. Surale, B.M. Patil, Utilization of plastic waste in manufacturing of paver block. Int. J. Res. Eng. Technol. **6**(4) (2019)
10. M. Elzafraney, P. Soroushian, M. Deru, Development of energy efficient concrete buildings using recycled plastic aggregate. J. Architect. Eng. (ASCE) **11**(4) (2005)

A Review on Applications of Steel Slag in Traditional and High-Strength Concrete

Uddeshya Misra, K. Senthil, and Kavita Rani

1 Introduction

An important sector of the economy is construction, which contributes to economic growth. In the history of civilization, the desire for living places has been a big motivation for major developments. Since the beginning of time, living people have been creating places to live. For this purpose, human beings came out with new solutions and innovated many new materials in the form of stone, mud, wood to fulfill the demands of construction and gradually with time, discovered new materials namely cement, bricks, steel rods, plywood, plastic, fiberglass, etc. and we need to pay special attention toward construction materials such as cement and concrete as they are widely used in the construction sector across the world and their consumption rate is quite high. Buildings for residential, infrastructural, and public uses have grown alongside construction technology and urbanization. Construction sector has grown and become one of the biggest sectors since the 19th century thanks to Portland cement and reinforced concrete. These materials contributed to faster production periods. Globally, concrete is one of the most widely used materials across the world after water. Cement is fabricated in an estimated 4.1 billion tons annually, half of which is produced in China (half a ton per person). Each year, Portland cement is used to make concrete per person of more than 1 m^3 [1].

The most common cement types today are blended cement and Portland cement. Other types include sulfate-resistant cement, volatile ash cement, and super sulfated cement. Thanks to cement technology, as it has accelerated modern construction. The cement industry itself produces 8% of total CO_2 produced in the world, which illustrates how significant it is in charge of the climate process along with ejection from

U. Misra · K. Senthil (✉) · K. Rani
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, G.T. Road, Amritsar Bypass, Jalandhar, Punjab 144011, India
e-mail: kasilingams@nitj.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_21

other sources. Both cement and concrete industries are continuously improving their production techniques and product standards as a means of reducing the harmful environmental effects. However, the processes (CO_2 retention systems, etc.) that are currently being implemented are not sufficient alone. The production of cement and concrete cannot be stopped, so the other solution to this issue can be recycling industrial wastes as an alternative. Steel and iron slag and coal ash at thermal power plants, as well as their disposal to the environment, cause serious, irreversible environmental problems. In the construction industry, there have been several initiatives to find use for sustainable building materials. One of these initiatives involves steel slag, which has proven to be a highly useful waste product [2–5]. By replacing fine aggregate with steel slag, and considering size distribution, compressive strength can be increased [6–10]**.** The steel slag, which was released into nature in the past and could be a serious environmental threat, is currently used in a variety of applications including concrete aggregate, asphalt pavement, clinker, and as ballast for railways. The steel slag usage for the above purpose has provided a means for preventing our limited natural resources from being depleted as quickly as possible and preventing the environmental degradation caused by waste. Approximately, the production of steel slag as 10–15% of crude steel. As per world Steel Association, 11.5 million ton slag is recycled out of 15.7 million tons.

Among the world's largest steelmakers, China, the amount of SS that is reused is approximately 30% and in China alone, about 80 Mt of SS are itself per annum [11]. Steel slag recycling rates in developing countries and some developed countries are relatively lower. Yet in developed nations, the rate is much higher [12]. Apart from being used as aggregate and cementitious materials, blast furnace slag and GGBS can be used as supplementary cementitious materials. There have also been numerous studies available on other uses of steel slag namely as construction, slag wool, concrete component, etc. [13, 14]. However, the possibility of utilization of steel slag in the concrete section and the benefits of high-strength concrete with steel slag is not revealed by the investigators. Therefore, the present manuscript focuses on the application of steel slag in the construction industry and the possibility in the construction industry in various ways. The production of steel slag and their availability in India is discussed in Sect. 2. The mechanical properties of the concrete with steel slag in terms of compression, flexure, split tensile strength, and absorption are discussed in Sect. 3.

2 Production of Steel Slag

Owing to the oxidation process in pig iron, one of the major by-products in the production of steel is steel slag. Various kinds of steel slag are produced depending upon the method of its production, however, the properties are more or less the same. Sponge iron, scrap metal, or peak iron that makes its way through the blast furnace are usually used as raw material in the steel production. The process of steel production is shown [15]. There are generally two processes used for the production of steel slag.

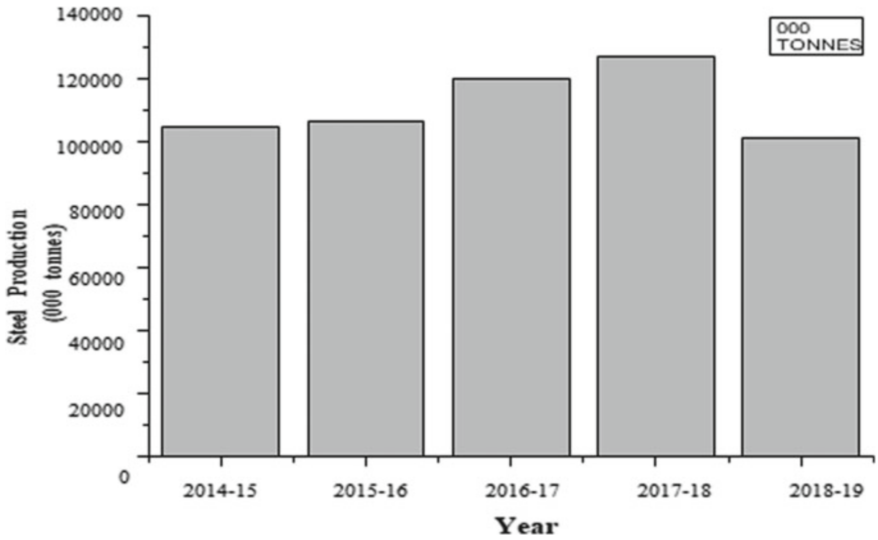


Fig. 1 Production of steel in India [16]

First method is Electric Arc Furnace (EAF) and the other is Basic Oxygen Furnace (BOF). Electrical energy fulfills the demand of heat in EAF for melting and to get rid of impurities in the steel. And these impurities oxidize in the presence of oxygen and form steel slag. A key component of BOF is the conversion of pig iron into steel using burned lime as flux to remove impurities. Fig 1 represents the graph between production of steel and the year [16] for 1 ton of steel production 100–150 kg of slag is generated. Slag, which is obtained during the steel production process from the iron and steel plants, is transported to the discharge plant by railways. A molten steel slag can be cooled in a range of ways, including simple cooling, cooling with air and water, or cooling in a pool. The most common method involves discharging the slag into a pool and cooling it with blasting water. As the slag contacts water, it becomes hardened and crystallized into a gray and less permeable substance**.**

3 Mechanical Properties of Concrete with Steel Slag

Among the most important concrete properties are serviceability, strength, and durability. These attributes are directly influenced by the quality of the materials used in concrete [17]. Using aggregates obtained through natural resources and cement paste, concrete forms from binding these aggregates together [18]. In comparison to the granulated blast furnace slag, steel slag has little to no pozzolanic activity, so it cannot be used to blend cement. That is a reason that the steel slag is usually preferred as an aggregate replacement [17] and [19]. A steel slag base can be used for building a retaining wall, a sound barrier, or even an insulation layer for radiation by comparing concrete produced by replacement of crushed limestone and steel slag. Maslehuddin et al. [18] obtained the mechanical properties and durability of the concrete**.** The slag/total aggregate ratio and concrete mix proportions were varied (0.45, 0.50, 0.55, 0.60 and 0.65) for steel slag mixtures. The cylinder 75 × 150 mm was made from concrete mixes to investigate 28 days compressive strength (containing 60% crushed limestone). The volume of permeable voids, split tensile strength, compressive strength, flexural strength, absorption and being shown in Figs 2, 3, 4 and 5 [18]. The concrete mixes containing steel slag aggregate have a higher specific bulk gravity than mixes containing limestone aggregate in crushed form. The compressive strength of samples with steel slag aggregate has also been found to be greater than samples of crushed limestone aggregate. With the escalation in steel slag rate, the volume of permeable pores decreased**.**

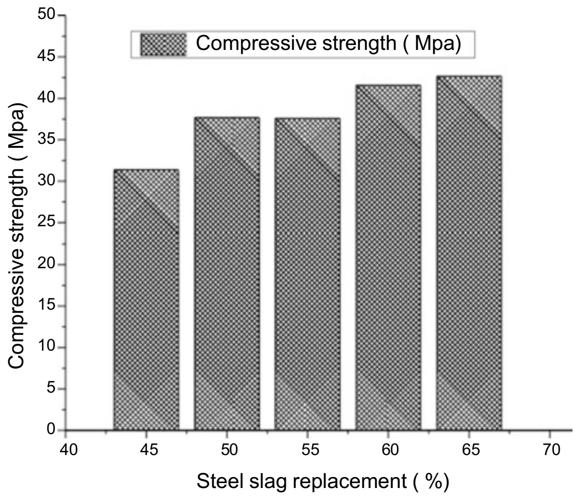


Fig. 2 Effect of steel slag on compressive strength [18]

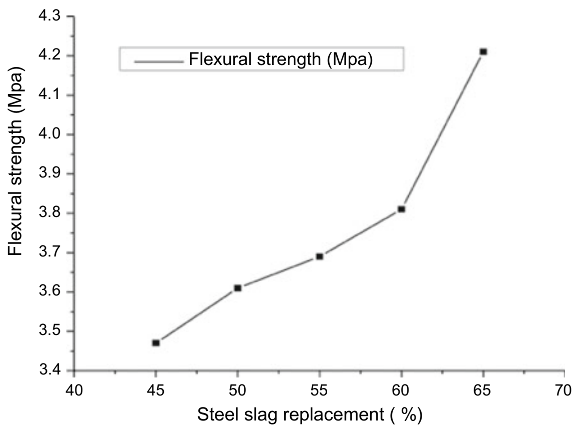


Fig. 3 Flexural strength [18]

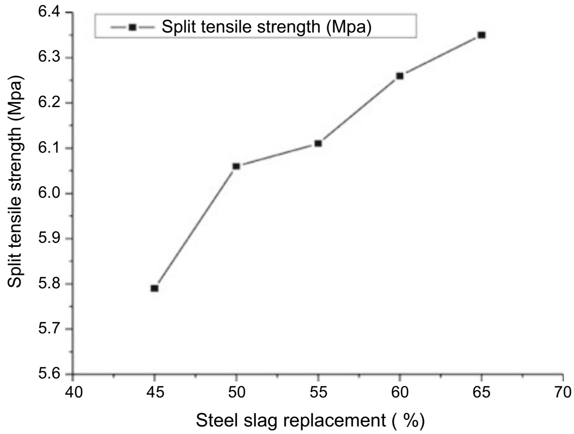


Fig. 4 Split tensile strength [18]

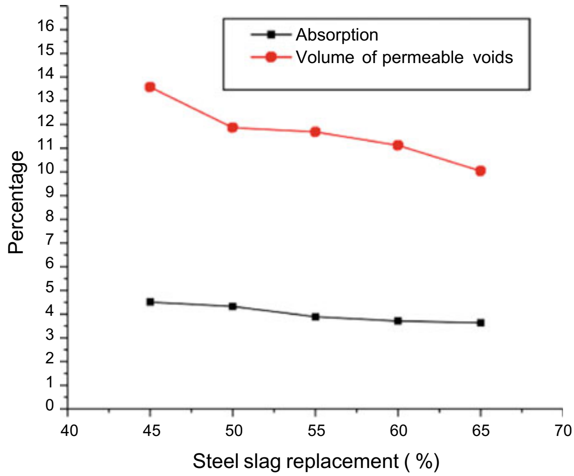


Fig. 5 Bulk density and permeable voids [18]

The concrete mixtures in which replacement is done by steel slag for their mechanical properties are investigated by Qasrawi et al. [17]. They tested steel slag mixtures relying on replacement ratios of 0, 15, 30, 50, and 100%. In the study, they examined mixtures with compressive strengths of 25, 35, and 45 MPa. For investigation of compressive strengths at 3, 7, 28, 90, and 180 days, samples of 100 × 100 × 100 were prepared**.** The concrete sample was subjected to curing at the laboratory under standard water curing until the test age was 7, 28, and 90 days. The specimens were obtained from 100 × 100 × 500 mm molds. At a 50% or more replacement ratio of steel slag, workability was negatively impacted. On the basis of replacement ratio & the grade of concrete, presence of steel slag fine aggregate enhanced compressive & tensile strengths. In the range of 15–30% replacement ratio, highest compressive strength has been observed [17].

With respect to control blend, obtained only from limestone aggregate in crushed form, slag coarse aggregate yielded higher strengths in the concrete mixtures. Steel slag has relatively more compressive strength than limestone, which contributes to the high strength of slag mixtures. In addition, the fineness modulus of the normal coarse aggregate was 5.53, while the slag coarse aggregate was 5.43. Therefore, the surface area of the aggregates increased with the use of slag instead of limestone, and so the demand for water too escalated. And eventually, a decreasing trend was observed in the ratio of water and cement. Due to the rough surface when compared to limestone and being more angular in shape, the transition zone becomes stronger and as a result, bonding between mortar and aggregate escalates too, which automatically increases strength too. This study also found that using SS fine aggregate decreased workability because of the angular structure of the slag. In the past, studies on the similar lines also agree with studies of Maslehuddin et al. [18] and Pellegrino and Gaddo [23]. According to Devi [6] and Yang [20], with the increase in percentage of replacement, concrete workability reduces**.** Study by Kothai and Malathy [21] showed that using steel slag as a replacement material for fine aggregates made for a better workability than substituting coarse aggregate under similar conditions A study [22] found that steel slag delays the setting time of adhesives. According to Guo et al. [8], high-strength silica-fume concrete was found to have great compressive strength at 30% replacement with steel slag.

Pellegrino and Gadde [23] study examined if steel slag could replace natural aggregates in traditional concrete. Some of the tests conducted by researchers are modulus of elasticity, tensile strength, compressive strength, and durability properties for different cases. Concrete mixes were prepared using natural aggregates and steel slag with slump value of approximately 185 mm, admixture rate of plasticizer as 0.4% air volume of 5%, water to cement ratio as 0.52, and admixture rate of entrained air as 0.016%. Different cases were investigated by the researchers in order to compare properties of traditional concrete with and without SS. The cases are natural aging of 74 days (C1), Warm water curing at 70° for 32 days (C2), A 90-day external weathering period followed by 32 days (C3), freezing and thawing for 25 days (C4), alternate wetting and drying for 30 days (C5). The result of the above five cases is shown in Fig. 6 [23] (Table 1).

4 Physical and Chemical Properties

Due to its physicochemical properties, there are lot of uses of steel slag in industrial work. The density of steel slag is between 3.3 and 3.6 g/cm^3 and is highly resistant to corrosion. The major components of steel slag are MgO, MnO, FeO, SiO_2, Al_2O_3, CaO, Fe_2O_3, and P_2O_5 [32]. It consists of minerals such as C2S, C3S, and C4AF [33]. A steel slag's chemical composition varies greatly according to the type of production. For example, steel slag produced from electric arc furnaces has less iron oxide when compared to steel slag produced from basic oxygen furnaces [34]. According to recent research, there are varying chemical compositions in steel slag

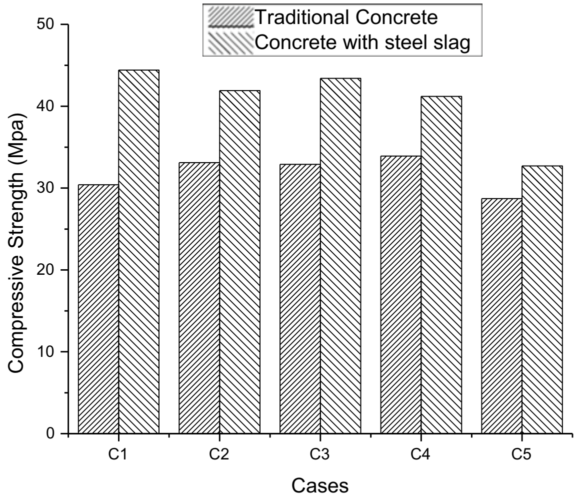


Fig. 6 Compressive strength of concrete for different cases [23]

Table 1 Mechanical properties

Authors	Compressive strength (MPa)		Flexural strength (MPa)		Split tensile strength (MPa)		Steel slag replacement
	Control Sample	SS	Control Sample	SS	Control Sample	SS	
Subramani and Ravi [24]	33.55	35.33–4.45	7.5	7.36–7.75			50–70% (CA)
Palankar et al. [25]	57.1	48.5–60.1	–	–	–	–	50%, (CA)
Patel [26]	35–43	29–42	4.72–5.17	4.38–4.80	3.2–3.26	3.15–3.88	100% naturel aggregate
San Jose et al. [27]	40.8	55.0–55.7	–	–	3.9	4.1–4.3	100% (FA, CA)
Wang et al. [28]	50.4	29.7–36.7	–	–	–	–	0–50% (cement)
Dineshkumar and Suchithra [29]	~ 65	~ 72.5	~ 5.5	~ 5.66	~ 4.2	~ 4.41	0–50%(FA)
Olonade et al. [30]	21.48	21.06	2.74	2.34	–	–	0–100% (FA)
Sekaran et al. [31]	36.4–39.62	34.1–42.29	5.8–7.2	6.2–7.53	3.69–4.37	3.87–4.43	0–50% (CA)

relying on the type of steel produced. Compared to carbon steel slag, stainless steel slag contains less FeO and more SiO_2 [35]. In Table 2, chemical compositions are given and in Table 3 some physical properties.

Table 2 Chemical properties

Authors	Component						
	MgO	CaO	Fe_2O_3 P_2O_5	SiO_2	Al_2O_3	MnO	FeO
Saxena and Tembhukar [10]	3.89	51.43	1.42	15.62	18.89	0.45	03.75
Guo et al. [8]	60–70	41–43	–	14–15	4.0–5.0	–	21–23
Anastasiou et al. [36]	3.63	20.60	–	22.80	8.46	–	32.60
Kourounis et al. [33]	6.45	35.70	–	17.53	6.25	2.50	02.36
Yuji [37]	5.61	42.00	1.99	16.00	1.50	–	07.78–17.6
Abu Eishah et al. [38]	9.23	39.62	–	17.23	4.08	0.70	20.40
Pang et al. [5]	6.27	46.73	1.67	14.77	5.52	2.76	18.42
Mohamad et al. [39]	4.83	45.18	2.11	18.48	3.76	3.61	19.45
He et al. [40]	8.86	50.56	1.32	21.36	4.62	–	03.16

Table 3 Physical properties of steel slag

Authors	Physical properties	
	Water absorption (%)	Specific gravity
Saxena and Tembhukar [10]	0.8–1.60	2.64
Pang et al. [5]	3.31	3.42
Mohamad et al. [39]	1.80	3.55
Abu Eishah et al. [38]	0.70	3.68
Yuji [37]	3.80	3.70
Devi and Gnanavel [6]	1.32–5.0	3–3.84
Dash et al. [3]	0.80–1.32	3–3.19
Kim et al. [41]	1.68	3.31–3.37
Gao et al. [42]	1.2–1.6	3.28–3.41

5 Durability of Concrete with Steel Slag

The density of steel slag is between 3.3 and 3.6 g/cm^3 and is a highly corrosion-resistant material. It means it will perform better in coastal areas as compared to normal concrete. Permeability plays a great role in case of durability, for lower percentage of steel slag around 15–20% permeability is less but in addition of steel slag between 30 and 45% the permeability is moderate [43]. So for a lower percentage of SS there will be less penetration of water and chemicals. SS improves cement paste and SS interaction thanks to its rough and porous surface [44]. which leads to higher compressive strength and durability. As steel slag contains a high amount of metal, it is less prone to abrasion, so it can be used as a wear course to improve performance. Overall it can be concluded that steel slag gives better durability then normal concrete at lower percentage of usage.

6 Benefits of Utilization of Steel Slag

Steel slag is a waste material for the steel industry and it can pollute the environment. So first of all the biggest benefit of utilization of SS is it will not pollute the environment. The cement industry itself produces 8% of total CO_2 produced in the world, by utilization of SS as replacement in construction materials it will reduce production of those materials which means less production of CO_2. Also, it has many benefits if we use it in concrete, for example, it improves the workability of concrete at the same mix proportion, it is easy to place and finish, at long term, it gives higher compressive strength as compared to normal concrete mix, its long term flexural strength is also greater than normal mix. By the usage of SS, the permeability of concrete can also be reduced. SS also has alkali-silica reaction mitigation properties. Usage of steel slag in concrete improves the durability and resilience of concrete.

7 Conclusion

Based on the detailed literature, it has been found that steel slag may be used in road and commercial buildings, as aggregate, coarse, and fine aggregate in concrete, and has a range of other applications. However, storage could pose a problem since a significant amount of material is still stored at treatment facilities. This poses a serious threat to the environment and is also economically detrimental. Recycling of waste could prove to be a game changer as it promotes sustainable development. Some of the major outcomes from this study is shown below;

- Specific bulk density increased approximately by 20–30% with concrete made with steel Slag when compared with conventional concrete.

- As coarse aggregate, steel slag proved to be more suitable due to its rough surface and physical properties.
- There are insignificant adverse effects on strength of traditional concrete when steel slag is substituted for natural aggregates up to 100%.
- An angular shape, free CaO content and rough surface of steel slag in concrete may cause concrete lead to expand and increase permeability, thereby reducing its durability. However, permeability also decreases if percentage replacement with fines is relatively less.
- The best result may be obtained at replacement of approximately 30% for high-strength silica-fume concrete.

References

1. K.L. Scrivener, R.J. Kirkpatrick, Innovation in use and research on cementitious material. Cem. Concr. Res. **38**(2), 128–136 (2008). https://doi.org/10.1016/j.cemconres.2007.09.025
2. A.S. Brand, J.R. Roesler, Steel furnace slag aggregate expansion and hardened concrete properties. Cem. Concr. Compos. **60**, 1–9 (2015). https://doi.org/10.1016/j.cemconcomp.2015.04.006
3. M.K. Dash, S.K. Patro, A.K. Rath, Sustainable use of industrial-waste as partial replacement of fine aggregate for preparation of concrete—a review. Int. J. Sustain. Built Environ. **5**(2), 484–516 (2016). https://doi.org/10.1016/j.ijsbe.2016.04.006
4. V.J. Ferreira et al., Evaluation of the steel slag incorporation as coarse aggregate for road construction: technical requirements and environmental impact assessment. J. Clean. Prod. **130**, 175–186 (2016). https://doi.org/10.1016/j.jclepro.2015.08.094
5. B. Pang, Z. Zhou, H. Xu, Utilization of carbonated and granulated steel slag aggregate in concrete. Constr. Build. Mater. **84**, 454–467 (2015). https://doi.org/10.1016/j.conbuildmat.2015.03.008
6. V. Subathra Devi, B. K. Gnanavel, Properties of concrete manufactured using steel slag. Procedia Eng. **97**, 95–104 (2014). https://doi.org/10.1016/j.proeng.2014.12.229
7. Y. Guo, J. Xie, W. Zheng, J. Li, Effects of steel slag as fine aggregate on static and impact behaviours of concrete. Constr. Build. Mater. **192**, 194–201 (2018). https://doi.org/10.1016/j.conbuildmat.2018.10.129
8. Y. Guo, J. Xie, J. Zhao, K. Zuo, Utilization of unprocessed steel slag as fine aggregate in normal- and high-strength concrete. Constr. Build. Mater. **204**, 41–49 (2019). https://doi.org/10.1016/j.conbuildmat.2019.01.178
9. J. Liu, R. Guo, Applications of steel slag powder and steel slag aggregate in ultra-high performance concrete. Adv. Civ. Eng. https://doi.org/10.1155/2018/1426037
10. S. Saxena, A.R. Tembhurkar, Impact of use of steel slag as coarse aggregate and wastewater on fresh and hardened properties of concrete. Constr. Build. Mater. **165**, 126–137 (2018). https://doi.org/10.1016/j.conbuildmat.2018.01.030
11. L. Kang, H. L. Du, H. Zhang, W. L. Ma, Systematic research on the application of steel slag resources under the background of big data. Complexity. https://doi.org/10.1155/2018/6703908
12. İ Yüksel, A review of steel slag usage in construction industry for sustainable development. Environ. Dev. Sustain. **19**(2), 369–384 (2017). https://doi.org/10.1007/s10668-016-9759-x
13. L.V. Fisher, A.R. Barron, The recycling and reuse of steelmaking slags—a review. Resour. Conserv. Recycl. **146**(March), 244–255 (2019). https://doi.org/10.1016/j.resconrec.2019.03.010

14. X. Zhang, J. Chen, J.J. Jiang, J. Li, R.D. Tyagi, R.Y. Surampalli, The potential utilization of slag generated from iron- and steelmaking industries: a review. Environ. Geochem. Health **42**(5), 1321–1334 (2020). https://doi.org/10.1007/s10653-019-00419-y
15. K. Arun, S. Raguvaran, M. S. Narayanan, R. Thangapandiyan, R. Venkateshwaran, *Comparitive Study of Steel Slag with Coarse Aggregate and Testing its Binding Properites with Bitumen* (2018)
16. I. Bhavan, *58th Edition Iron, Steel and Scrap and Slag (Advance Release) Government of India Ministry of Mines Indian Bureau Of Mines* (2019)
17. H. Qasrawi, F. Shalabi, I. Asi, Use of low CaO unprocessed steel slag in concrete as fine aggregate. Constr. Build. Mater. **23**(2), 1118–1125 (2009). https://doi.org/10.1016/j.conbuildmat.2008.06.003
18. M. Maslehuddin, A.M. Sharif, M. Shameem, M. Ibrahim, M.S. Barry, Comparison of properties of steel slag and crushed limestone aggregate concretes. Constr. Build. Mater. **17**(2), 105–112 (2003). https://doi.org/10.1016/S0950-0618(02)00095-8
19. L. Muhmood, S. Vitta, D. Venkateswaran, Cementitious and pozzolanic behavior of electric arc furnace steel slags. Cem. Concr. Res. **39**(2), 102–109 (2009). https://doi.org/10.1016/j.cemconres.2008.11.002
20. A. Piemonti, A. Conforti, L. Cominoli, S. Sorlini, A. Luciano, G. Plizzari, Use of iron and steel slags in concrete: state of the art and future perspectives. Sustain. **13**(2), 1–27 (2021). https://doi.org/10.3390/su13020556
21. P. Kothai, D. Malathy, *Utilization of Steel Slag in Concrete as a Partial Replacement Material for Fine Aggregates* (2014)
22. A. Rai, J. Prabakar, C.B. Raju, R.K. Morchalle, Metallurgical slag as a component in blended cement. Constr. Build. Mater. **16**(8), 489–494 (2002). https://doi.org/10.1016/S0950-0618(02)00046-6
23. C. Pellegrino, V. Gaddo, Mechanical and durability characteristics of concrete containing EAF slag as aggregate. Cem. Concr. Compos. **31**(9), 663–671 (2009). https://doi.org/10.1016/j.cemconcomp.2009.05.006
24. T. Subramani, G. Ravi, Experimental investigation of coarse aggregate with steel slag in concrete. IOSR J. Eng. **5**(5), 64–73 (2015). Available: www.iosrjen.org
25. N. Palankar, A. U. Ravi Shankar, B. M. Mithun, Durability studies on eco-friendly concrete mixes incorporating steel slag as coarse aggregates. J. Clean. Prod. **129**, 437–448 (2016). https://doi.org/10.1016/j.jclepro.2016.04.033
26. J. P. Patel, *Broader Use of Steel Slag Aggregates in Concrete* (Cleveland State University, Cleveland, vol. 7, no. 6, 2008), pp. 1–14
27. J.T. San-José, I. Vegas, I. Arribas, I. Marcos, The performance of steel-making slag concretes in the hardened state. Mater. Des. **60**, 612–619 (2014). https://doi.org/10.1016/j.matdes.2014.04.030
28. Q. Wang, J. Yang, P. Yan, Cementitious properties of super-fine steel slag. Powder Technol. **245**, 35–39 (2013). https://doi.org/10.1016/j.powtec.2013.04.016
29. R. Dineshkumar, S. Suchithra, Properties of concrete with partial replacement of steel slag with fine aggregate. 2017 Int. Conf. Energy, Commun. Data Anal. Soft Comput. ICECDS **2017**, 3850–3852 (2018). https://doi.org/10.1109/ICECDS.2017.8390185
30. K. Olonade, M. Kadiri, P. Aderemi, Performance of steel slag as fine aggregate in structural concrete. Niger. J. Technol. **34**(3), 452 (2015). https://doi.org/10.4314/njt.v34i3.4
31. A. Sekaran, M. Palaniswamy, S. Balaraju, A study on suitability of EAF oxidizing slag in concrete: an eco- friendly and sustainable replacement for natural coarse aggregate. Sci. World J. (2015). https://doi.org/10.1155/2015/972567
32. H. Motz, J. Geiseler, Products of steel slags an opportunity to save natural resources. Waste Manag. **21**(3), 285–293 (2001). https://doi.org/10.1016/S0956-053X(00)00102-1
33. S. Kourounis, S. Tsivilis, P.E. Tsakiridis, G.D. Papadimitriou, Z. Tsibouki, Properties and hydration of blended cements with steelmaking slag. Cem. Concr. Res. **37**(6), 815–822 (2007). https://doi.org/10.1016/j.cemconres.2007.03.008

34. C. Shi, Steel slag—its production, processing, characteristics, and cementitious properties. J. Mater. Civ. Eng. **16**(3), 230–236 (2004). https://doi.org/10.1061/(asce)0899-1561(2004)16:3(230)
35. G. Adegoloye, A.L. Beaucour, S. Ortola, A. Noumowe, Mineralogical composition of EAF slag and stabilised AOD slag aggregates and dimensional stability of slag aggregate concretes. Constr. Build. Mater. **115**, 171–178 (2016). https://doi.org/10.1016/j.conbuildmat.2016.04.036
36. E. Anastasiou, K. Georgiadis Filikas, M. Stefanidou, Utilization of fine recycled aggregates in concrete with fly ash and steel slag. Constr. Build. Mater. **50**, 154–161 (2014). https://doi.org/10.1016/j.conbuildmat.2013.09.037
37. W. Yuji, The effect of bond characteristics between steel slag fine aggregate and cement paste on mechanical properties of concrete and mortar
38. S.I. Abu-Eishah, A.S. El-Dieb, M.S. Bedir, Performance of concrete mixtures made with electric arc furnace (EAF) steel slag aggregate produced in the Arabian Gulf region. Constr. Build. Mater. **34**, 249–256 (2012). https://doi.org/10.1016/j.conbuildmat.2012.02.012
39. A. Y. Mohamad, M. Jamil, N. I. M. Yusoff, M. R. Taha, M. R. Karim, S. M. Fadzil, Feasibility study of utilizing steel slag and cathode ray tube glass as aggregate replacement for road base. Int. J. Nanoelectron. Mater. **13**(Special Issue ISSTE2019), 129–136 (2020)
40. F. He, Y. Fang, J. Xie, J. Xie, Fabrication and characterization of glass-ceramics materials developed from steel slag waste. Mater. Des. **42**, 198–203 (2012). https://doi.org/10.1016/j.matdes.2012.05.033
41. K. Kim, S. Haeng Jo, N. Kim, H. Kim, Characteristics of hot mix asphalt containing steel slag aggregate according to temperature and void percentage. Constr. Build. Mater. **188**, 1128–1136 (2018). https://doi.org/10.1016/j.conbuildmat.2018.08.172
42. J. Gao, A. Sha, Z. Wang, Z. Tong, Z. Liu, Utilization of steel slag as aggregate in asphalt mixtures for microwave deicing. J. Clean. Prod. **152**, 429–442 (2017). https://doi.org/10.1016/j.jclepro.2017.03.113
43. Q. Wang, P. Yan, J. Yang, B. Zhang, Influence of steel slag on mechanical properties and durability of concrete. Constr. Build. Mater. **47**, 1414–1420 (2013). https://doi.org/10.1016/j.conbuildmat.2013.06.044
44. S. Wang, G. Zhang, B. Wang, M. Wu, Mechanical strengths and durability properties of pervious concretes with blended steel slag and natural aggregate. J. Clean. Prod. **271**, 122590 (2020). https://doi.org/10.1016/j.jclepro.2020.122590

The Utilization of Industrial Waste as a Stabilizing Agent—A Review

Mayadarshini Laishram, Davinder Singh, and Sanjeev Kumar

1 Introduction

With the ever-increasing population and urbanization, the choices of land to choose for construction become lesser and lesser. In most geotechnical projects, it is always not possible to acquire construction sites that will meet the design necessity without ground moderation. This proves to be a significant engineering problem. And hence, the idea of soil stabilization comes into play. Soil stabilization is a broad term used for any physical or chemical treatment of altering a natural soil to meet an engineering cause.

In India, Expansive soils, also known locally as Black Cotton soil (BCS) are spread over 5,18,000 km^2 of land [1]. Due to seasonal fluctuations in moisture content, BCS is exposed to significant shrinkage and swelling, which can cause significant structural damage. Chemical stabilization will be used on this soil, which is described as the process of combining and blending chemical additives to improve the soil's geotechnical properties. Generally, Calcium-based additives, such as lime and cement, are commonly used for stabilization to increase strength, reduce swelling, and even out the settlement. However, mounting concerns about carbon dioxide emissions and the resulting climate crisis necessitate the innovation of more sustainable soil stabilization techniques based on waste materials [2].

On the other hand, as the rate of industrialization increases, so does the rate of production of industrial waste, resulting in a slew of environmental challenges around its disposal [3]. In developing countries, the utilization of waste material in soil stabilization creates a sustainable platform for the management of waste [4–6]. The use of Granulated Blast Furnace Slag (GBS) as a stabilizing agent was found to have increased the strength and physical properties of soil [7]. Certain engineering

M. Laishram (✉) · D. Singh · S. Kumar
Dr. B. R. Ambedkar National Institute of Technology Jalandhar, Jalandhar 144011, India
e-mail: l.mayadarshini@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_22

properties like the CBR resulted in an increase in value with the addition of CS as an additive in the problematic soil [8]. Stabilizing with cement kiln dust (CKD) showed enhancement in soil mixture strength with values increased up to a certain factor [9]. The use of rice husk ash (RHA) with calcium carbide residue (CCR) as an additive shows great feasibility and effectiveness as a cementing material giving a good performance, better economy and disposal costs, and lesser distress to the environment [10]. Coal combustion fly ash (CFA) blended with an additive like cement can be used in varying quantities to acquire the best possible stabilizing mixture [11] (Fig. 1).

The stabilizing efficiency and sustainability of various industrial wastes with pozzolanic character (as shown in Fig. 2) will be explored in terms of varying engineering physical strength qualities in this article. In summary, the paper intends to give a full understanding of the feasibility and possible aspects of soil stabilization through the utilization of various industrial wastes that would otherwise be disposed of and would have taken up space in landfills.

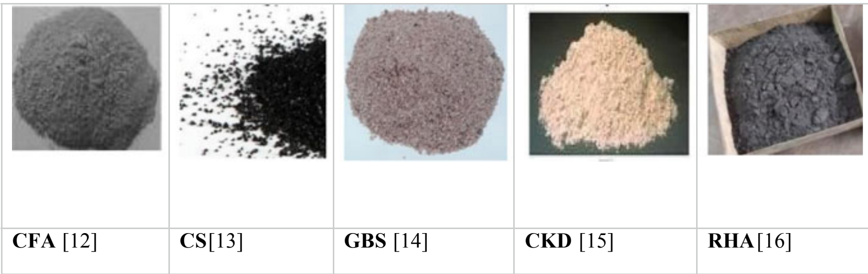


Fig. 1 Different types of industrial waste

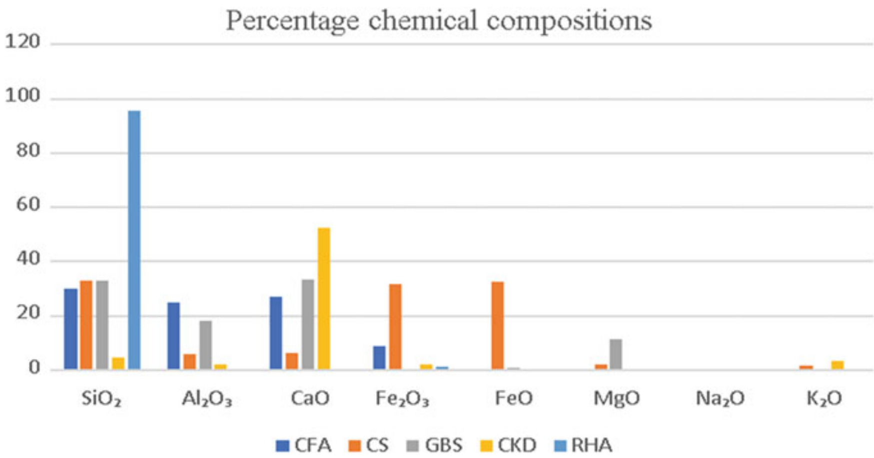


Fig. 2 Chemical composition of CFA [17], CS [18], GBS [19], CKD [20] and RHA [21]

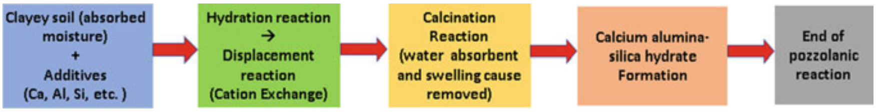


Fig. 3 The flow chart of pozzolanic reaction

2 Pozzolanic Reaction

The volume of clayey soils changes due to absorbed moisture, which forms a double diffused layer on the particles after contact with moisture. This leads to dispersion and flotation of the clayey particles forming voids and pores [2]. To close the gaps between the clayey soil particles, stabilizations of these soils are conducted using chemical additives. This can be attained by blending with a stabilizing agent containing Al, Ca, Si, etc. which causes a hydration reaction succeeded by a displacement reaction [22, 23]. Ca and Na-ions are then displaced during the calcination reaction. The entire process gives rise to a pozzolanic reaction, forming calcium alumina-silica hydrate as the final product, which is the main binding phase responsible for strength gain [24] (Fig. 3).

3 Effect of Industrial Waste on Geotechnical Properties of Soil

3.1 Coal Combustion Fly Ash (CFA)

Coal combustion fly ash is an industrial by-product obtained from the burning of coal for various purposes. In 2020, around 5% of electricity in India was generated by coal-fired thermal power plants [25]. The use of only CFA gives a negligible improvement in bearing capacity, owing to no pozzolanic reaction. In addition to secondary additives (such as cement, lime), there are visible improvements in the engineering properties [11]. The incorporation of CFA directly into soil reduces CBR because non-plastic fines replace plastic fines in the expansive soil, reducing cohesiveness [26]. As noted by Karami, lime was the best addition to enhance CBR, owing to its capability to activate CFA in the soil, promote pozzolanic reactions, and form cementitious materials [27] (Table 1).

3.2 Copper Slag

Copper slag is an industrial by-product formed during the pyrometallurgical processing of metals from copper concentrates. Approximately 2.2 tons of slag are

Table 1 The alteration in geotechnical properties of soil due to the addition of CBS

S. No.	% Added	Type	UCS (N/mm^2)	CBR (%)	MDD (gm/cm^3)	OMC (%)	PI (%)	Reference
1	15% CFA	Raw	–	3.20	1.73	19.2	–	[27]
	+Lime	Stabilized	–	2.9	1.8	18.8	–	
2	15% CFA	Raw	0.168	2.18	–	–	1.2	[11]
		Stabilized	0.177	2.26	–	–	1.4	
3	5% CFA+	Raw	0.500	–	2	22	30	[28]
	4% Lime	Stabilized	0.990	–	3	38	18	
4	10% CFA	Raw	0.31	25	1.79	17	–	[26]
		Stabilized	0.44	35	1.75	16	–	

Table 2 The alteration in geotechnical properties of soil due to the addition of CS

S. No.	% Added	Type	UCS (N/mm^2)	CBR (%)	MDD (gm/cm^3)	OMC (%)	PI (%)	Reference
1	3% CS	Raw		–	2.862	14	3.78	[29]
		Stabilized	–	–	2.280	12	5	
2	20% CS	Raw	–	7.50	1.597	12	–	[30]
		Stabilized	–	24.50	1.674	18	–	
3	20% CS	Raw	2.4	–	1.6	12	–	[13]
		Stabilized	3.4	–	2.1	7	–	
4	20% CS	Raw	–	–	1.570	18	–	[31]
		Stabilized	–	–	1.811	15.379	–	

generated per ton of copper produced. And around 37.8 million tons of CS are produced worldwide each year [18]. In their study, Shahiri and Ghasemi conclude that the use of CS decreases OMC and increases MDD, while the use of cement as a secondary additive reverses the effects. As CS absorbed water, the larger particles were able to penetrate the soil [13]. Gobinath reported an increase of up to 50% more in tensile strength on the use of CS as an additive. The noteworthy result is noticed in the CBR values of the soil, which is a result of the ceasing of the swell condition on the addition of CS [29]. The more addition of CS leads to higher MDD (up to 8.85% increase in MDD than the natural clay) resulting in a decrease in the plasticity [30] (Table 2).

3.3 Granulated Blast Furnace Slag (GBS)

GBS is a by-product of iron and steel production that is made by extinguishing molten iron slag from a blast furnace in water or steam, resulting in a glassy, granular product that is subsequently dried and grounded into a fine powder. In 2016, the production

Table 3 The alteration in geotechnical properties of soil due to the addition of GBS

S. No.	% Added	Type	UCS (N/mm^2)	CBR (%)	MDD (gm/cm^3)	OMC (%)	PI (%)	Reference
1	10% GBS+	Raw	<0.1	–	–	–	–	[33]
	1% cement	Stabilized	7.1	–	–	–	–	
2	20% GBS	Raw	1.02	3.12	1.75	8	11.26	[4]
		Stabilized	1.25	3.38	1.88	12	12.29	
3	12% GBS	Raw	1.18	8.14	1.72	11	17	[7]
		Stabilized	1.48	16.5	1.79	9.9	13.1	
4	12% GBS	Raw	1.34	–	1.6	22	18.4	[32]
		Stabilized	2.6	–	1.63	19.8	14	

of blast furnace slag in the world was 430 million tons. It's approximated to have produced 0.3–0.5 tons of slag per ton of pig iron. [19]. The addition to NaOH results in the formation of a cementitious compound, thereby increasing the UCS value as the proportion of GBS increases [7]. Pathak and Panday observed the PI and OMC values decrease while MDD increases with the addition of GBS. Even though there is improvement found in the soil on the addition of GBS, the values are not noteworthy. The study concludes GBS is a latent hydraulic material that requires an activator to disintegrate its glassy stage [32] (Table 3).

3.4 Cement Kiln Dust

The highly alkaline, solid, fine-grained industrial by-product extracted from cement kiln exhaust gas is referred to as CKD. The manufacturing of each ton of Portland Cement produces 54–200 kg of CKD. The global cement production was approximated to be 4.20 billion tons in 2019 [20]. As the need for cement as a construction material grows, vast production occurs, resulting in a large amount of CKD as a by-product. Thus, the use of CKD as a stabilizing agent becomes a sustainable cause. The inclusion of CKD, in various amounts, results in a considerable drop in PI. The highest PI decrease was observed with 10% CKD treated soil according to Rimal and Poudal [34]. The strength of the CKD stabilized soil increases gradually up to the 14th day but then increases dramatically by the 28th day. Amadi and Osu concluded that there is a delay in strength development during the initial stages of curing due to the initiation period required for the pozzolanic interaction between the chemical stabilizers and the soil particles to generate cementitious products [9] (Table 4).

Table 4 The alteration in geotechnical properties of soil due to the addition of CKD

S. No.	% Added	Type	UCS (N/mm^2)	CBR (%)	MDD (gm/cm^3)	OMC (%)	PI (%)	Reference
1	10% CKD	Raw	1.531	–	15.2	22.1	20	[34]
		Stabilized	10.156	–	16.9	24.2	–	
2	12.5% CKD	Raw	–	0.55	1.7	18	81.52	[35]
		Stabilized	–	16.5	1.73	20	51	
3	16% CKD	Raw	1.1	–	–	14.8	38.09	[9]
	+Quarry	Stabilized	6.2	–	–	13.4	19	
4	15% CKD	Raw	0.83	1.65	1.68	20	32.3	[36]
		Stabilized	2.6	8.03	1.72	19.3	15.2	

3.5 Rice Husk Ash (RHA)

RHA is an agricultural by-product obtained from the burning of rice husk. With agriculture providing a living for more than half of India's population, the country produces around 120 million tons of rice paddy each year, resulting in 24 million tons of rice husk per year [16]. Liu observed that the swelling properties can be hugely reduced by increasing RHA content with CCR as a secondary additive [10]. On increasing the proportion of the RHA, the OMC increases which is due to the elevation in mix proportion and lowering in the quantity of free silt [21]. There is as much as 3.1 times increase in strength of soil mixed with 15% RHA after curing for 28 days [10] (Table 5).

Table 5 The alteration in geotechnical properties of soil due the addition of RHA

S. No.	% Added	Type	UCS (N/mm^2)	CBR (%)	MDD (gm/cm^3)	OMC (%)	PI (%)	Reference
1	12%	Stabilized	1.1	–	1.925	13	–	[16]
	RHA	Raw	1.52	–	1.921	13.2	–	
2	10%	Stabilized	1.02	3.12	1.75	8	11.26	[4]
	RHA	Raw	1.07	3.29	1.67	8	31.56	
3	15%	Stabilized	0.9	–	1.47	–	–	[10]
	RHA + CCR	Raw	3.2	–	–	–	–	–
4	10%	Stabilized	1.5	6.5	1.64	17	12.2	[21]
	RHA	Raw	1.68	12	1.56	20	10	

4 Conclusion

An overview of various research papers on industrial waste used as stabilizing agents is presented in this paper. The majority of the industrial waste was found to improve certain soil geotechnical properties. However, the improvements found on the use of industrial waste as an additive were not enough to be recommended for use. For remarkable results, most of the papers recommended the use of secondary additives like lime, cement, enzymes, or quarry. The following are notable features of certain industrial waste and their effects on soil geotechnics or environmental impact.

- CFA alone does not significantly promote strength; however, combining it with lime and cement can lead to noticeable improvements. CFA has certain disadvantages, one of which is the fact that transportation is mostly limited to within 300 km of the Thermal Power Plant.
- In most of the studies, the use of CS as an additive increases MDD, resulting in a lower PI. And due to the ceasing of swell properties, it is found to have improved the CBR of the soil.
- GBS demonstrates improvement in UCS, CBR, and MDD of the soil, but it cannot be relied upon alone. As a result, it is recommended to use an activator when adding GBS as an additive, because GBS is a latent hydraulic material that requires activation to break the glassy phase.
- In tandem with the ever-increasing demand for cement, the manufacturing of CKD as a by-product has also increased. The presence of CKD as a stabilizing agent is shown to reduce the PI significantly. And most of the improvements in strength occur around the 28th curing day of being stabilized with CKD.
- India being an agriculture dominant society. RHA is one of the most vastly available by-products in every part of the country. The use of RHA alone does not result in significant increases in UCS value, but the inclusion of compounds such as CCR results in a significant rise in value.

A lack of systematic and independent research articles made it difficult for this paper to come to a valid conclusion. It was found that all industrial wastes improved the quality of soils up to a certain extent through better economic and environmental efficiency. This paper identifies a future need of the research on the protocols of obtaining the waste for public utilization, mass availability of materials, in situ engineering properties, durability, and sustainability issue of the industrial waste stabilized soil.

References

1. C. McDowell, Stabilization of soils with lime, lime-flyash, and other lime reactive materials. Highw. Res. Board Bull., 60–66 (1959), [Online]. Available: http://onlinepubs.trb.org/Onlinepubs/hrbbulletin/231/231-004.pdf

2. S.Y. Amakye, S.J. Abbey, Understanding the performance of expansive subgrade materials treated with non-traditional stabilisers: a review. Clean. Eng. Technol. **4**, 100159 (2021). https://doi.org/10.1016/J.CLET.2021.100159
3. S. Kumar, D. Singh, Municipal solid waste incineration bottom ash: a competent raw material with new possibilities. Innov. Infrastruct. Solut. **6**(4), 1–15 (2021). https://doi.org/10.1007/S41062-021-00567-0
4. R. Sanjay, C. Nivetha, D.S. Vijayan, D. Parthiban, Utilization of waste materials in soil stabilization. Int. J. Innov. Technol. Explor. Eng. **9**(2), 4459–4463 (2019). https://doi.org/10.35940/ijitee.b8126.129219
5. P. Alam, D. Singh, S. Kumar, Incinerated municipal solid waste bottom ash bricks: a sustainable and cost-efficient building material. Mater. Today Proc. (2021). https://doi.org/10.1016/J.MATPR.2021.07.346
6. D. Singh, A. Kumar, Geo-environmental application of municipal solid waste incinerator ash stabilized with cement. J. Rock Mech. Geotech. Eng. **9**(2), 370–375 (2017). https://doi.org/10.1016/j.jrmge.2016.11.008
7. L. Yadu, R.K. Tripathi, Effects of granulated blast furnace slag in the engineering behaviour of stabilized soft soil. Procedia Eng. **51**, 125–131 (2013). https://doi.org/10.1016/j.proeng.2013.01.019
8. A. N. K. Saranya, K. Rohini, A review on utilization of copper slag and silica fume in geotechnical engineering. Int. Res. J. Eng. Technol. **4**(2), 1836–1838 (2017), [Online]. Available: https://irjet.net/archives/V4/i2/IRJET-V4I2361.pdf
9. A.A. Amadi, A.S. Osu, Effect of curing time on strength development in black cotton soil—quarry fines composite stabilized with cement kiln dust (CKD). J. King Saud Univ. Eng. Sci. **30**(4), 305–312 (2018). https://doi.org/10.1016/J.JKSUES.2016.04.001
10. Y. Liu et al., Stabilization of expansive soil using cementing material from rice husk ash and calcium carbide residue. Constr. Build. Mater. **221**, 1–11 (2019). https://doi.org/10.1016/J.CONBUILDMAT.2019.05.157
11. P.G. Kumar, S. Harika, Stabilization of expansive subgrade soil by using fly ash. Mater. Today Proc. **45**, 6558–6562 (2021). https://doi.org/10.1016/J.MATPR.2020.11.469
12. X. Dong et al., Facile use of coal combustion fly ash (CCFA) as Ni-Re bime-tallic catalyst support for high-performance CO_2 methanation. Waste Manag. **107**, 244–251 (2020). https://doi.org/10.1016/j.wasman.2020.04.014
13. J. Shahiri, M. Ghasemi, Utilization of soil stabilization with cement and copper slag as subgrade materials in road embankment construction (Vol. 5, no. 1, 2017)
14. I. Yuksel, Blast-furnace slag. Waste Suppl. Cem. Mater. Concr. Charact. Prop. Appl., 361–415 (2018). https://doi.org/10.1016/B978-0-08-102156-9.00012-2
15. H.M. Saleh, F.A. El-Saied, T.A. Salaheldin, A.A. Hezo, Macro- and nanomaterials for improvement of mechanical and physical properties of cement kiln dust-based composite materials. J. Clean. Prod. **204**, 532–541 (2018). https://doi.org/10.1016/J.JCLEPRO.2018.08.303
16. S. Verma, V.S. Khanduri, A. Mittal, Stabilization of colluvial soil using rice husk ash and micro silica powder. Mater. Today Proc. **32**, 819–823 (2020). https://doi.org/10.1016/J.MATPR.2020.04.019
17. V. Gupta, S. Siddique, S. Chaudhary, Characterization of different types of fly ash collected from various sources in Central India. Mater. Today Proc. **18**, 5076–5080 (2019). https://doi.org/10.1016/J.MATPR.2019.07.503
18. T.C. Phiri, P. Singh, A.N. Nikoloski, The potential for copper slag waste as a resource for a circular economy: a review—part II. Miner. Eng. **172**, 107150 (2021). https://doi.org/10.1016/J.MINENG.2021.107150
19. S.K. Tripathy, J. Dasu, Y.R. Murthy, G. Kapure, A.R. Pal, L.O. Filippov, Utilisation perspective on water quenched and air-cooled blast furnace slags. J. Clean. Prod. **262**, 121354 (2020). https://doi.org/10.1016/J.JCLEPRO.2020.121354
20. A. A. Saleh, H. A. Abdel-Gawwad, M. G. Abd EL-Moghny, M. S. El-Deab, The sustainable utilization of weathered cement kiln dust in the cleaner production of alkali activated binder incorporating glass sludge. Constr. Build. Mater. **300**, 124308 (2021). https://doi.org/10.1016/J.CONBUILDMAT.2021.124308

21. A. Kumar Yadav, K. Gaurav, R. Kishor, S. K. Suman, Stabilization of alluvial soil for subgrade using rice husk ash, sugarcane bagasse ash and cow dung ash for rural roads. Int. J. Pavement Res. Technol. **10**(3), 254–261 (2017). https://doi.org/10.1016/J.IJPRT.2017.02.001
22. D. Singh, A. Kumar, Factors affecting properties of MSWI bottom ash employing cement and fiber for geotechnical applications. Environ. Dev. Sustain. **22**(7), 6891–6905 (2020). https://doi.org/10.1007/s10668-019-00519-w
23. D. Singh, A. Kumar, Performance evaluation and geo-characterization of municipal solid waste incineration ash material amended with cement and fibre. Int. J. Geosynth. Gr. Eng. **3**(2) (2017). https://doi.org/10.1007/s40891-017-0094-6
24. K.C. Onyelowe, M.E. Onyia, D.B. Van, H. Baykara, H.U. Ugwu, Pozzolanic reaction in clayey soils for stabilization purposes: a classical overview of sustainable transport geotechnics. Adv. Mater. Sci. Eng. **2021**, 1–7 (2021). https://doi.org/10.1155/2021/6632171
25. B. K. Saikia, J. C. Hower, N. Islam, A. Sharma, P. Das, Geochemistry and petrology of coal and coal fly ash from a thermal power plant in India. Fuel. **291**, 120122 (2021). https://doi.org/10.1016/j.fuel.2020.120122
26. R. Renjith, D. Robert, S. Setunge, S. Costa, A. Mohajerani, Optimization of fly ash based soil stabilization using secondary admixtures for sustainable road construction. J. Clean. Prod. **294**, 126264 (2021). https://doi.org/10.1016/J.JCLEPRO.2021.126264
27. H. Karami, J. Pooni, D. Robert, S. Costa, J. Li, S. Setunge, Use of secondary additives in fly ash based soil stabilization for soft subgrades. Transp. Geotech. **29**, 100585 (2021). https://doi.org/10.1016/J.TRGEO.2021.100585
28. M. S. Deepak, S. Rohini, B. S. Harini, G. B. G. Ananthi, Influence of fly-ash on the engineering characteristics of stabilised clay soil. Mater. Today Proc. **37**(Part 2), 2014–2018 (2021). https://doi.org/10.1016/J.MATPR.2020.07.497
29. R. Gobinath, I. Akinwumi, G.P. Ganapathy, R. Mithuna, Compaction and shear strength enhancement of weak soil by copper slag addition. Mater. Today Proc. **39**, 834–838 (2021). https://doi.org/10.1016/J.MATPR.2020.10.092
30. R. Ekkabaram, *Enhancing the Clay Soil Characteristics using Copper Slag Stabilization Enhancing the Clay Soil Characteristics using Copper Slag Stabilization* (Vol. 12, 2016), pp. 1–6
31. R. C. Gupta, B. S. Thomas, P. Gupta, L. Rajan, D. Thagriya, An experimental study of clayey soil. Int. J. Struct. Civ. Eng. Res. **1**(1), 110–119 (2012), [Online]. Available: https://ishitvtech.in/pdf/sajet-vol-3-no7-15.pdf
32. A. K. Pathak, V. Pandey, K. M. J. P. Singh, *Soil Stabilisation Using Ground Granulated Blast Furnace Slag* (Vol. 4, no. 5, 2014), pp. 164–171
33. T. Wattez, C. Patapy, L. Frouin, J. Waligora, M. Cyr, Interactions between alkali-activated ground granulated blastfurnace slag and organic matter in soil stabilization/solidification. Transp. Geotech. **26**, 100412 (2021). https://doi.org/10.1016/J.TRGEO.2020.100412
34. S. Rimal, R.K. Poudel, D. Gautam, Experimental study on properties of natural soils treated with cement kiln dust. Case Stud. Constr. Mater. **10**, e00223 (2019). https://doi.org/10.1016/J.CSCM.2019.E00223
35. E. A. Adeyanju, C. A. Okeke, Clay soil stabilization using cement kiln dust. IOP Conf. Ser. Mater. Sci. Eng. **640**(1) (2019). https://doi.org/10.1088/1757-899X/640/1/012080
36. J. Sudheer Kumar, U. Janewoo, Stabilization of expansive soil with cement Kiln Dust and RBI grade 81 at subgrade level. Geotech. Geol. Eng. **34**(4), 1037–1046 (2016). https://doi.org/10.1007/s10706-016-0024-8

Sustainable Infrastructure Engineering and Others

Characterisation of Microsurfacing Mix Design: A Review

Anmol Tyagi, Rajiv Kumar, and Kanish Kapoor

1 Introduction

The significance of road infrastructure in every country's social and economic growth is critical. As of April 2019, India has the world's second-largest road network, with 142,126 km of national roadway. The two elements of road development are the construction of new roads and the maintenance and preservation of existing highways. To maintain a high level of quality, it is essential to do preventative maintenance on road pavements before they are irreparably damaged. According to studies, timely preventive maintenance of any road may save money and prolong the life of the pavement [1].

Microsurfacing is a kind of cost-effective and environmentally friendly pavement preventative maintenance method that has become a popular sustainable technology. Microsurfacing is most often utilised in flexible pavement, although it may also be used in stiff pavement with minor changes. Microsurfacing is the process of applying a combination of crumpled mineral aggregate, mineral filler, water, and a hardening-controlling agent to an asphalt emulsion. In a semi-liquid condition, this mixture is applied using specialised paving equipment [2]. When the combination is applied, it undergoes a chemical transformation and settles rapidly, resulting in a uniform layer of thick cold mix material that allows traffic to resume in two hours. The microsurfacing mix cures and advances strength over time as an outcome of the chemical interaction between the rapid-setting emulsion and the aggregate surface. By adsorbing on the aggregate surface, the emulsifier creates a lipophilic surface.

A. Tyagi (✉) · K. Kapoor
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, G. T. Road, Amritsar Bypass, Jalandhar, Punjab 144011, India
e-mail: anmoltyagi436@gmail.com

R. Kumar
CSIR-Central Road, Research Institute, Mathura Road, New Delhi 110025, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_23

By flocculating on the aggregate surface and dislodging water, the asphalt droplets form a layer around the aggregates [3].

Despite the fact that microsurfacing behaviour is known to be reliant on its components, few studies have looked at how to measure micro surfacing behaviour during mix design. Several aspects must be allocated during mix design, including emulsifier dosage, asphalt type, solvent, filler features, and mineral filler category and dose. Several studies have shown that there is a small microsurfacing behaviour which may be significantly altered by changes in microsurfacing components such as aggregate gradation, emulsion, additive, and filler [3]. Due to complex chemical interactions, mixing microsurfacing has proved to be a challenging process, and forecasting the behaviour of microsurfacing mix has proven to be problematic. Even the ASTM and ISSA microsurfacing mix design methods explicitly indicate that they should only be used as a reference for mix design [4].

Microsurfacing is one of many preventative maintenance methods that are gaining popularity these days as a result of its environmentally friendly nature and significant benefits in mending pavement surface conditions. Microsurfacing has been subjected to a life cycle analysis, which clearly shows that it outperforms all other PM methods in terms of environmental performance. Microsurfacing has the lowest energy usage, saving about 40% more energy than hot mix overlay, according to the BASF Corporation's eco-efficiency study [5].

2 Motivation and Objective

The study's goal is to better comprehend microsurfacing mixing technique and critically evaluate material optimisation for microsurfacing. What effect does changing a component of microsurfacing have on its performance, and what is the optimal amount of each parameter to employ to increase efficiency of microsurfacing treatment?

This article also encourages readers to learn about microsurfacing life cycle evaluation as well as its analysis and environmental effect.

The primary goal of this research is to examine many aspects of microsurfacing mix design, such as its environmental impact, components of microsurfacing, mix process difficulties, and advantages and disadvantages compared to alternative pavement treatments.

3 Advantage of Microsurfacing

When utilised for both pavement preservation and preventive maintenance, microsurfacing offers a number of benefits over conventional PM methods. It is a tried-and-true technique for resurfacing as a wearing course [6].

- It is less costly when compared to the hot mix treatment.
- A smooth surface that does not interfere with the existing profile.
- Prevents pavement deterioration due to oxidation induced by polymer emulsion.
- It slows the occurrence of failures.
- Lessens the amount of maintenance that has to be done on a regular basis.
- The route may be open to traffic in two hours with little damage to current road.
- There will be no problems with drainage.
- The mixing and laying are both done at the same time.

4 Disadvantage of Microsurfacing

- Bituminous microsurfacing cannot use if the road surface or air temperature is below 10 °C and dropping.
- Microsurfacing is not done while its raining or the air temperature is anticipated to dip lower than freezing within 24 h after use.
- Bituminous mix may be used when the road surface and air temperatures are beyond 7 °C and increasing, or over 10 °C.
- If the surface or air temperature is less than 10 °C, microsurfacing should be halted.

5 Mix Design Practice for Microsurfacing

According to the literature study, the optimum amount of each component should be used to guarantee microsurfacing durability. Various standard values for microsurfacing mix design have been developed by ISSA and MoRTH.

5.1 Material Selection

Aggregate attributes such as mineralogical structure, clarity, clay percentage, soundness, corrosion resistance, and reactivity have a main impact on the breaking procedure and performance due to the rapid-setting features of microsurfacing mix.

In microsurfacing mixes, cationic emulsions are frequently used. The composition of the constituents employed in its making, such as emulsifier variety and amount, total acidity, binder type, and content, determines the emulsion's properties. Emulsion is a thermally recursive system that is unstable because to high interfacial pressure between the bitumen and water phases [3].

Mineral filler, like aggregates and emulsion, contributes to the efficacy of microsurfacing by ensuring adequate fracture and crack resistance, mastic stiffness, and segregation reduction.

Table 1 Physical properties of aggregate

Test	Test method		Specifications
	AASHTO	ASTM	
Sand equivalent value of soils	T176	D 2419	45 minimum
Soundness of aggregate by using sodium sulphate or magnesium sulphate	T104	C 88	15% maximum w/NA2SO4 25% maximum w/MgSO4
Resistance to degradation of small size coarse aggregate by abrasion and impact in the Los Angeles machine	T96	C 131	35% maximum

As specified by the ISSA and MoRTH, other components, such as water filler, are also used with these components. Several kinds of materials, such as fly ash, rubber powder, and waste material, may be utilised to enhance the engineering characteristics of microsurfacing, according to a literature review.

Different specification like MoRTH, ISSA, IRC:SP:100-2014 AND, IRC:SP:81-2008 are used in microsurfacing mix design.

5.2 Aggregate Gradation

The aggregate should be crumpled stone, such as granite, sandstone, chat, or another high-quality material, or a combination. The smooth textured crusher fines must have a water absorption rate of less than 1.25%. The aggregate must be grey in colour, devoid of organic waste, other hazardous elements, and clay balls, and it must be clean.

The aggregate gradation in the mix must be any of the types listed below.

Class I: aggregates are designed to fill surface gaps, repair minor surface distresses, and provide weather protection. Fracture penetration is feasible due to the fineness of this combination.

Class II: aggregate is used to fill surface cracks, repair more serious surface distresses, seal, and produce a long- lasting wearing upper surface.

Class III: This gradation of aggregate offers the best skid resistance and durability. This surface is suitable for severely travelled pavements, rut filling, and usage on extremely textured surfaces when bigger aggregate is required to fill gaps [6].

If there is too much granular material or clay balls, the task will be stopped, and aggregate follows some physical properties standards as shown in Table 1.

5.3 Emulsion

The strength of microsurfacing is determined by the asphalt binder [7].

Emulsion is a two-phase arrangement with asphalt and water as the discrete and constant phases, respectively. In the manufacture of emulsion, bitumen, water, emulsifiers, additives, solvents, bond boosters, and either $CaCl_2$ or NaCl, are often used.

Cationic emulsions are the most common cationic emulsions used in microsurfacing mix creation. It is typically found in a neutral basic form that has to be acidified to become water soluble and positively charged [8].

5.4 Mineral Filler and Additive

Mineral filler may improve homogeneity and change the breaking and curing properties of a mixture. Portland cement, hydrated lime, sandstone dust, fly ash, or any appropriate filler that satisfies ASTM D 242 requirements must be followed if the mix plan asks for it.

Additives are also utilised in the design of microsurfacing mixes to speed up or slow down the mixing process, depending on MoRTH.

To improve the characteristics of a microsurfacing mix, mineral fillers such as fly ash, Portland cement, industrial waste, rubber powder, and fibres may be used.

5.5 Mixing and Compaction

The microsurfacing mix may be prepared either onsite or in the field.

The availability of resources and transportation choices is the main determinants. The mixing procedure should be identical to that performed in the laboratory. Microsurfacing mixture should be produced in a concrete drum mixer and laid by hands to the requisite thickness since microsurfacing pavers cannot be used in rural India due to a lack of finances. On a country road, there are several different types of mixing that may be used [6]:

- Mixing in batches,
- Continuous blending,
- Mixing by hand.

5.6 Effect of Variation of Components on Mix Properties

To increase the efficiency of microsurfacing mix design, a lot of literature review has been done and with different component behaviours of microsurfacing mix have been analysed.

Different components impart different properties in the microsurfacing mix, and hence, to analyses the change in microsurfacing, different parameters of microsurfacing mix such as consistency, breaking time, we track abrasion, etc., which were analysed.

The effect of use of different materials in microsurfacing mix can be explained as following.

5.7 Variation in Aggregate Gradation

With the assistance of reliability analysis, which indicates the likelihood that the pavement will meet the performance requirements throughout the course of its design life? A total of ten distinct aggregate gradation combinations were chosen, with the first five based on specification limitations and the remaining five created at random using Monte Carlo simulation. The overall surface area of aggregates and the inorganic filler concentration in the mixture were the main contributors to the variability. Each test's stated limitations were used to perform a reliability study of the test parameters. The dependability of each experiment parameter was determined to be above than 90%. The total dependability, which took into account all of the test factors, was 73%. When aggregate gradation have a tendency to a lesser specification limit was removed, the dependability of the microsurfacing mix satisfying all performance criteria rose to 90%. Furthermore, each test parameter's individual dependability was greater than 95%. Microsurfacing blend with a lower total surface area and lower mineral filler percentage should be avoided throughout the manufacturing phase of microsurfacing mix to guarantee better dependability [9].

5.8 Use of Fly Ash in Microsurfacing

Fly ash is a common industrial waste that may be utilised to replace cement in microsurfacing mixes at a lower cost. When fly ash was added to microsurfacing mix, substantial technical and economic advantages were discovered, as seen in Fig. 1.

The findings indicate that fly ash is more active than cement, which is beneficial when microsurfacing is done at low temperatures. Furthermore, since fly ash has a greater activity than cement, it requires fewer additives.

When the initial aggregate mixture has a high amount of filler, this has a beneficial impact on the total filler content. As a result, the fly ash by-product, which has a significant environmental impact, may be utilised as a substitute for cement in microsurfacing. Fly ash lowers the total cost of microsurfacing [10].

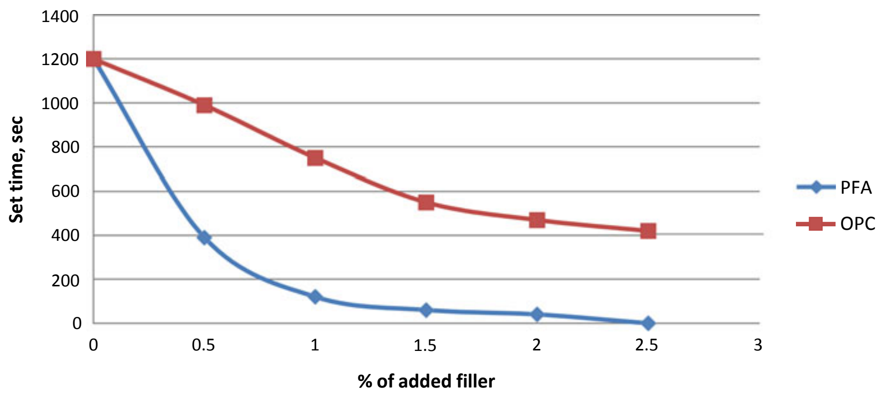


Fig. 1 PFA and OPC behaviour

5.9 *Use of Rubber Powder*

Because the practice of rubber powder in the microsurfacing is a relatively recent research in the area of microsurfacing, only a few literature reviews have been conducted. The International Slurry Surfacing Association's ISSA A143 requirement was used to evaluate the performance of microsurfacing mixes with various quantities of crumb rubber. As a substitute for aggregates, 0.5–3% crumb rubber with a grain magnitude of maximum 0.33 mm was utilised. The rubber powder utilised in this research contains six distinct quantities, which are employed with two kinds of grading, passing through 50 and 100 sieves. Table 2 shows the chemical makeup of rubber powder [11].

The 14% bitumen blend with 0.5% crumb rubber produced the greatest results among various quantities of rubber powder, and using this quantity of crumb rubber decreased the quantity of optima.

Table 2 Component used in mix

Material	Percentage (%)
Rubber	55
Carbon black	30
Textile	2
Sulphur	1
Oxidize zinc	1
Additive	11

5.10 Use of Waste Material in Microsurfacing Mix

The cost of microsurfacing mix design may be effectively lowered by using waste material. Waste materials such as pulverised fuel ash (PFA), red porphyry sand, artificial aggregates, steel slag, crumb rubber, and smashed glass were used in this research. Plastic cells were shown to substantially decrease shear distortions of CBEMs under loading throughout their early lifetimes, according to the findings. Plastic grids in the top layer of a two-layer cold mix structure proved to be highly promising, and the addition of 1–2% cementation materials was shown to be critical for enhancing CBEM performance. Steel slags may be hazardous when used as coarse aggregate in CBEMs. Throughout a 40'C curing regime, cracks were found in samples containing steel slag, which were thought to be produced by the volume growth of the steel slag under wet circumstances [12].

5.10.1 Validation of Filler Using Machine Learning

Machine learning methods are utilised in this research to forecast different amounts of substitute filler used in microsurfacing mix composition. SVM, ANN, and isotonic regression are used to forecast the compositions of unconventional fillers such as copper slag, fly ash, and high calcium fly ash. Mixing time, cohesion (30 min), cohesion (60 min), set time, and wet track abrasion loss are all utilised as experimental inputs to determine the appropriateness of each trial mix.

The results indicate that the lowest and highest values of all the fillers determined experimentally were 0% and 4%, respectively. For the prediction of microsurfacing mix composition, Table 3 provides the least and extreme values of inputs, as well as different filler compositions [13].

Table 3 Result of machine learning technique

	Filler composition loss (%)		Mixing time (sec)		Cohesion (30 min) kg.cm		Set time (sec)		Wet track abrasion loss (g/m^2)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Fly ash	0	4	156	667	2	26	234	1067	347	841
High calcium ash	0	4	45	566	5	29	72	906	201	695
Copper slag	0	4	57	578	3	27	91	925	221	715

6 Challenges in Microsurfacing Mix Procedure

It is difficult to anticipate the behaviour of microsurfacing mix because of the chemical complexity of the emulsion employed in it. To understand the behaviour of microsurfacing mix with different components such as filler, water, additive, and asphalt type, a lot of literature review was done, and to analyse the behaviour of mix, different types of tests such as consistency test, wet track abrasion test, and cohesion test were performed. Balling, raid breaking, inconsistent setup, and other issues were discovered in the.

Nishant Bhargava and his colleagues replaced the filler to solve the problem of pre-mature breakage, which was caused by the aggregates' high reactivity. Following that, a cohesion test was used to govern the kind and dose of filler. Surprisingly, the arrangement of cement (2%) and fly ash (1%) produced the greatest cohesiveness, showing the advantages of including waste materials with pozzolanic properties into the mix.

They concluded that the fast breaking may be due to one or more of the factors mentioned below.

- Emulsifier interaction,
- Inadequate emulsifier quantity,
- Compatibility of filler with emulsion.

According to their research, using a greater emulsifier dose caused an interruption in the curing procedure, which led in poor cohesiveness, ravelling, and rutting resistance. Ravelling resistance was also shown to be influenced by the solvent used. The OEC was defined as the midpoint of the acceptable emulsion content range, which in this research was determined to be 14% by dry mass of aggregates [3].

According to Dr. Rajiv Kumar and Dr. Teiborlang Lyngdoh Ryntathiang, there is no precise technique of mix design for microsurfacing at this time. Even the ISSA and ASTM methodologies explicitly declare that they are only to be used as a guide. And, the issue of balling is still evident in all prior techniques of combining microsurfacing. As a result, they developed a novel laboratory technique for the microsurfacing mix process that is based on performance rather than experience. For their research, they look at the aggregate gradation types II and III [4].

They used the ISSA consistency test to evaluate the performance of a combination with different water and emulsion levels as shown in Fig. 2. Using 400 g of aggregate at room temperature, the best emulsion, and various water concentrations, many experimental mixes were created.

They also performed a modified marshal test on the mix to determine its flow characteristics.

According to their findings, this technique produces acceptable results, and the issue of balling in the microsurfacing mix has been substantially minimised. The required consistency for type II and type III is found in the ranges of 18 to 20% emulsion content and 14 to 16% emulsion content, respectively.

Fig. 2 Consistency test

7 Life Cycle Assessment and Environmental Impact of Microsurfacing

Because of its environmentally benign nature, microsurfacing is gaining a position in pavement preservation methods. Because it is a kind of cold mix pavement preservation method, it has a far lower environmental effect than a hot mix pavement rehabilitation process.

Because they provide substantial benefits in recovering pavement surface conditions, microsurfacing and asphalt overlay are currently regarded the major PM methods in developing maintenance programmes. Mulian Zheng and his colleagues conducted a thorough examination of microsurfacing life cycle evaluation. It has been discovered that microsurfacing treatment can be utilised for early type preventive maintenance and double-layered microsurfacing may be used for mid-type preventive maintenance [14].

For their research, they used a 1 cm microsurfacing layer and a total pavement surface of 1000 m^2. Mixture production, mixture transportation, construction, maintenance, and end of life are the six stages of maintenance method that they examine.

Ozone depletion (OD), global warming (GW), photochemical smog formation (PSF), acidification (AC), eutrophication (EU), human health carcinogenic (HHC), human health non-carcinogenic (HHN), human health particulate (HHP), eco-toxicity (EC), and fossil fuel depletion are some of the factors that have an impact on the environment (FFD). In addition, the total embodied energy (TEE) was included in this LCA analysis [14].

With their life cycle assessment studies, they discovered that microsurfacing had a significant influence on environmental protection, with an overall impact score improvement of more than 50%. Diesel, with a value of 325.4 kg, was determined to be the second greater contributor to microsurfacing.

With Fig. 3, we can understand the contribution of microsurfacing in different types of environment pollution.

Figure 4 explains how microsurfacing contributes to different types of pollution at its different stage of life. We can conclude from here that microsurfacing contributes good amount in pollution at its later stage of life.

The LCEI produced by microsurfacing was determined to be the least. Microsurfacing has a considerable environmental performance, according to the findings. Furthermore, as a method for middle-PM, the composite seal outperforms the ultra-thin asphalt overlay in terms of environmental performance.

Takamura et al. examined the environmentally beneficial approach of microsurfacing in 2001 and found that microsurfacing is further "environmentally friendly"

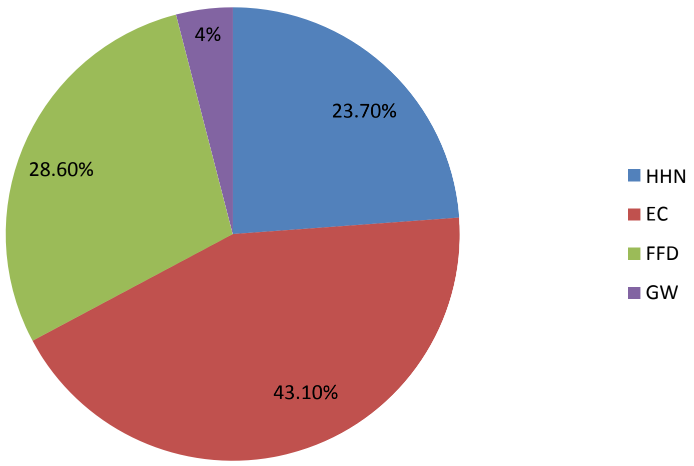


Fig. 3 Contribution of microsurfacing in different pollutions

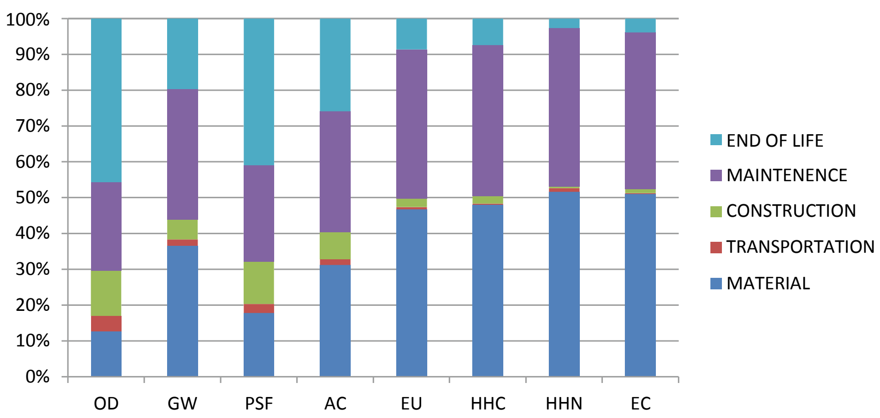


Fig. 4 Microsurfacing pollution at different stages

than a hot mix overlay [15]. This is due to less material being utilised, less material transportation, and fewer total emissions throughout the treatment's lifetime. Future advancements in microsurfacing technology, according to the research, may result in significant economic and environmental benefits. He evaluated the environmental effect of microsurfacing to that of HMA and modified hot mix asphalt. For each of the three options, energy consumption, possible health consequence, and the risk of accident and misapplication are calculated as shown in Fig. 5. Microsurfacing exhibited a smaller environmental "footprint" when all variables were taken into account, as illustrated in Fig. 5 [16].

In this Fig. 6, the environmental effects of three pavement preservations and maintenance procedures are compared, and it can be determined that microsurfacing has a lesser environmental impact than the other two options.

Estimated air emissions that may cause global warming, acid rain, and photochemical ozone formation are shown in the graph as tonnes of CO_2-equivalents, kilogrammes of NO_2 equivalents, and kilogrammes of ethane equivalents per lane mile

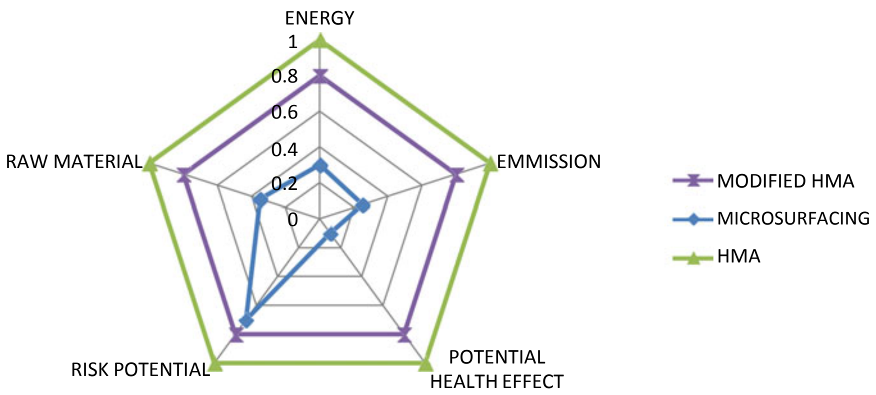


Fig. 5 Comparison of microsurfacing, HMA, MHMA

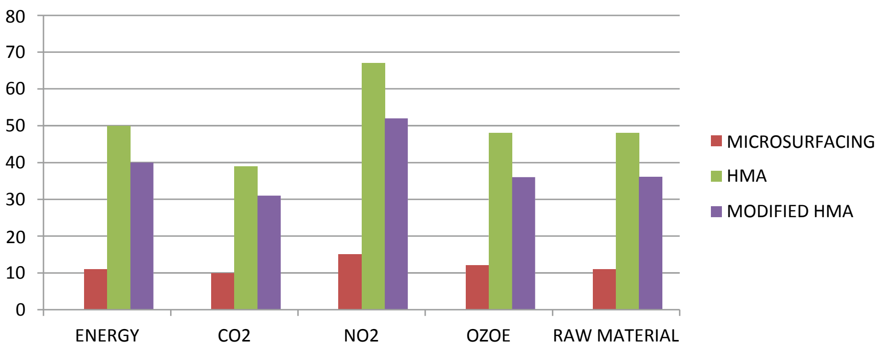


Fig. 6 Comparison of microsurfacing, HMA, MHMA

per year of treatment life, respectively. Microsurfacing has the least environmental effect of these three PM methods.

Although the environmentally benign aspect of microsurfacing is one of the primary reasons for its growing popularity across the globe, research indicates that the majority of maintenance professionals do not consider environmental effect when developing microsurfacing projects.

8 Summary and Conclusion

Microsurfacing is a relatively recent pavement maintenance technology that may be employed in the early stages of pavement degradation. Microsurfacing is a road surface maintenance and preservation technique with minimal technological and operational constraints. These conclusions may be drawn from this research.

- While preventative maintenance programmes offer a number of benefits, their implementation needs a shift in mindset and prudence in terms of monitoring and programming in order to choose the appropriate moment for intervention.
- Periodically, the study of treatment scheduling should be revisited in the light of industry developments that influence both treatment cost and performance. Modifications to the optimal time of therapy administration may have an effect on the cost–benefit analysis.
- The addition of various components such as rubber powder, fly ash, a new kind of emulsion, or waste material may substantially change the characteristics of the mix, even if they are added in a tiny amount. When used properly, this addition may help decrease the cost of microsurfacing mixes but may degrade the mix's performance. Gradation of aggregates has a significant effect on the final characteristics of microsurfacing mixes.
- There is currently no standard technique for microsurfacing mix procedures, and therefore, the process used is dependent on experience. Thus, a suitable mix technique should be established for the microsurfacing mix design in order to resolve issues such as balling, fast breaking, and so on.
- Why microsurfacing is more environmentally friendly than hot mix overlays. This is because less material is utilised, less material is transported, and total emissions are reduced throughout the treatment's life. Additionally, the research indicates that future advancements in microsurfacing technology may result in significant economic and environmental benefits.
- When compared to a hot mix method, microsurfacing has a reduced overall environmental effect.

9 Future Recommendations

The following summarises the future research needs identified in the examined literature.

- Developing an appropriate mix approach for microsurfacing mix design that is research-based rather than experience-based.
- Evaluating the impact of external conditions on the moistness loss, ravelling, rutting resistance of microsurfacing mixes, including curing time, temperature, moisture [8].
- Entire life cycle agency and user costs are analysed in more detail to determine the sustainability of PM methods and planning, which is essential for the creation of sustainable pavement management.
- Additional field tests should be performed to ascertain the real behaviour of microsurfacing mixes produced with the same kinds and amounts of asphalt emulsion and aggregates as in this research.
- The absence of rigorous field tests based on rational quantification of quantifiable microsurfacing properties prompts the suggestion that research be conducted to develop a suite of field tests that enable an inspector to test the microsurfacing mix after it has been laid, as well as tests to determine when the mix has cured sufficiently to allow traffic to pass without damaging it.

References

1. J. Masarova, Importance of road infrastructure in the economic development and competitiveness. https://doi.org/10.5755/j01.em.18.2.4253
2. S. Labi, K. Sinha, J. Transportation, W. Lafayette, S. O. Building, F. Report. **7**(2) (2003)
3. N. Bhargava, A.K. Siddagangaiah, T.L. Ryntathiang, Systematic approach to address challenges in microsurfacing mix design. Constr. Build. Mater. **270**, 121759 (2021). https://doi.org/10.1016/j.conbuildmat.2020.121759
4. R. Kumar, T. L. Ryntathiang, New laboratory mix methodology of microsurfacing and mix design. Transp. Res. Proc. **17**, 488–497 (2016). https://doi.org/10.1016/j.trpro.2016.11.098
5. C. Drive, F. Park, in *Submission for Verification of Eco-efficiency Analysis Under NSF Protocol P352 , Part B Walltite ECO^{TM} Insulation Air Barrier and Vapor Barrier System Eco-Efficiency Analysis February 2010 Submitted by* (2010)
6. R. Kumar, I. I. T. Guwahati, in *Rural Road Preventive Maintenance with Microsurfacing Rural Road Preventive Maintenance with Microsurfacing* (2015)
7. Y. Luo, K. Zhang, X. Xie, X. Yao, Performance evaluation and material optimization of microsurfacing based on cracking and rutting resistance. Constr. Build. Mater. **206**, 193–200 (2019). https://doi.org/10.1016/j.conbuildmat.2019.02.066
8. N. Bhargava, A. K. Siddagangaiah, T. L. Ryntathiang, State of the art review on design and performance of microsurfacing (2020). https://doi.org/10.1080/14680629.2019.1607771
9. N. Bhargava, A. K. Siddagangaiah, Reliability of microsurfacing mix subjected to variation in aggregate gradation (2020). https://doi.org/10.1177/0361198120948855
10. R. Rutherford, No the use of fly ash as a substitute of cement in microsurfacing A. Encycl. Volcanoes., 662, 2000 (1995)

11. E. Hesami, A. Ataollahi, V. Sadeghi, Performance evaluation of microsurfacing with rubber powder (2020), pp. 1–18. https://doi.org/10.1177/0892705720930760
12. I. N. A. Thanaya, Improving the performance emulsion of cold bituminous (CBEMs) incorporating waste. Univ. Leeds Sch. Civ. Eng. (2003)
13. R. Gujar, V. Vakharia, Prediction and validation of alternative fillers used in micro surfacing mix-design using machine learning techniques. Constr. Build. Mater. **207**, 519–527 (2019). https://doi.org/10.1016/j.conbuildmat.2019.02.136
14. M. Zheng, W. Chen, X. Ding, W. Zhang, S. Yu, Comprehensive life cycle environmental assessment of preventive maintenance techniques for asphalt pavement. Sustain. **13**(9) (2021). https://doi.org/10.3390/su13094887
15. K. Takamura, in *Applications for Asphalt Modification*, vol. 7. (2002), pp. 301–327
16. K. Takamura, P. Lok, Microsurfacing for preventive maintenance : eco-efficient strategy microsurfacing for preventive maintenance : eco-efficient strategy (2014)

A Review on Microstructural Properties of Concrete Incorporating Different Mineral Admixtures

Ashish Choudhary, Kanish Kapoor, S. P. Singh, and Paramveer Singh

1 Introduction

To increase the quality of the concrete, various mineral additives such as fly ash (FA), silica fume (SF), blast furnace slag (GGBS), and metakaolin (MK) are used, each of which has a distinct effect on the characteristics of the concrete. Mineral admixtures' reported benefits are frequently linked to concrete's curing properties; however, they can also affect the characteristics of wet cement between mixing and curing in one or more of the following ways: they can affect water needs, and so on. There is a scarcity of literature that describes the impact of various mineral additions on concrete structural characteristics. Mineral additives' impact on the mechanical and durability characteristics of concrete has piqued researchers' curiosity. The characteristics of new concrete are critical since they can impact the concrete's durability and mechanical capabilities. the impact of slag sand and fly ash on the hydration of new cement paste [1], the effect of silica dust (SF), metakaolin (MK), fly ash (FA), and slag sand (GGBS) on the setting times of high-strength concrete [2] The purpose of this article is to explain the background, production, and reactivity of mineral additives in ordinary Portland cement. Fresh concrete has several unique properties were also discussed.

A. Choudhary (✉) · K. Kapoor · S. P. Singh · P. Singh
Department of Civil Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar, India
e-mail: ashishc.sc.19@nitj.ac.in

K. Kapoor
e-mail: kapoork@nitj.ac.in

S. P. Singh
e-mail: spsingh@nitj.ac.in

P. Singh
e-mail: paramveers.ce.19@nitj.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_24

2 Background

In 1934, Powers and Macmillan were among the first to utilise fly ash in concrete [3]. Fly ash (FA) or powder fuel ash (PFA) is a pozzolanic ingredient that may be transported and makes stronger, less porous concrete. This pozzolanic substance was initially characterised as a hazardous alkaline reaction modifier (ASR) by Blanks in 1949 [4]. The amount of alkali accessible in fly ash concrete is generally larger than in non-fly ash concrete, indicating that fly ash helps to inhibit the alkaline silica reaction [3].

Emil Langen developed GGBS in Germany in 1862; nevertheless, commercial manufacture and usage of GGBS began in Germany in 1865 [5]. Around 1880, GGBS was first used as a partial replacement in Portland cement (PC). It has now been adopted in a number of European nations.

In 1947, Norway became the first country to manufacture silica fumes. When the oven exhaust is filtered, it is referred to as smoke. The majority of these steams include a significant proportion of extremely fine silica particles. The filtering of the gas begins. The first standard on the use of silica fume in industrial cement, NS 3050, was issued in 1976, and there is a large body of literature on silica fume and silica clay [5]. It's a high- grade substance that's utilised in the cement and concrete industries. Due to the tiny particles of quartz fume, it has been observed that when SF is added to concrete at a concentration of 8–10 wt% cement, the concrete mixture becomes more thick and coherent [3].

Metakaolin is an amorphous silica substance produced by calcining kaolin at temperatures ranging from 600 to 850 degrees Celsius [6–9]. Kaolin is a natural material whose chemical and mineral makeup is heavily influenced by the rock from which it was produced [10]. Kaolin is whitish clay that disintegrates feldspar spontaneously. It's mostly utilized in the production of porcelain and as filler in papers and fabrics [5].

3 Manufacturing

Fly ash is created when coal is burnt at a temperature of 16,000 °C to generate energy [11]. This burning also produces non- combustible elements, such as silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), which combine to create glass spherical droplets as well as other trace elements. There are two forms of fly ash, as per ASTM C 61,805, based on the carbon source. Anthracite coal, which includes silicon and possesses pozzolanic characteristics, is used to make Class F fly ash. Heating lignite and sub-bituminous coal produces Class C fly ash, which includes lime and has a high MgO concentration. Class C fly ash has a lighter colour and is more prone to swelling, and its high temperature resistance has yet to be confirmed [12, 13].

Calcium silicate and aluminosilicate, which are by-products of blast furnaces in the metallurgical sector, are also found in GGBS. Granulation and pelletization, are the two methods that may be utilised to create GGBS. During the grinding process, slag is introduced. The high-pressure water jet weir may swiftly cool the slag into granules with a diameter of 5 mm; nevertheless, the molten slag is pumped into a spinning drum filled with cold water during the granulation process. The molten slag in the drum is swiftly cooled by external air and water. This method generates 100 mm particles whereas, GGBS is made with particles that are smaller than 6 mm. GGBS with a glassy matrix may be made using these two methods [5].

During the silicon manufacturing process, silica vapour is produced a by- product of high-purity quartzite and coal heated up to 2000 °C in an electric furnace. Exhaust gas and SiO are oxidized and condensed to create very small spherical micro-silica particles, which are extremely reactive with $Ca(OH)_2$ produced during cement hydration [5]. Silica fume has pozzolanic characteristics and is made up of very tiny particles with an average diameter of 0.1 m [12, 13].

When heated to 600–850 °C, kaolin transforms into metakaolin [6–9]. MK is a highly reactive pozzolana, but its physicochemical characteristics are influenced by the raw resources used and the temperatures at which it is calcined and refined [5]. The temperature and time of calcination are determined by the mineral content of the raw ingredient kaolin [8, 9].

4 Reactivity of Mineral Admixtures with Ordinary Portland Cement

Cabrera and Plowman discovered in 1987 that calcium hydroxide, also known as lime, uses up with time. When fly ash is mixed with cement, it begins to gain strength over time when compared to conventional Portland cement concrete; nevertheless, despite the lime decrease, there is not enough lime present to maintain a high pH. It is crucial to note that the goods that arise from the inclusion of fly ash are not the same as the products that come from the use of OPC concrete. Fly ash generates an extremely thin pore structure over time, assuming that water is available to keep the hydration going [5]. To begin the reaction, a pH of 13 and a temperature of 200C with lime are necessary to decompose the Si–O–Si bond in fly ash [14].

Fly ash, in which the Si–O–Si link must be broken, is excessively reactive with lime, whereas GGBS must be activated in order to react with lime. In the presence of activators, GGBS, which has a glass-like structure, interacts slowly with water. Sulphates or alkalis are commonly used as activators, and they react chemical with the GGBS. These activators cause the system's pH to rise by disrupting the crystal structure. GGBS, unlike fly ash, requires a pH level of less than 12. $Ca(OH)_2$ is generated in concrete as a result of cement hydration and acts as an accelerator [14].

As a cementitious substance, SF interacts with $Ca(OH)_2$, and at 28 days, around 25–30% of SF may consume the majority of the calcium hydroxide. This is critical because $Ca(OH)_2$ crystals are very weak, non-cementitious and fractures can readily form near areas where $Ca(OH)_2$ crystals are concentrated [15].

Kaolin undergoes a transition from crystalline to amorphous during the calcination process. The activity of additives influences the amount as well as the kind of amorphous phase [16]. Chemical activity and the micro filler effect are two aspects that make up the activity of additives. Dehydroxylation of kaolinite at atmospheric pressure results in a mass loss of 13.76%, converting $SiO_22Al_2O_32H_2O$ to $SiO_22Al_2O_3$ [17]. It has also been observed that kaolin entirely transforms to the amorphous phase following dehydroxylation at 5700C, and that formation is a linear function of amorphous phase concentration in the range of 50–100% [17]. In terms of pozzolanic activity, metakaolin with less than 20% amorphous phase content can be termed inert materials [17]. The activity strength index in MK has also been impacted by amorphous phase contents, although there is no rise in activity strength index when the amorphous index exceeds 55% [17].

5 Properties of Fresh Concrete on Different Mineral Admixtures

Bleeding—Gebler and Klieger reported in 1986 [18] that concrete containing fly ash bled less than regular concrete. Furthermore, concrete with Class C fly ash bled less than concrete with Class F fly ash. The reduced bleeding is attributable to the larger surface area of fly ash particles and the decreased water content of fly ash for a given workability [11]. Concrete with silica fume, on the other hand, does not bleed [19]. Similarly, using metakaolin as a substitute for cement in new concrete decreases bleeding [5].

Reactivity—the Chapelle test is used to assess the reactivity of pozzolana. This test is carried out by reacting calcium hydroxide with diluted slurry of pozzolana at 950 °C for 18 h. After the reaction, the amount of calcium hydroxide used is calculated. Largent presented the findings in 1978 [20], demonstrating that metakaolin had a greater reactivity than other pozzolanic compounds. Despite this, MK lowers the calcium hydroxide content in concrete while keeping the pH constant [21].

Setting Time- In the case of fly ash, the setting time of concrete is affected by the air temperatures, cement ratio, and chemical composition of the fly ash [11]. Concretes containing Class C fly ash need relatively little water. In Class F fly ash concrete, there was no decrease in water. Fly ash concretes showed a little increase in setting time [18].

Since GGBS slowly reacts with water as compared to Portland cement, therefore setting time of concrete is high in GGBS. The setting time will be greater at high replacement levels above 50% [5]. Silica fume, having a greater surface area and higher silicon dioxide content, is found to be more reactive than fly ash or GGBS. The high reactivity increases the hydration rate of the C3S and thus decreases the setting time [5].

The initial and final setting times of concrete with 10% MK are sped up. In contrast to 10% MK concrete, a slight reduction in initial setting time is seen when the replacement amount is increased to 15% [22]. This might be related to metakaolin's increased water demand at the higher replacement rate. Concrete gets denser as the MK content increases, which speeds up the setting time [22]. However, using an efficient superplasticizer dose in concrete reduces the water content, which slows down the curing period [22].

As a result of the comparison of various admixtures, it was discovered that Silica fume, fly ash concrete has a different setting time than plain concrete. This might be owing to the hydration process in concrete containing silica fume and fly ash speeding up after the initial set [22]. Water content, starting and curing temperatures, dose, superplasticizer and cement composition all impact the time it takes for concrete to set [22]. Increasing the replacement amounts of admixtures in concrete reduces the setting time under comparable conditions [22].

6 Conclusions

The following conclusion may be reached based on the review:

(1) Concrete's initial and final setting times are influenced by water content, starting and curing temperatures, superplasticizer dose and the correct use of chemical reactive admixtures.
(2) The setting time of concrete decreases as replacement levels of chemically active minerals additives rise, but it rises as percentage replacement of microfiller mineral admixtures rise.
(3) With correct proportions of all components, all mineral admixtures examined decrease bleed in concrete.

References

1. C.L. Hwang, D.H. Shen, The effects of blast-furnace slag and fly ash on the hydration of Portland cement. Cem. Concr. Res. **21**(4), 410–425 (1991)
2. J. J. Brooks, M. A. Megat Johari, M. Mazloom, Effect of admixtures on the setting times of high-strength concrete. Cem. Concr. Compos. **22**(4), 293–301 (2000)
3. M. Thomas, R.D. Hooton, C. Rogers, B. Fournier, 50 years old and still going strong. Concr. Int. **34**, 35 (2012)
4. R. F. Blanks, The use of portland-pozzolan cement by the bureau of reclamation. ACI J. Proc. (1949)
5. J. B. Newman, Advanced concrete technology: constituent materials. Butterworth-Heinemann (2003)
6. A. Shvarzman, K. Kovler, G.S. Grader, G.E. Shter, The effect of dehydroxylation/amorphization degree on pozzolanic activity of kaolinite. Cem. Concr. Res. **33**(3), 405–416 (2003)

7. C. Bich, J. Ambroise, J. P´era, Influence of degree of dehydroxylation on the pozzolanic activity of metakaolin. Appl. Clay Sci. **44**(3–4), 194–200 (2009)
8. E. Badogiannis, G. Kakali, S. Tsivilis, Metakaolin as supplementary cementitious material: optimization of kaolin to metakaolin conversion. J. Therm. Anal. Calorim. **81**(2), 457–462 (2005)
9. E. Guneyisi, M. Gesoglu, T. Ozturan, and K. Mermerdas, Microstructural properties and pozzolanic activity of calcined kaolins as supplementary cementing materials. Canadian J. Civ. Eng. **39**(12), 1274–1284 (2012)
10. H. Baioumy, A. R. Ibrahim, Mineralogical variations among the Kaolin deposits in Malaysia
11. ACI Committee 232, Use of fly ash in concrete. Tech. Rep. ACI 232. 2R-03 (2003)
12. ACI Committee 363, State of the art report on high-strength concrete. ACI J. Proc. (1984)
13. A. M. Neville, J. J. Brooks, *Concrete Technology* (Longman Scientific & Technical, 2010)
14. J. Bijen, Benefits of slag and fly ash. Constr. Build. Mater. **10**(5), 309–314 (1996)
15. G.A. Rao, Investigations on the performance of silica fume incorporated cement pastes and mortars. Cem. Concr. Res. **33**(11), 1765–1770 (2003)
16. P. C. Hewlett, Ed., *Lea's Chemistry of Cement and Concrete* (Elsevier Science & Technology, 2004)
17. A. Shvarzman, K. Kovler, G.S. Grader, G.E. Shter, The effect of dehydroxylation/amorphization degree on pozzolanicactivity of kaolinite. Cem. Concr. Res. **33**(3), 405–416 (2003)
18. S. H. Gebler and P. Klieger, *Effect of Fly Ash on Physical Properties of Concrete*, Proceedings of the 2nd International Conference on the use of Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete (CANMET/ACI '86, 1986), pp. 1–50
19. M.-H. Zhang, V.M. Malhotra, High-performance concreteincorporating rice husk ash as a supplementary cementing material. ACI Mater. J. **93**(6), 629–636 (1996)
20. R. Largent, *Evaluation of Pozzolanic Activity-Attempt at Finding a Test, Bulletin De Liaison Des Lab Des Ponts Et Chaussees* (1978)
21. A. Asbridge, G. Walters, T. Jones, Ternary Blended Concretes OPC/Ggbfs/Metakaolin (Concrete Across Borders, Denmark, 1994)
22. J. J. Brooks, M. A. Megat Johari, Effect of metakaolin on creep and shrinkage of concrete. Cem. Concr. Compos. **23**(6), 495–502 (2001)

Evaluation of Mechanical Properties of Metakaolin Geo-Polymer Concrete

Rashmi Pantawane and Pushpendra Kumar Sharma

1 Introduction

Geo-polymer concrete is the new age concrete, it is heavily accepted worldwide due to its sustainability and eco-friendly properties. It has reduced carbon emission content. It includes very less cement content or it has no cement in its manufacturing process. It has its properties very familiar to the traditional concrete and performs better than the traditional one.

The extensive industrialization happening in this century is having great demand to utilize its by-products or waste products which are dumped, causing hazardous dis- tress to the surrounding environment leading to the causes such as ozone layer depletion, climate change, global warming, etc. The waste products used in the manufacturing of geo-polymer are fly ash, rice husk ash, blast furnace slag which is pozzolanic in nature and can be replaced with cement.

Geo-polymer concrete is basically the mixture of its source materials like pozzolanic material which are rich in silica and aluminia, aggregates and activating them with the alkaline solutions such as sodium silicates or potassium silicates and sodium hydroxide or potassium hydroxide in proper proportions. The reaction leads to the process of polymerization, formation of Si–O–Al bonds which is crucial for the achievement of strength.

The significance of using geo-polymer is to reduce the rapid destruction of lime-stone mines and carbon footprint. To introduce a material which is creating less nuisance and can be regularly used in bulk quantity. As there is no proper design or code practice for the geo-polymer, it is hence required to find out its mechanical properties.

R. Pantawane · P. K. Sharma (✉)
SCE, Lovely Professional University, Phagwara, Punjab 144411, India
e-mail: p.sharmaji10@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_25

The mechanical properties are very important for using any construction material, as the strength provides an idea about the performance of the material. The most important test to determine the mechanical property is the compressive strength. The compressive strength determination process is the same as conventional concrete but there is a difference in the curing process to the geo-polymeric concrete. It requires ambient curing or oven curing. Depending upon the availability, any of the mentioned methods of curing can be adopted.

The concentration of alkali-activated solution influences the compressive strength of geo-polymer concrete [3]. Increasing the concentration of sodium hydroxide improves the compressive strength [3]. Usage of metakaolin has been found to have high achievement in mechanical properties of geo-polymer [4]. High performance, high strength, high grade and lightweight concrete are achieved by using metakaolin in geo-polymer [4] (Tables 1 and 2).

Table 1 Physical properties of metakaolin

Property	Value
Specific gravity	2.60
Bulk density (g/cm^3)	0.3–0.4
Physical form	Powder
Colour	Off-white
GE brightness	79–82
D10	<2.0 μm
D50	<4.5 μm

Table 2 Chemical composition of metakaolin

Types	% by mass
SiO_2	51.52
Al_2O_3	40.18
Fe_2O_3	1.23
CaO	2.0
MgO	0.12
K2O	0.53
SO_3	0.0
TiO_2	2.27
Na_2O	0.08
L.O.I	2.01

2 Specimen Preparation

Alkaline solution is prepared by dissolving the sodium hydroxide pellets in the water to make one litre solution of the required molarity. The ratio of sodium silicate and sodium hydroxide solution is taken as 2.5. This prepared solution is stored at room temperature for about 24 h before mixing it with other source materials to prevent exothermic reaction.

In this experimental work, the source material used to make geo-polymer was meta kaolin clay as binder. Geo-polymer contains 75–80% combined aggregates as per mass. The activators used in the study were sodium silicate and sodium hydroxide as they are cheaper than the potassium-based activators. The molarity of the sodium hydroxide solution prepared was kept in the range of 18.

Meta kaolin clay and aggregates were first mixed together thoroughly and then the prepared alkali-activated solution was added and mixed for about four minutes. Flow test, initial setting time and final setting time tests were performed. The prepared fresh geo-polymer was then casted into moulds for testing strengths. The specimens were compacted three times by tamping rod after placing each layer and vibrated using vibrating table.

Specimens prepared were then placed in the oven for 24 h at 60 °C. After providing initial heat curing to the specimens, they were kept in open air till the day of testing. In this experimental work both the methods of curing, heat and ambient were used. A UTM machine was used to test the compressive strength and tensile strength of the specimens prepared (Table 3).

The mechanical strengths were calculated according to Indian standards. Direct compressive load was applied to the specimens of size 150 mm * 150 mm * 150 mm. The load at which the specimen shows surface crack was noted down and average of three specimens was recorded. Tensile strength was taken by placing the cylindrical specimen of size 150 mm in diameter and 300 mm long in a manner that longitudinal axis is perpendicular to the load. The maximum applied load indicated by testing machine at failure is recorded.

Table 3 Mix design of metakaolin-based geo-polymer concrete

Constituents	Weight (Kg/ m^3)
Meta kaolin clay	405
Coarse aggregates	1268.66
Fine aggregates	683.13
Sodium silicate	95
Sodium hydroxide	47
Water	108.35

3 Observations

See Tables 4, 5 and 6 and Figs. 1, 2 and 3.

Table 4 Compressive strength

Days	Strength (MPa)
7	42.7
14	43.6
28	46.7
90	51.4
120	50.6

Table 5 Split tensile strength

Days	Strength (MPa)
7	25.3
14	26.2
28	27.4
90	30
120	29.5

Table 6 Flexural strength

Days	Strength (MPa)
7	9.4
14	9.5
28	10.3
90	11.3
120	11.2

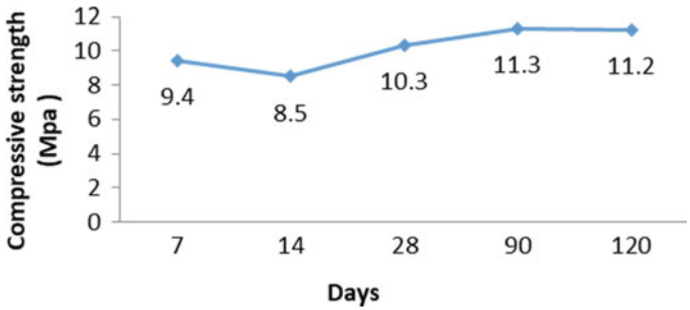


Fig. 1 Compressive strength (MPa) of geo-polymer concrete

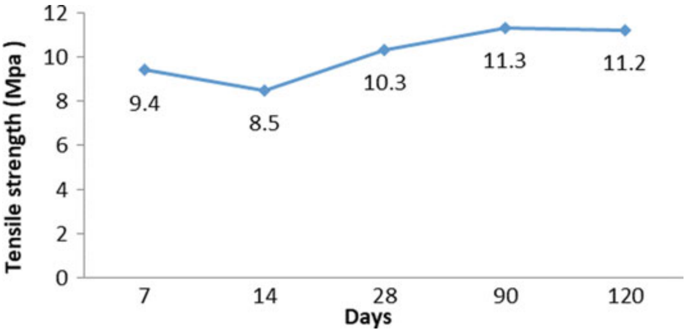


Fig. 2 Tensile strength of geo-polymer concrete

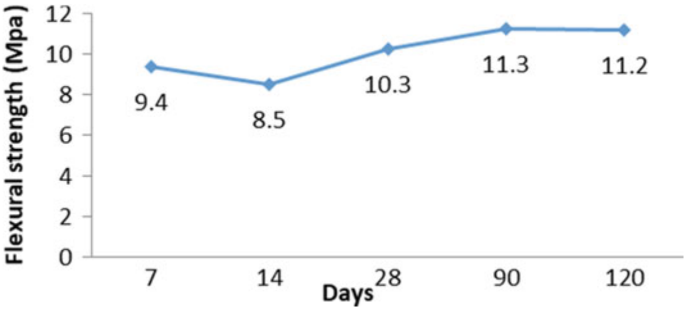


Fig. 3 Flexural strength of geo-polymer concrete

4 Conclusions

From the experimental work done, it can be concluded that meta kaolin geo-polymer concrete provides high early strength, it can be due to the heat curing provided-ed at the early stage. The early strength achieved at 7 days is nearly close to the strength achieved at 28 days. There is 83% strength achieved at 7 days. The maximum strength achieved by geo-polymer is at 90 days, after which it decreases drastically. Geo-polymer concrete can be used where high early strength is required such as in retaining walls, pavements and precast construction.

References

1. T. Lakshmi Prasad, H. Sudarsana Rao, V. G. Ghorpade, Flexural and tensile strength properties of GGBS and phosphogypsum blended geopolymer concrete. Int. J. Chem. Tech. Res. **10**(6), 661–667 (2017)
2. P.R. Vora, U.V. Dave, Parametric studies on compressive strength of geo-polymer concrete. Proc. Eng. **51**, 210–219 (2013)

3. H. Ivindra Pane, I. Imran, B. Budiono, Compressive strength of fly ash-based geopolymer concrete with a variable of sodium hydroxide (NaOH) solution molarity. MATEC Web Conf. **147**, 01004 (2018)
4. Dr. D. Jadhao Pradip, P. Shelorkar Ajay, Determination of durability of metakaolin blend high grade concrete by using water permeability test. OSR J. Mech. Civ. Eng. (IOSR-JMCE) **5**(2), 35–39 (2013). e-ISSN: 2278-1684
5. A. Sachdeva, P. K. Sharma, A. Kumar, Strength and durability properties improvement of bottom ash concrete using ultra-fine slag cementitious material. J. Mech. Eng. Res. Develop. (JMERD) **44**(10), 57–65 (2021). ISSN: 1024-1752
6. A. Garg, P. K. Sharma, Mechanical properties of glass fiber reinforced concrete with recycled aggregates. J. Appl. Sci. Eng. **24**(6), 1033–1039 (2021). https://doi.org/10.6180/jase.202112_24(6).0018

Performance Analysis of the Sustainable Windows Glazing System for Built Environment

Amit Kumar Dhir and Pushpendra Kumar Sharma

1 Introduction

Energy consumption in the buildings is increasing at unmatched pace with its generation and will reach eight times from 2012 [1], buildings are taking 54% share of global scenario and releasing 23% carbon dioxide from global perspective. The energy demand will rise enormously and needs to be slow down. Residential building sector consumes 25% of the total consumption in India [2]. Thus, the energy demand in building section is increased and envelope is responsible for letting the heat and light inside the building, windows is the critical component of envelope for major heat loss and gain [3]. Thus, it is mandatory to study the energy aspect through the glass system that is integrated as windows to resist the heat gain or loss. On the other hand, the changing life style demands the bigger size of windows required for well-being and comfort to the users [4]. Even the productivity analysis shows the betterment in various built environment such as teaching institution and hospitals to enhance the productivity at all built environment, nowadays it is must to have larger portion of the envelope to be covered by windows [5]. A balance needs to be maintaining with changing life styles and energy consumption. The impact of windows should be carefully studied in terms of light efficiency and thermal comforts [6]. Many parameters crucial for the windows such as orientation, climate, choosing the optimal and efficient glass as per climatic conditions etc. will be carefully designed along with energy analysis so as to make the user confident [7]. Studies has been performed empirically about 68.5% and analytically 11.7%, software 19.8% on the various aspects of windows making it energy efficient, experimentation is not taken

A. K. Dhir · P. K. Sharma (✉)
Department of Civil Engineering, Lovely Professional University, Phagwara, India
e-mail: p.sharmaji10@gmail.com

A. K. Dhir
e-mail: Amitdhir2k4@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_26

to large level [8, 9]. Experimentation is very much required so that the product that is windows when installed at consumer location, the results should not deviate with the statistics provided in the manual [7]. Thus, experimentation in the windows for buildings is the need of hour. Many novel configurations have been used and recommended by researchers [10–12]. Energy savings of 15% are possible using active building envelope technology [13]. Various types of glasses are available which has the capability to cut the heat ingress in to the buildings and can reduce the cooling loads in the built sector [14]. Double glazing units are shown better results than traditional units in energy savings for various climates [15–17]. A window should be carefully designed according to key parameters and especially for climate condition [18].

This paper evaluates the performance of five different windows and suitable glazing is recommended as per budget and savings to minimize the energy consumption.

2 Experimental Setup

The objective of this study is to ascertain the most budgeted windows from the five different windows taken for experimentation. The focus is on the energy consumption criteria that the cooling loads be minimized in the building with the help of economical windows wherein the savings should offset the increased initial cost of the window. To achieve the objective, one single room 12 feet × 12 feet having 10 feet height is considered for study. The five different types of windows are listed in Table 1. The temperature is recorded with the help of sensor based instrument and reading is taken from 12 to 2 PM on June 21, 2021. The prototype is framed out of ply wood ½ inches. The provision is provided where the window glass is replaced one by one and recorded the readings of temperature inside and outside the prototype. The window is placed at 48% widow-to-wall ratio (WWR). Calculation of energy is empirically performed with the help of three-star air-conditioner having 12,000 BTU. Analysis is carried on comparison basis with respect to its cost calculation which is further verified by the expert vendors. Recommendation is provided to the consumer so that the energy balance can be maintained and also to lower the initial cost with the increased number of window units to lower initial cost. The research procedure is shown in the Fig. 1. Data is gathered from the experimental setup and analyzed for various scopes.

3 Results and Discussion

The result was performed for hot and dry climate. The window which is budgeted and performance in cutting the heat is considered and recommended. The different types of windows are shown in Table 1. The south side window facing is used in the

Table 1 Different type of windows

W0CG	Clear glass 6 mm
W1LEG	Low E glass 6 mm
W2SCG	Solar control glass 6 mm
W3STG	ST167 glass 12 mm
W4DGU1	Clear glass 6 mm + 12 mm air + clear glass 6 mm (24 mm width)
W5DGU2	Clear glass 6 mm + 12 mm argon + clear glass 6 mm (24 mm width)

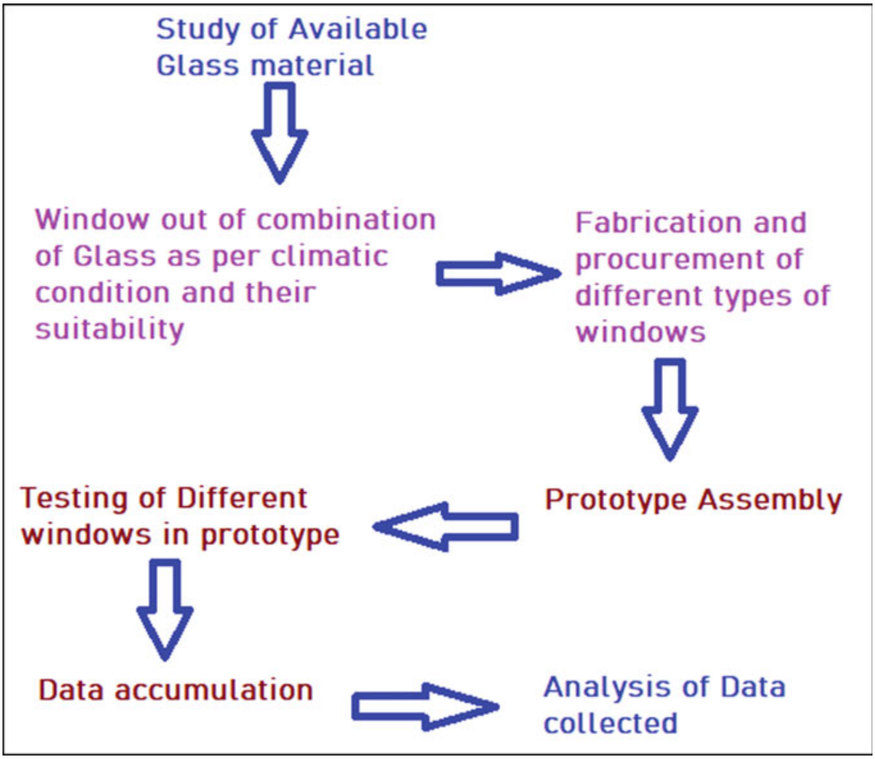


Fig. 1 Research procedure flow chart

experiment having WWR as 48%. The optimum window should be recommended which is economical as far as payback period is concerned.

As shown in Fig. 2, W5DGU2 has the highest performance in resisting the temperature of inside from outside is 8.7 °C, next is W3STG. The reason is of the double skin which is acting as barrier as of argon gas and STG type of glass is having benefits to resist the heat.

Seeing the benefit of lowering temperature from outside to inside with respect to traditionally used windows, still the usage is limited in the residential buildings,

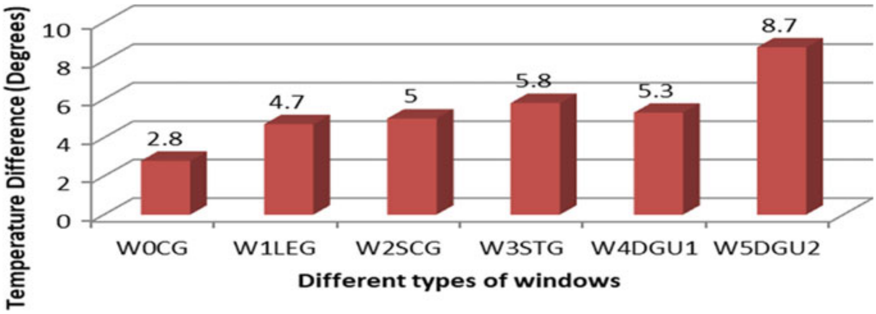


Fig. 2 Difference in temperature for different types of windows

Fig. 3 Initial cost with respect to traditional window

the reason is the owners behaviour [19] and also are not versed with the benefits and types of glass in relation to energy and savings [20]. The challenging part is the initial cost of the windows with a view from traditional windows. Figure 3 represents the initial cost of the glass in the windows (frames and other cost are not taken in account). The windows W3STG, W4DGU1, and W5DGU2 falls 3.44 to 3.7 times more cost than traditional windows. The initial cost will be offset by the savings with performance windows.

Figure 4 shows the payback period which is due to the savings over the energy consumption. W5DGU2 has added benefit of argon gas which lowers the payback period to 2.94 years taking 10 months of usage of air-conditioner in one year.

Figure 5 shows the comparison of widows in terms of payback analysis versus the initial cost of the windows with respect to traditional window. Seeing the differences between both parameters, W5DGU2 is the suitable window that is recommended to be use in warm and hot climate in built environment.

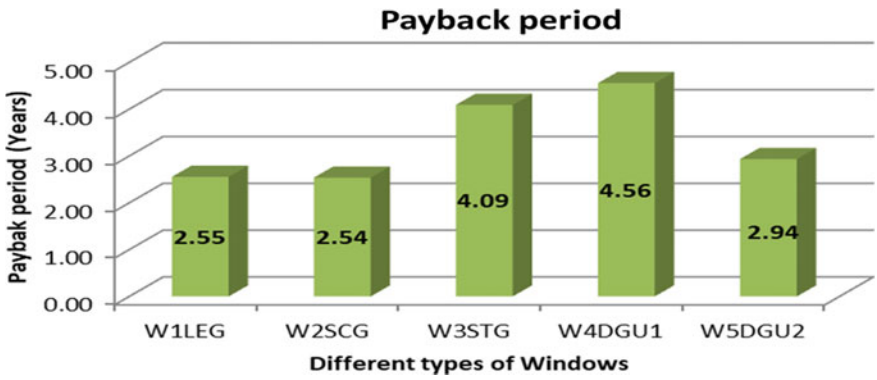


Fig. 4 Payback period of different types of windows

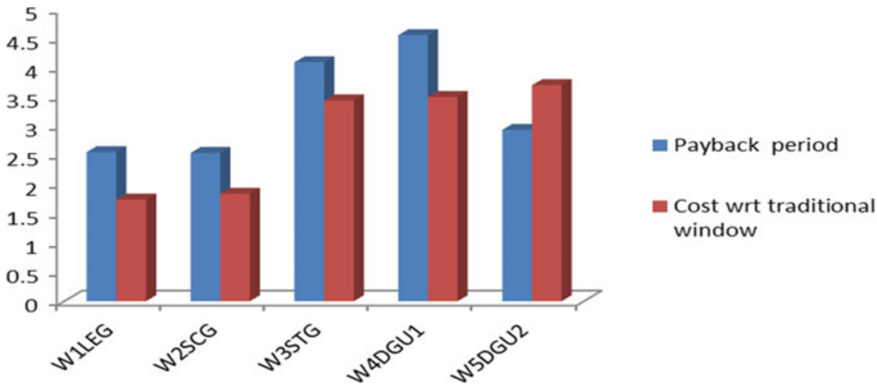


Fig. 5 Comparison of windows

Based on this study, it is suggested that for hot climates, the parameters such as WWR should be 48%, south facing window, the window W5DGU2 which is having clear glass in double skin with argon gas should be used in order to minimize the cooling loads. The recommended solution is economical as well because of its pay-back period.

4 Conclusion

As the result shows with the usage of innovative windows, the energy consumption can be lowered substantially. In hot climates, the energy consumption increases which is also the challenge to developing countries to struggle with. The results are analogous with the previous studies about the impact of double skin windows having argon gas. Such recommendation is helping the engineers and designers to select suit able windows at early design stages of buildings and also covers the energy analysis where the initial cost can offset with the savings.

Out of five different windows studied in comparison with the most widely and cheap traditional windows, the most suitable follow-up of the windows are in order as W5DGU2, W3STG, and W4DGU1. W5DGU2 has payback period of 2.94 years, reduce the temperature difference to 8.7 °C out of five different performance windows. The cost versus payback period is lesser among all the windows. W3STG is also a second viable solution and its cost is 3.44 times which increases the payback period. The author will use this window in residential building to check the actual consumption and satisfaction of the owner in future studies. This way the owner feels confident and the research can be recommended to policy makers to make the national sustainable. With this proposed windows, the electricity bills can be minimized.

References

1. J. Morrissey, Better data. Mod. Healthc. **27**(27), 43 (1997). [Online]. Available: http://search.ebscohost.com/login.aspx?direct=true&AuthType=cookie,ip,shib&db=rzh&AN=106102832&site=ehost-live
2. CSO, Energy statistics 2019 (twenty sixth issue), (2019) pp. 1–123, [Online]. Available: http://mospi.nic.in/sites/default/files/publication_reports/EnergyStatistics2019-finall.pdf
3. E. Cuce, C.H. Young, S.B. Riffat, Performance investigation of heat insulation solar glass for low-carbon buildings. Energy Convers. Manag. **88**(12), 834–841 (2014). https://doi.org/10.1016/j.enconman.2014.09.021
4. S. Yeom, H. Kim, T. Hong, M. Lee, Determining the optimal window size of office buildings considering the workers' task performance and the building's energy consumption. Build. Environ. **177**(3), 106872 (2020). https://doi.org/10.1016/j.buildenv.2020.106872
5. P. Pilechiha, M. Mahdavinejad, F. Pour Rahimian, P. Carnemolla, S. Seyedzadeh, Multi-objective optimisation framework for designing office windows: quality of view, daylight and energy efficiency. Appl. Energy **261**(7), 114356 (2020). https://doi.org/10.1016/j.apenergy.2019.114356
6. R. Alsharif, M. Arashpour, V. Chang, J. Zhou, A review of building parameters' roles in conserving energy versus maintaining comfort. J. Build. Eng. **35**(12), 102087 (2021). https://doi.org/10.1016/j.jobe.2020.102087
7. E. Cuce, Accurate and reliable U-value assessment of argon-filled double glazed windows: a numerical and experimental investigation. Energy Build. **171**, 100–106 (2018). https://doi.org/10.1016/j.enbuild.2018.04.036
8. M. Casini, Active dynamic windows for buildings: a review. Renew. Energy. **119**, 923–934 (01 April 2018). https://doi.org/10.1016/j.renene.2017.12.049. Elsevier Ltd
9. T.J. Dabe, A.R. Dongre, Analysis of performance of the daylight into critical liveable area of 'type design' dwelling unit on the basis of daylight metrics for hot and dry climate. Indoor Built. Environ. **27**(1), 129–142 (2018). https://doi.org/10.1177/1420326X16669844
10. R. Tafakkori, A. Fattahi, Introducing novel configurations for double-glazed windows with lower energy loss. Sustain. Energy Technol. Assessments **43**(11), 100919 (2021). https://doi.org/10.1016/j.seta.2020.100919
11. R. Tafakkori, A. Fattahi, Introducing novel configurations for double-glazed windows with lower energy loss. Sustain. Energy Technol. Assessments **43**(9), 100919 (2021). https://doi.org/10.1016/j.seta.2020.100919

12. J. Hirvonen, et al., Emissions and power demand in optimal energy retrofit scenarios of the finnish building stock by 2050. Sustain. Cities. Soc. **70**(12) (2021). https://doi.org/10.1016/j.scs.2021.102896
13. F. Mokhtari, D. Semmar, M. Chikhi, N. Kasbadji Merzouk, S. Oukaci (2020) Investigation of the improvement building envelope impact on energy consumption using energy audit, in *MATEC Web Conference*, vol. 307, p. 01031. https://doi.org/10.1051/matecconf/202030701031
14. Y. Yaşar, S.M. Kalfa, The effects of window alternatives on energy efficiency and building economy in high-rise residential buildings in moderate to humid climates. Energ. Convers. Manag. **64**(4), 170–181 (2012). https://doi.org/10.1016/j.enconman.2012.05.023
15. W. Zhang, L. Lu, X. Xu, Thermal and daylighting performance of glass window using a newly developed transparent heat insulated coating. Energ. Procedia. **158**, 1080–1085 (2019). https://doi.org/10.1016/j.egypro.2019.01.262
16. K. Gorantla, S. Shaik, A.B.T.P. Setty, Effect of different double glazing window combinations on heat gain in buildings for passive cooling in various climatic regions of India. Mater. Today Proc. **4**(2), 1910–1916 (2017). https://doi.org/10.1016/j.matpr.2017.02.036
17. M.A. Fasi, I.M. Budaiwi, Energy performance of windows in office buildings considering daylight integration and visual comfort in hot climates. Energ. Build. **108**, 307–316 (2015). https://doi.org/10.1016/j.enbuild.2015.09.024
18. A. Dhir, P.K. Sharma, A evaluation for role of suitable glazing in saving energy. **6**(1) (2019)
19. S. Jami, N. Forouzandeh, Z.S. Zomorodian, M. Tahsildoost, M. Khoshbakht, The effect of occupant behaviors on energy retrofit: a case study of student dormitories in Tehran. J. Clean. Prod. **278**, 123556 (2021). https://doi.org/10.1016/j.jclepro.2020.123556
20. A.K. Dhir, Role of suitable glazing in minimizing energy consumption in Jalandhar region. **5**(4), 1527–1530 (2018)

Strength and Flow Characteristics of Controlled Low Strength Material by Using Industrial Byproduct

Minakshi Uchibagle and B. Ram Rathan Lal

1 Introduction

ACI 229 R suggested controlled low strength material as a material which is having compressive strength in the range of 3–8.3 MPa at 28 days. The controlled low strength material having 8.3 MPa are used in structural filling where the future excavation is unlikely and the filling where future excavation is expected the compressive strength should be 3.0 MPa [1]. The application of CLSM has a broad range like structural fill conduit bedding, pavement base, trench backfilling, conduit bedding, and void filling [2]. CLSM is also called as flowable fill self-compacted backfill material, soil cement, slurry, and flowable mortar, etc., [3, 4]. For making flowable material CLSM required more water which required more time to harden [5]. CLSM can be made by using different materials like pond ash [6], bottom ash, cement, kiln dust, and wood ash [7, 8]. CLSM also address material like treated oil west as a partial replacement of sand [9] copper slag also use in the CLSM mix [10] other material like native soil, native high plastic clay sewage sludge [11, 12]. EPS beats [12]. Recently, Uchibagle and Ramrathan Lal have present controlled low strength material using gypsum dry wallboard and pond ash through its characteristics [13]. A finite element study was done on CLSM for narrow trenches [14]. The bond strength between steel bar and CLSM was found out by finite element simulation by abacus software, which shows bond strength increase with increasing bar diameter [15]. Fly ash and pond ash which is good in spherical particles which are widely used for the construction of controlled low strength material has many advantages like good flowability, improves bleeding, reduce segregation, and reduce material cost [16, 17].

M. Uchibagle (✉) · B. R. R. Lal
KITS Ramtek, Parsod, Maharastra, India
e-mail: meenakshi.uchibagale@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_27

In India, huge amount of industrial west generated out of that maximum amount used in landfilling which is not a suitable solution, so need to search for an alternative to using this industrial product in some other application like controlled low strength material. Very few studies were done in India on the controlled low strength material. No study was done in the vicinity on local pond ash and blast furnace slag. The present study show local pond ash and blast furnace slag have the potential possibility to be used in controlled low strength material production by incorporating west and by elimination of sand in CLSM production it will contribute to sustainable development by saving natural resources like sand and reducing landfilling demand and solve the problem of disposal of such industrial by product like local pond ash and blast furnace slag.

2 Material and Methods

Pond ash was obtained from an NTPC power plant, Mouda Nagpur, Blast furnace slag collected from steel industries Sunflag Bhandra. The physical properties of pond ash and blast furnace slag are shown in Table 1. Chemical analysis (XRF-Scan and X-Ray florescence) test was done at the Indian Bureau of Mines Modern Mineral Processing Laboratory and Pilot Plant, Nagpur to identify the percentage of basic chemical present in the material. X-Ray fluorescence test was performed by using an X-Ray fluorescence spectrometer to identify the percentage of basic chemicals present in the pond ash and blast furnace slag. The basic chemical compound present in pond ash and blast furnace slag are shown in Table 2. Portland cement of grade 53 was used in the present work. CLSM required more water to become flowable so good quality simple tap water was used. Figure 1 shows the grain size distribution curve of pond ash.

Table 1 Physical property

Properties	Pond ash	Blast furnace slag
Specific gravity (G)	2.0	2.35
Optimum moisture content OMC	16%	16%
Maximum dry unit weight (γd max)	1.3 g/cc	1.067 g/cc
pH	9.596	8.852
Partical size distribution		
D10 mm	0.0069 mm	0.52 mm
D30 mm	0.018 mm	0.75 mm
D60 mm	0.04 mm	1.1 mm

Table 2 Chemical property

Compound	Pond ash (%)	Blast furnace slag (%)
SiO_2	62.67	32.13
Al_2O_3	26.18	19.80
Fe_2O_3	3.72	0.43
CaO	2.36	34.80
K_2O	1.06	0.64
TiO_2	1.67	1.13
P_2O_5	0.44	0.006

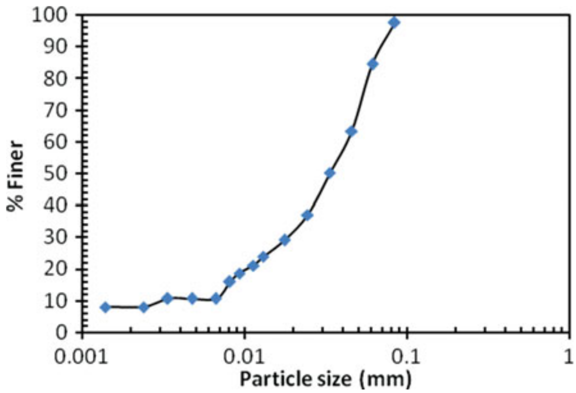


Fig. 1 Grain size distribution of pond ash

3 Mix Proportions

The ACI Committee 229 was a frame up in 1985 establish a report which includes applications, handling, performance, proportioning, and placement of CLSM mixture for different applications. As there is no other than this code available for CLSM since 1999, it is used for the present paper. Generally, for establishing the mix design of CLSM trial and error or past experience were used. In the present paper, mix ratio is defined as the ratio of the volume of cement to the volume of blast furnace slag. The mix proportion of various CLSM mixture is shown in Table 3.

4 Test Result

4.1 Compressive Strength

The compressive strength of CLSM is a very important property and it is correlated to mix components of material as mainly CLSM is used as structural fill or backfill.

Table 3 Mix proportion of different CLSM mixture

Mix	*Vc/Vbfs* (%)	Water Contain (%)	*Vpa/Vbfs*
M1C1S3	10	55	0.1
M1C2S3	20	55	0.1
M1C3S3	30	55	0.1
M2C1S3	10	55	0.3
M2C2S3	20	55	0.3
M2C3S3	30	55	0.3
M3C1S3	10	55	0.5
M3C2S3	20	55	0.5
M3C3S3	30	55	0.3
M4C1S3	10	55	0.3
M4C2S3	20	55	0.3
M4C3S3	30	55	0.3
M5C1S3	10	55	0.3
M5C2S3	20	55	0.3
M5C3S3	30	55	0.3

In the present study, a cylinder of size 75 × 150 mm was used for testing compressive strength as per ASTM D4832 and ACI229R. The material is flowable so the cylindrical mold was covered by plastic and no vibration and rodding were required. For each mix total, 12 cylinders were cast for the compressive strength test. Figure 2 shows the casting of cylindrical specimen. The curing was done for 7, 14, 28, and 56 days. The water content was maintained at 55% and, the cement content was varied 10, 20, and 30% for all CLSM mixtures. The moisture pond ash was kept in the oven for 30 min. The mixture cement by pond ash is consider 0.1, 0.2, and 0.3 and volume of pond ash to volume of blast furnace slag is considered 0.1, 0.3, 0.5 and 1, 2. Compressive strength test result are shown in Table 4.

Figure 3 shows the variation of compressive strength measured for pond ash specimen concerning mix ratio for volume for different curing periods and a linear relationship was observed between compressive strength and mix ratio. The maximum compressive strength was observed at 28 days curing ratio 0.3, M2C3S3, and the compressive strength linearly decreases to its minimum value at a mix ratio of 2, for sample M5C1S1. The compressive strength value from mix ratio 0.1 starts converging toward a mix ratio of 1. The compressive strength was highest for 56-day curing period for 12.8 Mpa for M2C3S3, This is due to a higher amount of blast furnace slag in M2C3S3. As per ACI 229 R, the CLSM mix which is compressive strength nearer to 8.3 Mpa suitable for structural fill application. The mix M1C3S3, M2C3S3, and M3C3S3 maybe use in structural fill application, and the rest all the mix may be applicable in the other filling application like conduit bedding, void filling, pavement base and backfilling for retaining wall, etc.,

Fig. 2 Casting of cylinder

Table 4 Compressive strength for different CLSM mixtures

Mix ratio	Compressive Strength in Mpa for 55% water content											
	C/BFS											
	3 Day			14 Day			28 Day			56 Day		
	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3	0.1	0.2	0.3
0.1	1.02	2.8	4.4	1.12	3.8	7.8	2.2	4.32	7.14	6.21	6.6	11.6
0.3	2.6	2.8	5.8	3.4	3.56	6.78	3.29	4.89	8.8	7.8	7.5	12.89
0.5	1.14	2.4	4.6	2.01	3.2	6.8	2.97	4.66	8.1	5.86	6.87	11.3
1	1.3	1.68	3.01	1.4	2.89	5.45	2.29	2.48	6.4	5.56	5.8	9.5
2	1	1.6	3.5	1.3	1.9	4.47	1.4	2.3	5.5	4.4	4.9	10.2

Figure 4 shows the relationship between compressive strength and curing period for all the various mix ratio. A linear relationship was observed for compressive strength and curing period for all the mixes. The specimen was tested for 7, 14, 28, and 56 days. It was observed that compressive strength increases by increasing cement content. The graph shows that CLSM strength increases as the curing period

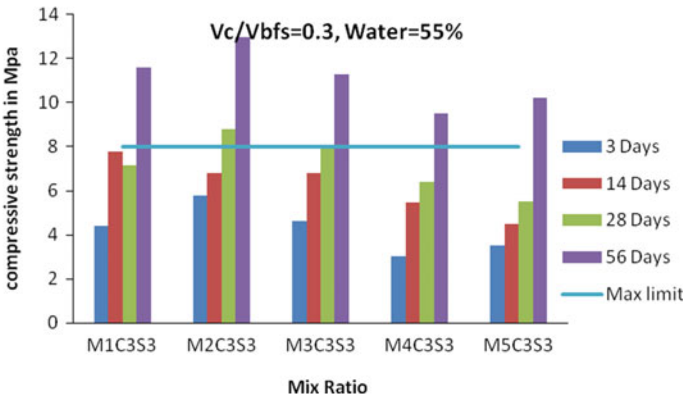


Fig. 3 Compressive strength for different CLSM mixtures for $Vc/Vpa = 0.3$

increases strength are increases as the curing period increases and the same trend observed for all types of mix.

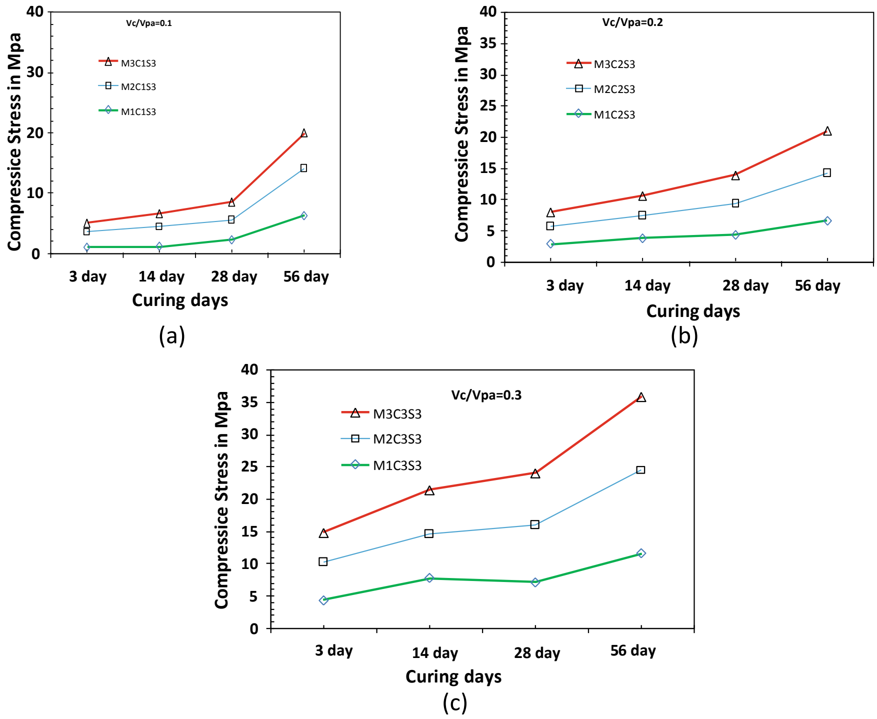


Fig. 4 Variation in compressive strength with respect to mix ratio for curing period

Fig. 5 Measurement of flowability

4.2 Flowability

Flowability is an important property of controlled low strength material is its ability to be self-leveling; to flow into and easily fill a void or congested area, without the need for conventional compaction and placing which considerably reduce the labor and enhance the construction speed. ASTM D6103 "Flow Consistency of Controlled Low Strength Material" this method is used in the present study which is the cylinder open ended of size 75 mm diameter and 150 mm long. CLSM mix powered in cylinder and cylinder allows to lift and CLSM mix allow to spread and the slump increases its diameter. The final diameter is measured in both the direction and maximum diameter treated as the flowability shown in Fig. 6. A good flowability is achieved when the diameter of CLSM is spread above 200 mm.

From figure 5 it is clear that when water content increases flowability increases and it was observed that flowability reduces by increasing cement content. Flowability obtain in the range from 190 to 310 mm. Result indicates that for all CLSM mix the flowability is in the range of moderate as well as high flowability as per ACI 229R. For mix ratio of 0.5, 1, and 2 mixes show high flowability range which is suitable for structural fill application, and the remaining mix presents moderate flowability. This result is due to more contain of pond ash as pond ash have the smooth and rounded fine practical.

4.3 Density

ASTM D6023 is used as a test method for density. The density of CLSM mix significantly influences by the mix ratio. The density measure at the time of casting is fresh density and the density measured on time of testing of 28 days sample is treated as dry density. Dry density was measured after attending 7, 14, and 28 days curing at the time of testing. Density was calculated by taking an average of densities of three cylinders. The first weight of the cylinder was calculated accurately as well volume of the cylinder was determine, and the densities of the mixtures were calculated in kg/m^3. The density was observed in the range of 940–1170 kg/m^3. Figure 6 shows that for the mix ratio 0.1, the density linearly increases to the mix ratio of 2. The

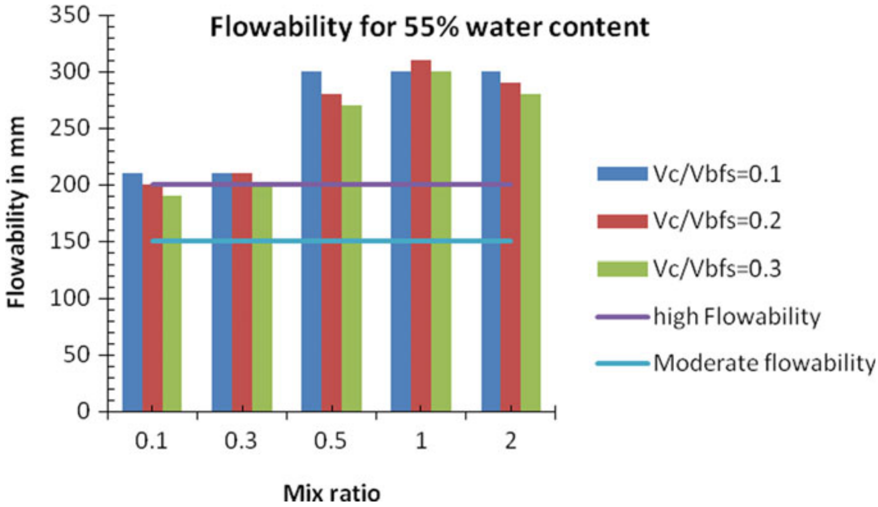


Fig. 6 Flowability for different mix ratio

highest density observed for the mix ratio of 0.5, and the lowest density observed for the mix ratio 0.1.

Figure 7 shows that density of all mix for the *Vc*/*Vpa* ratio 0.1 this indicate, the density of CLSM mix slightly increases as increasing mix ratio. And, the same trend observed for $Vc/Vpa = 0.2$ and 0.3.

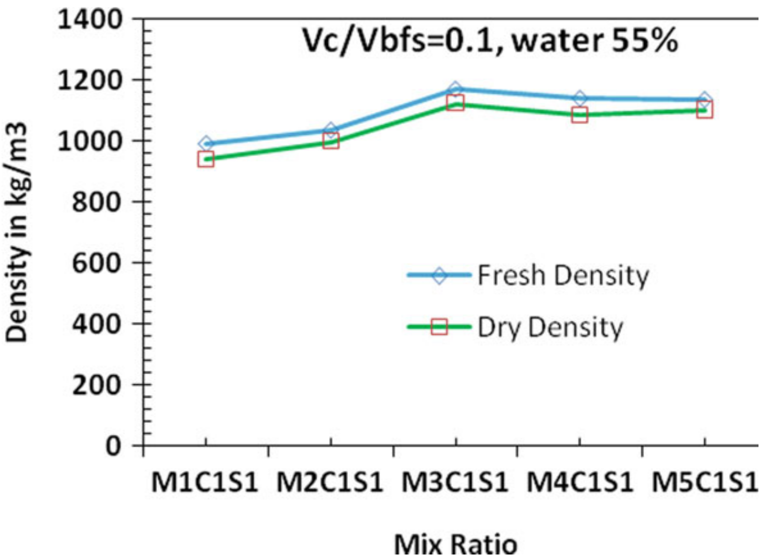


Fig. 7 Density of material

4.4 Initial Setting Time of CLSM Mix

The initial and the final setting times of the mixtures were determined according to ASTM.

Some mix need a minimum time 24 h to set and some required 36 h to set. Initial setting time for all CLSM mix ranging from 24 to 36 h.

5 Conclusions

Present studies show the properties of newly developed CLSM. Based on the experimental study the following conclusion are drawn as follows:

1. According to ACI 229R, M1C3S3, M2C3S3, and M3C3S3 is feasible for structural fill application and rest of mix can be used for other fill application like a void filling, backfill behind retaining wall, conduit bedding, pavement base, etc.,
2. Compressive strength increases as *Vc*/*Vbfs* ratio increases and also increases as the curing period increases 8.8Mpa compressive strength for 28 days was notice and 56 days strength is 12.98 for sample M2C3S3.
3. Plastic properties like flowability and bleeding were found to increase with the increase in the water content in the mix. In-service properties like unconfined compressive strength were also found to get reduced with an increase in flowability values. Moderate-to-high flowability range 190–310 mm obtain in the mix as per ASTM D6103.
4. The density was observed in the range of 940–1170 kg/m^3. For the mix ratio 0.1, the density linearly increases to the mix ratio of 2. The highest density observed for the mix ratio of 0.5, and the lowest density observed for the mix ratio of 0.1.
5. It was also observed that a maximum of three (10, 20, and 30) % of cement was required to achieve the flowability and UCS requirements for a regular excavatable flowable fill for the considered pond ash. The addition of chemical admixtures was not required for obtaining the required properties for the fills. Thus, the pond ash and cement together can be used effectively for CLSM production thereby reducing waste disposal and environmental pollution.
6. Pond ash and blast furnace slag have the potential possibility to be used in controlled low strength material production by incorporating west and by elimination of and sand in CLSM production it will contribute to sustainable development by saving natural resources like sand and reducing land-filling demand.

References

1. ACI Committee 233, *Ground Granulated Blast-furnace Slag as a Cementitious Constituent in Concrete, ACI 233R-95*. Report of ACI Committee 233, American concrete institute, Detroit, USA
2. ASTM D6103-04, Test method for flow consistency of controlled low strength material. ASTM Int. **4**(9), 1–3 (2004)
3. J.L. Hitch, Test methods for controlled low-strength material CLSM past present and future, in: *The design and application of controlled low-strength materials ASTM STP 1331. American society for testing and materials*, ed. by Howard Hitch AK, (1998) pp. 3–10
4. P. Tikalsky, M. Gaffney, Properties of controlled low strength material containing foundry sand. ACI Mater. J. **97**(6), 698–702 (2000)
5. B.W. Ramme, T.R. Naik, Construction experience with CLSM fly ash slurry for underground facilities fly ash slag silica fume and other natural Pozzolans, in *Proceedings, Fifth International Conference* (American Concrete Institute, Farming ton Hill Mich, 1995), pp. 403–441
6. K.L. Dev, R. Robinson, Pond ash based controlled low strength flowable fills for geotechnical engineering applications. Int. J. Geosynth. Ground. Eng. **1**(4), 1–13 (2015)
7. R. Siddique, Utilization of waste materials and by-products in producing controlled low-strength materials. Resour. Conserv. Recy. **54**, 1–8 (2009)
8. R. Siddique, A. Noumowe, Utilization of spent foundry sand in controlled low-strength materials and concrete. Resour. Conserv. Recy. **53**, 27–35 (2016)
9. V. Miren, A. Javier, P. Eugenia, G. Alain, Use of recycle fine aggregate for controlled low strength material (CLSM). Constr. Build. Mater. **44**, 142–148 (2013)
10. P.S. Prasad, G.V. Ramana, Imperial smelting furnace slag as a structural fill reinforced soil structure. J. Geotext. Geomembr. **44**, 406–429 (2016)
11. B. Chittoori, A. Puppal, Strength and stiffness characterization of controlled low-strength material using native high-plasticity clay. Mater. Civil. Eng. **6** (2014)
12. T. Horiguchi, R. Fujita, K. Shimura, Applicability of controlled low-strength materials with incinerated sewage sludge ash and crushed-stone powder. Mater. Civil. Eng. ASCE **23**(6), 767–771 (2011)
13. M. Uchibagle, Rathan Lal, Flow and strength characteristic of CLSM by using gypsum dry wall. *International Conference on Advances in Civil Engineering ACE2020 at VNIT Nagpur, SCOPUS*, (2020). https://doi.org/10.1007/978-981-16-4396-5
14. A. Blanco, P. Pujadas, Methodology for the design of controlled low strength material application to the backfill of narrow trenches. Constr. Build. Mater. Sci. Dir. 23–30 (2014)
15. V. Alizadeh, S. Helwany, A. Ghorbanpoor, K. Sobolev, Design and application of controlled low strength material as a structural fill. Constr. Build. Mater., Sci. Dir. **53**, 425–431 (2014)
16. Y.S. Kim, T.M. Do, H.K. Kim, G. Kang, Utilization of excavated soil in coal ash-based controlled low strength material. Constr. Build. Mater., Sci. Dir. **124**, 598–605 (2016)
17. M. Uchibagle, Rathan Lal, Performance of industrial west in structural fill controlled low strength material (CLSM). *International Conference on Latest Trends in Civil, Mechanical and Electrical Engineering*, Springer (LTCMEE-2021) April 12–13 (2021)

Experimental Investigation on Fresh Properties and Optimization of Self-Compacting Concrete Reinforced with Waste Plastic

V. Sai Neeraja and Vaibhav Sharma

1 Introduction

Some of the service industries manufacturing processes will generate large amounts of waste materials and by-products. Consequently, solid waste management has emerged as one of the world's most biggest environmental challenges. Because of rising environmental consciousness, scarcity of land-fill area and its ever-increasing cost, using waste materials and by-products has become an appealing option to disposal. The too much consumption of natural resources, the increasing production of hazardous wastes, and the contamination of the environment need to have the advancement of cutting-edge solutions for sustainable advancement.

SCC is a sort of novel concrete that, because of its excellent deformability, can actually be laid and also consolidated under its own weight without any vibration initiative, while also being cohesive to be managed without segregation or bleed. Due to its flowability, it is capable of loading formwork as well as accomplishing full consolidation also in the presence of heavy reinforcement. Without the support of vibrations, SCC compacts under its own weight. It is proportioned as though it enables movement and also flow without partition. It promotes appropriate filling right into forms with strong reinforcement, leading to great and sound concrete. On the contrary, if not correctly vibrated, regular vibrated concrete leaves big honeycomb-like structures in comparable applications, and it includes faults, as an example pores as well as air gaps that arise throughout the curing course [1].

More over in order to pass through congested reinforcing bars, SCC needs not only a high deformability of the paste or mortar, but also resistance to coarse aggregate and mortar segregation. In order to attain these outcomes, inert (limestone) or

V. Sai Neeraja · V. Sharma (✉)
School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India
e-mail: civil.vaibhav.sharma@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_28

cementitious (fly ash, silica fumes) accompaniments are generally used. Furthermore, super plasticizers or viscosity modifying chemicals help to reduce segregation and console-ty in concrete [2]. To produce self-compact ability, approaches such as limited aggregate content, water-to-powder ratio, and employment of superplasticizer have been used [3]. A high-quality SCC must have 3 key qualities in contrast to traditional concrete: filling up ability—the ability to stream into the formwork and entirely load all areas by its very own weight; passing capability—the propensity to move through and around constrained spaces between steel enhancing bars without segregation or blocking; and also segregation resistance—the capacity to stay uniform during transport, positioning, and after placement.

Copper slag is a large metallurgical by-product produced in smelters during the transformation of copper ore concentrates into metallic copper [4]. The only disadvantage of SCC over traditional concrete is its high cost, which is attributable to the higher cement content. This disadvantage of SCC can be overcome by using supplementary cementing material [5]. Many different alternatives have now been devised to utilize or dispose of the vast volumes of fly ash produced by power generating [6]. Furthermore, the usage of fly ash as a cement binder replacement has a wide ranging ecological impact. Initially, using this material in cement and concrete technologies helps for the decrease of problematic rubbish dumps containing this waste. The lowering of cement binder in the concrete mix composition, on the other hand, has a favorable influence on the reduction of carbon emissions and the level of energy produced in the Portland cement manufacturing process.

As sustainability plays a crucial role nowadays in construction sector the use of industrial by-products like fly ash, plastic waste, recycled coarse aggregate, and copper slag, replacement in the development of green self-compacting concrete. There is less research work carried out for copper slag as cement replacement and plastic waste to fine aggregate replacement, as rapid service industrial waste can create a circular economy this study was carried out to show its significance.

2 Materials

Class F fly ash obtained from Rayalaseema Thermal Power Station is sited at Yerraguntla (Md) in Kadapa (Dist), Andhra Pradesh. The power station is a coal-fired power plant owned by APGENCO, OPC 43 grade cement as an external calcium source obtained from the local market, PVC granules of 0.05–1.4 of density (g/cm^3), hardness of 155 (Rockwell). In this investigation, RCA of local demolished construction was employed. IS 8112:1989 approved OPC grade 43 was used and the test results properties are represented in Table 1. A 1.1 specific gravity poly-carboxylic ether-based super plasticizer that is commercially available was used.

The fine aggregate used was river sand with a 3% of bulking nature falling in IS Zone II having a fineness modulus of 3.12. The physical properties of fine aggregate were represented in Table 2. Plastic waste (PVC granules) was used as a replacement

Table 1 Cement properties

S. No	Property	Test value
1	Specific gravity	3.13
2	Normal consistency	33%
3	Time for initial setting (min)	42
4	Time for final setting (min)	350
5	Fineness	6

Table 2 Fine aggregate properties

S. No.	Property	Test value
1	Specific gravity	2.62
2	Bulking of sand	3%
3	Fineness modulus	3.12
4	Fineness	II

Table 3 Coarse aggregate properties

S. No.	Property	Test value
1	Specific gravity	2.76
2	Water absorption	0.41%
3	Elongation index	20.20%
4	Flakiness index	21.40%
5	Fineness modulus	7.36
6	Bulk density	1541 kg/m^3

of sand as 0, 5, 10, 15, and 20 %. The typical properties of PVC granules are represented in Table 4. A locally available coarse aggregate of 7.36 fineness and 0.41% water absorption capacity is used in this study. The physical properties of coarse aggregate are represented in Table 3.

Table 4 PVC granules properties

S. No.	Property	Test value
1	Density (g/cm^3)	0.05–1.40
2	Water absorption, 24 h (%)	0
3	Max operating temp (°F/°C)	140/60
4	Tensile strength (Kpa)	51,675
5	Flexural strength (Kpa)	88,192
6	Hardness	115 (Rockwell R)
7	Heat deflection temp (°F/°C) at 1818.96 kPa	176/80
8	Melting temp (°F/°C)	N A

3 Design of Experiment

Optimization of performance characteristic for a process product plays a crucial role in the present era. Moreover, orthogonal array concept is resulting from the factorial design methodology with paired wise balancing attribute [7]. In order to consolidate a lot of repeated values into a single value the signal-to-noise proportion from Taguchi technique was embraced for recognizing the precise existing information variation. In the Taguchi approach, the signal-to-noise ratio is used to consolidate a number of repeated values into a single value which is the depiction of the existing variant in the data [8].

During this current study, Taguchi design approach was adopted to minimize sensitivity of uncontrolled factors (S/N ratio). Owing to a wide range of SCC, in general more experimentation is to be performed to decide a suitable concrete mix for reaching target desired strengths. As a result, the Taguchi technique of optimization will significantly reduce the number of experiments required to analyze the interaction, effects, and factors employed. For experimentation, a robust design of L25 orthogonal array was developed. Four controlled factors fly ash, copper slag, plastic waste, and recycled coarse aggregates and five levels are used in the present study with an overall 25 runs. The optimization specifications are slump flow result, V funnel result of circulation time, as well as L box outcome of passing capacity. There is one kind of data characteristic discovered in the present trials which was thought about as ‘Larger is better’ quality feature. Higher signal-to-noise proportion (S/N) dimensions determine control variable settings that reduce the influence of noise elements [9]. The signal-to-noise ratio attempts to determine exactly how the response varies with respect to the small or target value under various noise situations (Table 5).

Factor A is the substitute of cement by fly ash (replaced by 25, 30, 35, 40, 45 %), factor B is the substitute of cement by industrial waste copper slag (replaced by 0, 3, 6, 9, 12 %), factor C is the substitute of fine aggregate by PVC granules (0, 5, 10, 15, 20 %), and factor D represents substitute of coarse aggregate by recycled coarse aggregate (replaced with 0, 25, 50, 75, 100 %).

Table 5 Design of parameters considered for Taguchi method

Notation	Factors	Levels
A	Fly ash	25, 30, 35, 40, 45
B	Copper slag	0, 3, 6, 9, 12
C	Plastic waste	0, 5, 10, 15, 20
D	RCA	0, 25, 50, 75, 100

4 Experimental Investigation

Moreover for a specified target factors, different levels of approach results will be obtained, and based on the test results, individual parameter performance can be evaluated [10]. Table 6 displays the average S/N ratios of the control factors for the slump flow test by considering lager is better quality characteristic. The basic decision making output parameter is the S/N ratio. In general, three basic S/N equations are generally employed to categorize the target function as 'larger the better, smaller the better, and nominal the best' [10]. The rank of RCA stood first which means that it shows more effect on the slump flow property, later leaded by fly ash and plastic waste.

From Table 6, it was clearly observed that copper slag stood in fourth rank which shows very less effect on slump flow property of SCC as computed based on S/N ratio. The means of slump flow are represented in Table 7 which represent RCA in first rank and copper slag in fourth rank.

The rank of RCA stood first which means that it shows more effect on the passing ability property, later followed by plastic waste and fly ash. From Table 8, it was clearly observed that copper slag stood in fourth rank which shows very less effect on passing ability property of SCC as computed based on S/N ratio.

Table 6 Response table for signal-to-noise ratios of slump flow

Level	Fly ash	Copper slag	Plastic waste	RCA
1	55.42	55.61	55.75	56.28
2	55.63	55.73	55.78	56.04
3	55.53	55.52	55.64	55.89
4	55.64	55.60	55.49	55.60
5	55.82	55.57	55.38	54.23
Delta	0.40	0.21	0.40	2.04
Rank	2	4	3	1

Table 7 Response table for means of slump flow

Level	Fly ash	Copper slag	Plastic waste	RCA
1	593.6	605.6	614.0	651.4
2	607.4	612.4	616.6	633.6
3	599.2	599.8	607.6	622.8
4	606.6	604.4	597.2	602.8
5	619.2	603.8	590.6	515.4
Delta	25.6	12.6	26.0	136.0
Rank	3	4	2	1

Table 8 Response table for signal-to-noise ratios of L box

Level	Fly ash	Copper slag	Plastic waste	RCA
1	− 1.1264	−0.9634	−0.9209	−0.6695
2	−1.0016	−0.9948	−0.8996	−0.7622
3	−1.0368	−1.0801	−1.0957	−0.9158
4	−1.0148	−0.9579	−1.0592	−1.1503
5	−0.9201	−1.1036	−1.1243	−1.6019
Delta	0.2063	0.1458	0.2247	0.9324
Rank	3	4	2	1

The average S/N ratios of the control factors intended for the L box test by considering lager are better quality characteristic which are represented in Table 8. Response table for means was represented in Table 9 which tells the passing ability rank stood first for RCA and last for copper slag because of its bulk density variation.

The V-shaped funnel test results are used to evaluate the stability of produced concrete [11]. The rank of fly ash stood first which means that it shows more effect on the filling ability property, later leaded by copper slag and RCA as given in Table 10 when large is better quality characteristic was considered.

Table 9 Response table for means of L box

Level	Fly ash	Copper slag	Plastic waste	RCA
1	0.8800	0.8960	0.9000	0.9260
2	0.8920	0.8920	0.9020	0.9160
3	0.8880	0.8840	0.8820	0.9000
4	0.8900	0.8960	0.8860	0.8760
5	0.9000	0.8820	0.8800	0.8320
Delta	0.0200	0.0140	0.0220	0.0940
Rank	3	4	2	1

Table 10 Response table for signal-to-noise ratios for V funnel

Level	Fly ash	Copper slag	Plastic waste	RCA
1	21.92	23.65	24.35	25.11
2	23.81	22.76	23.21	23.89
3	24.41	23.95	22.63	23.15
4	24.51	23.36	23.77	22.78
5	24.23	25.16	24.91	23.94
Delta	2.58	2.40	2.28	2.33
Rank	1	2	4	3

Table 11 Response table for means of U box

Level	Fly ash	Copper slag	Plastic waste	RCA
1	13.32	15.39	16.63	18.01
2	15.84	14.08	14.79	15.93
3	16.72	16.24	13.95	14.80
4	16.84	15.29	16.09	14.33
5	16.41	18.13	17.66	16.05
Delta	3.52	4.05	3.71	3.68
Rank	4	1	2	3

Response table for means was represented in Table 11 which tells the passing ability rank stood first for copper slag**.**

5 Results and Discussion

It is important to use a systematic move toward for identifying optimal mixes and investigate the most efficient factors under a set of constraints [11]. Design of experimentation as carried out using Taguchi method and the obtained 25 mixes is represented in Fig. 1 along with fresh properties test results. Slump flow varies from a minimum of 480 to 664 mm, and L box results vary from a minimum of 0.82 to a maximum of 0.95. Minimum time period taken to fill V funnel varies from 8.36 s to a maximum of 18.20 s. Using IS 10262–2019 [12], SCC mix design was carried for M1 to M25 mixes by considering 0.45 water-powder ratio and conplast admixture.

Increasing fly ash content increases slump flow diameter but increase in copper slag decreases the slump flow diameter. Increasing plastic waste content decreases slump flow diameter but increase in the percentage of recycled coarse aggregate decreases the slump flow diameter tremendously as shown in Fig. 2.

Addition of fly ash has increased the paste volume so that the flowability was gained by SCC. Due to high density, the increase in the copper slag reduces the concrete flowability as shown in Fig. 3. However, the variation of slump flow was observed more when recycled aggregates are used.

Increasing fly ash content increases passing ability but increase in copper slag decreases the passing ability of SCC. Increasing plastic waste content decreases passing ability but increase in the percentage of recycled coarse aggregate decreases the slump flow diameter tremendously as shown in Fig. 4.

Addition of fly ash has increased the paste volume so that the passing ability was gained by SCC. Due to high density, the increase in the copper slag reduces the concrete flowability as shown in Fig. 5. Most of the investigations show that the plastic waste affects the passing ability in increasing and decreasing nature beyond the replacement of 10% with fine aggregate as shown in Fig. 5, this property may be

MIXES	FLY ASH(%)	COPPER SLAG(%)	PLASTIC WASTE(%)	RCA(%)	SLUMP(mm)	L BOX RATIO	V FUNNEL (sec)
M1	25	0	0	0	660	0.95	18.20
M2	25	3	5	25	634	0.91	10.52
M3	25	6	10	50	611	0.88	9.41
M4	25	9	15	75	583	0.87	8.36
M5	25	12	20	100	480	0.79	20.10
M6	30	0	5	50	637	0.91	12.43
M7	30	3	10	75	618	0.88	11.67
M8	30	6	15	100	499	0.82	19.56
M9	30	9	20	0	646	0.93	18.00
M10	30	12	0	25	637	0.92	17.55
M11	35	0	10	100	511	0.83	13.20
M12	35	3	15	0	638	0.91	18.20
M13	35	6	20	25	619	0.91	16.70
M14	35	9	0	50	612	0.9	17.40
M15	35	12	5	75	616	0.89	18.10
M16	40	0	15	25	629	0.92	17.00
M17	40	3	20	50	617	0.9	17.40
M18	40	6	0	75	606	0.87	17.42
M19	40	9	5	100	532	0.86	14.80
M20	40	12	10	0	649	0.9	17.56
M21	45	0	20	75	591	0.87	16.10
M22	45	3	0	100	555	0.86	12.60
M23	45	6	5	0	664	0.94	18.10
M24	45	9	10	25	649	0.92	17.90
M25	45	12	15	50	637	0.91	17.35

Fig. 1 SCC mix with fresh properties result

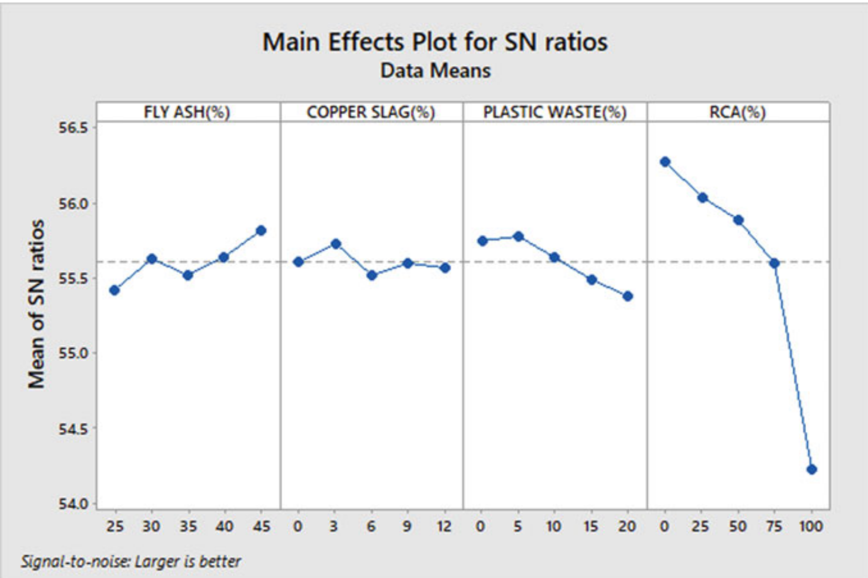


Fig. 2 Main effect plot for S/N ratio of slump flow test (larger is better)

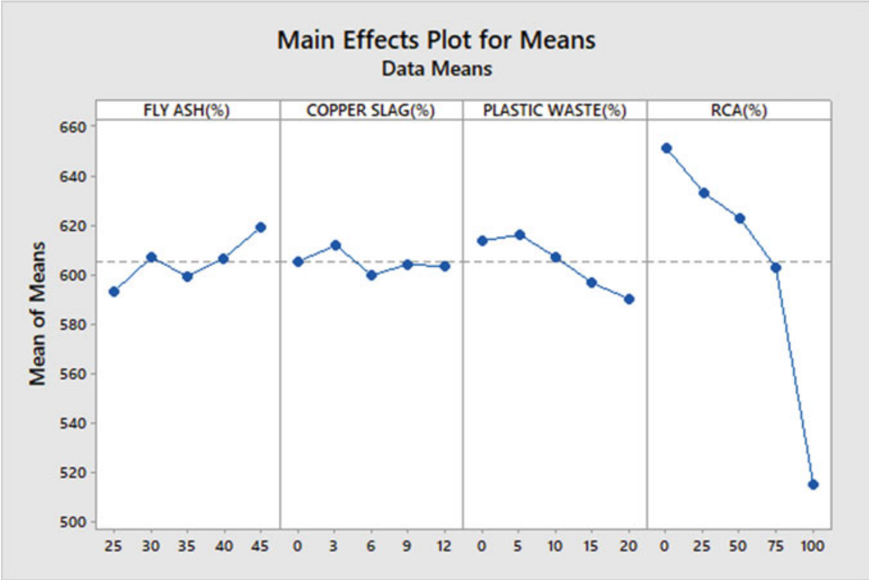


Fig. 3 Main effect plot for means of slump flow test (larger is better)

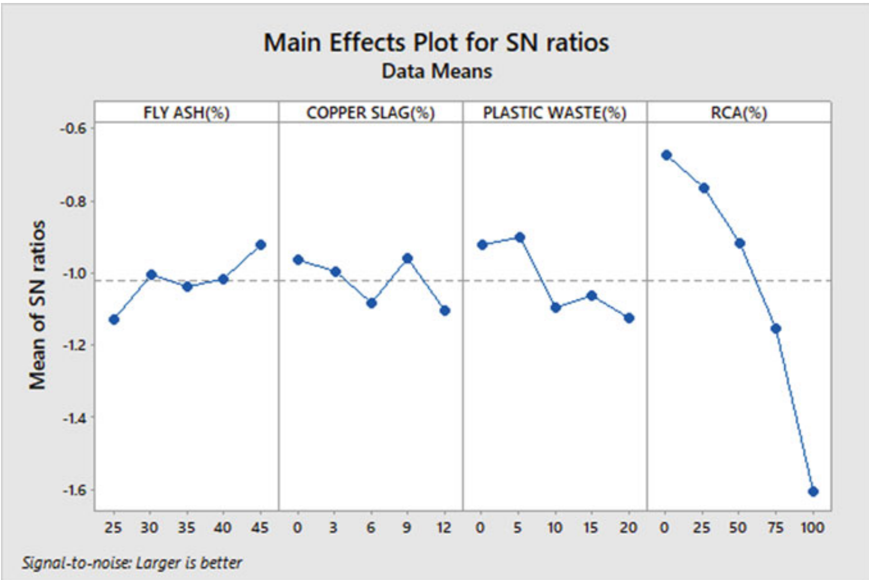


Fig. 4 Main effect plot for S/N ratio of L box test (larger is better)

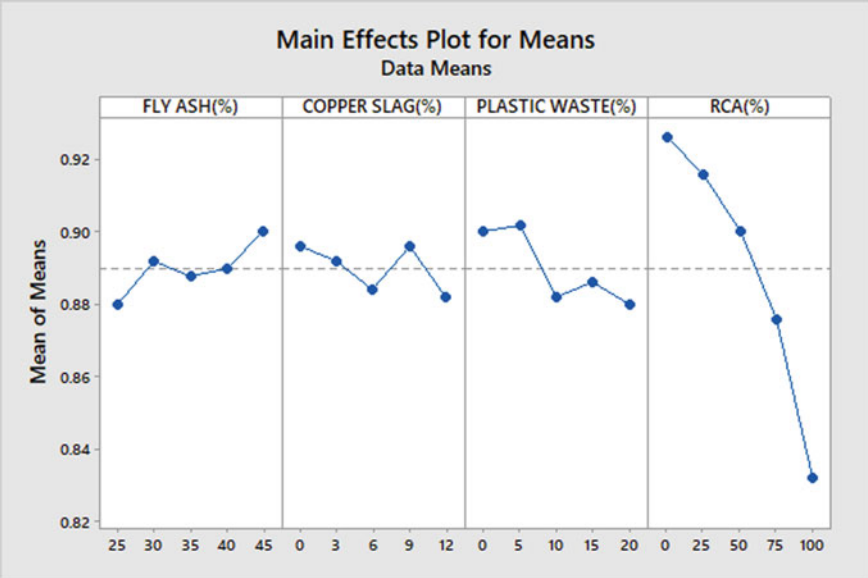


Fig. 5 Main effect plot for means of L box test (larger is better)

because of the interlocking texture effects of cement paste [13] with smooth surface of PVC granules.

Increasing fly ash, copper slag, and plastic waste content increase filling ability but increase in RCA decreases the filling ability of SCC. Increasing plastic waste content increases passing ability due to the ease of move moment of PVC granules by taking cement paste plasticity property into action [14] as shown in Fig. 6. Main effect plot for means of V funnel test was represented in Fig. 7. Larger is better quality characteristic was considered to study the filling ability of the SCC as shown in Fig. 7.

6 Conclusion

1. Taguchi optimization strategy is utilized to recognize the impact of powder material and top quality of plastic waste, and RCA on relative fresh properties for SCC is explored in this paper.
2. A personalized method for evaluating signal-to-noise ratio is suggested, which is based on the concept of the mean's error balancing property.
3. Fly ash and copper slag waste content are used as fillers for the concrete production instead of cement which leads to an increase in surface area and obstructs the flow of SCC.

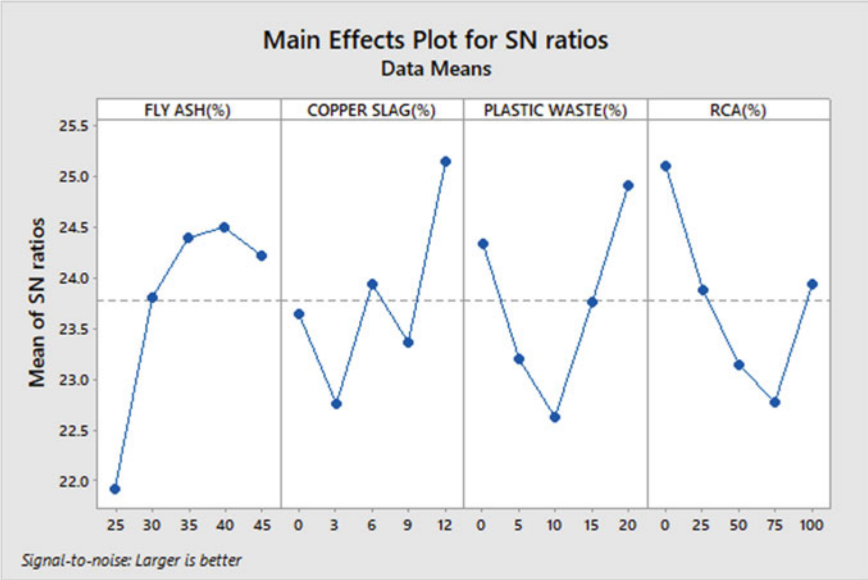


Fig. 6 Main effect plot for S/N ratio of V funnel test (larger is better)

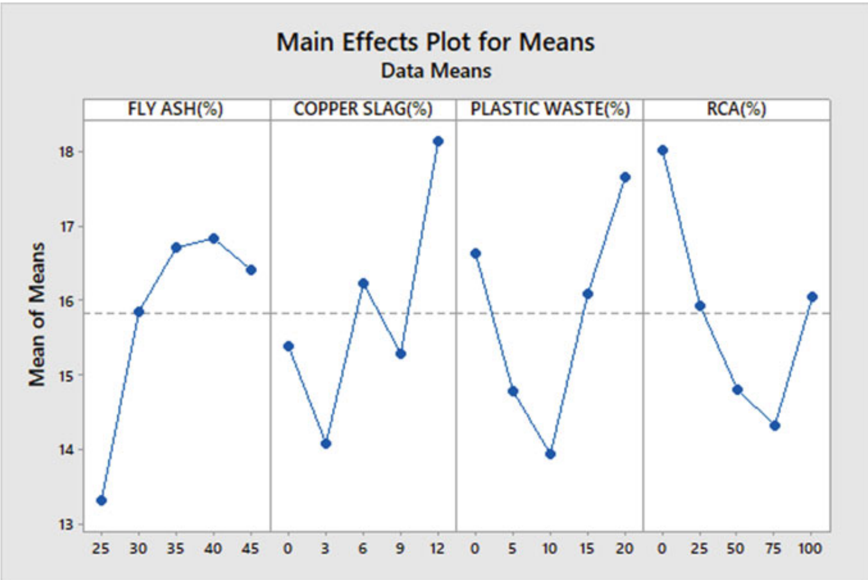


Fig. 7 Main effect plot for means of V funnel test (larger is better)

4. Use of RCA as coarse aggregate replacement shows that increase in RCA effect the slump property of SCC.
5. Plastic waste used as a replacement to fine agglomerates shows effect on passing ability of SCC.

References

1. T. Hemalatha, J.M. Chandra Kishen, A. Ramaswamy, Investigation on the relationship between microstructure and fracture properties of self-compacting concrete (SCC). Adv. Civ. Eng. Mater. **6**(1), 20170055 (2017). https://doi.org/10.1520/acem20170055
2. N. Gupta, R. Siddique, Durability characteristics of self-compacting concrete made with copper slag. Constr. Build. Mater. **247**, 118580 (2020). https://doi.org/10.1016/j.conbuildmat.2020.118580
3. H. Okamura, K. Ozawa, Mix design for self-compacting concrete. *Concrete Library of JSCE No. 25*, (1995). https://nanopdf.com/download/concrete-library-of-jsce-no-25-june-1995_pdf. Accessed 25 Sep 2021
4. K. Murari, R. Siddique, K.K. Jain, Use of waste copper slag, a sustainable material. J. Mater. Cycles Waste Manage. **17**(1), 13–26 (2014). https://doi.org/10.1007/s10163-014-0254-x. Springer, Tokyo
5. R. Sharma, R.A. Khan, Sustainable use of copper slag in self compacting concrete containing supplementary cementitious materials. J. Clean. Prod. **151**, 179–192 (2017). https://doi.org/10.1016/j.jclepro.2017.03.031
6. G.L. Golewski, The influence of microcrack width on the mechanical parameters in concrete with the addition of fly ash: consideration of technological and ecological benefits. Constr. Build. Mater. **197**, 849–861 (2019). https://doi.org/10.1016/j.conbuildmat.2018.08.157
7. D. Das, A. Chatterjee, Taguchi and ANOVA approach for optimization of flow characteristics of self-compacting concrete. Emerg. Mater. Res. **3**(1), 37–45 (2014). https://doi.org/10.1680/emr.13.00016
8. A. Chatterjee, D. Das, Assessing flow response of self-compacting mortar by Taguchi method and ANOVA interaction. Mater. Res. **16**(5), 1084–1091 (2013). https://doi.org/10.1590/S1516-14392013005000083
9. A. Joshaghani, A.A. Ramezanianpour, O. Ataei, A. Golroo, Optimizing pervious concrete pavement mixture design by using the Taguchi method. Constr. Build. Mater. **101**, 317–325 (2015). https://doi.org/10.1016/j.conbuildmat.2015.10.094
10. M.A. Emara, F.M. Eid, A.A. Nasser, M.A. Safaan, Prediction of self-compacting rubberized concrete mechanical and fresh properties using Taguchi method. J. Civ. Environ. Eng. **8**(2) (2018). https://doi.org/10.4172/2165-784x.1000301
11. E. Ozbay, A. Oztas, A. Baykasoglu, H. Ozbebek, Investigating mix proportions of high strength self-compacting concrete by using Taguchi method. Constr. Build. Mater. **23**(2), 694–702 (2009). https://doi.org/10.1016/j.conbuildmat.2008.02.014
12. IS 10262-2019 concrete mix proportioning guidelines. https://drive.google.com/file/d/18pNhhSWEAJoCOXQ1wzRqHfVIB1rwBWY0/view. Accessed 25 Sep 2021
13. M.K. Mohammed, A.I. Al-Hadithi, M.H. Mohammed, Production and optimization of eco-efficient self-compacting concrete SCC with limestone and PET. Constr. Build. Mater. **197**, 734–746 (2019). https://doi.org/10.1016/j.conbuildmat.2018.11.189
14. V.S. Neeraja, A. Sharma, Enviro safe concrete using plastic waste. Procedia Environ. Sci. Eng. Manag. **6**(4), 565–574 (2019)

Construction Sustainability in Indian Perspective-A Review

Junaid Manzoor and Pushpendra Kumar Sharma

1 Introduction

India is the 7th largest country in the world and has been a home for more than a billion people. Construction industries of India take about 6.5% of country's GDP. During the last few decades, the investors found an open opportunity in bringing sustainability into play, particularly the commercial and residential construction, as these two groups contribute toward a major part of the industry, as both of them consume more energy and ultimately causing more and more emission of gasses. So, it becomes obvious for all the businesses related and the policymakers to endorse sustainability into construction project management. There is a lot of literature available about sustainable construction practices, among which PPMBOK (Project Management Body of Knowledge) is the most common and actively used.

1.1 Concept of Sustainability in Project Management

The word sustainability is derived from the Latin word 'sustinere' which means 'to hold'. In the context of the construction project, it means the act of balancing the social, economic, and most importantly the environmental facets of any project without compromising the needs of future generations. Due to the growing urbanization of cities, the level of pollution, and resource exploitation, it has become the need of the hour to implement the sustainable practices of project management into our construction industries. This article attempts to bring forward the scenario of

J. Manzoor · P. K. Sharma (✉)
School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India
e-mail: p.sharmaji10@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_29

sustainable construction practices in Indian industries and also the obstacles faced by the industries in implementing sustainability in their projects.

2 Literature Review

Sádaba et al. [1] performed a detailed literature analysis with over 100 references to examine the relationships between the two fields. In this article, the author tries to put forward a new set of guidelines for project managers to deal with the projects in a pretty sustainable way. Also, the author has a future agenda of how project management can lead to sustainability in construction companies and construction projects.

Sharma et al. [2] to find a use of 'Adobe' as a sustainable building material, several tests on the commonly used building material in rural hilly areas were performed, i.e., 'Adobe'. The tests such as sieve analysis, proctor compaction test, compressive strength test, etc. The tests conclude that the use of Adobe as a sustainable material can help rural construction in many sustainable ways.

Mokal et al. [3] analyzed the need for using eco-friendly materials in our construction practices. In this article, the author finds some eco-friendly materials which can be used as a substitute to conventional building materials without compromising the strength and durability of the structure. Materials such as lime, eco-friendly tiles, sand-lime bricks, etc. are the materials that can be used to replace the conventional building materials so that the sustainability of projects can be achieved.

Boks et al. [4] in their review of literature in the context of design for sustainability (DFS) and project management, tried to find the gap between the project management literature and design for sustainability.

Banihashemi et al. [5] in their work have highlighted the most vital factors in attaining sustainable project management. Their work engrossed on the significant methods of integrating sustainability into construction project management. Factors such as the role of clients, first-class workmanship, tactical direction, health and safety procedures, project manager's knowledge, etc. were recognized as some of the chief focuses in making a sustainable construction project management.

Ogunde et al. [6] surveyed different construction companies by giving them questionnaires and receiving the data in terms of feedback. This data was used to analyze different success factors such as project manager's involvement, client's interest, effective communication, efforts of workforce, etc.

Reddy et al. [7] worked on the measure of finding innovative methods of using sustainable building construction materials in building modern cities. Also, waste production by the Indian construction sector is a major cause of pollution. So, using sustainable materials could reduce wastage and hence lead to sustainable construction.

Gupta et al. [8] carried out a case study in which the whole intention was to make efforts for using sustainable building materials rather than using natural resources. He also found that natural resources tend to be cheaper and readily available over indigenous materials such as low VOC paint, LED lighting system, etc. Moreover, the use of green building designs is also helpful for attaining eco-friendly construction.

Reddy et al. [9] worked on building a Sustainable Building Assessment Tool (SBAT) to compare the level of sustainability of any building structure. The already present and widely used assessment tools like GRIHA, LEED, and IGBC seem to have limitations against Indian construction. So, here arises the need of developing a Sustainable Building Assessment Tool.

Agarchand and Laishram [10] carried out their study on infrastructure develop through public–private partnership (PPP). Though the construction in this mode in this mode is going at a good pace there arises there need for establishing the guidelines for sustainable construction practice. The work was carried by the means of literature review and interview.

Chawla et al. [11] carried out a study in which various issues in connection with the sustainability aspect of the project were identified. These issues were found between the year 1987–2018. Threats, opportunities, and challenges related to sustainable construction project management were pointed out in this study.

Syamimi and Ling [12] worked on finding the main factors that would force the construction companies to incorporate sustainable construction project management. According to their article government policies, client awareness, high fuel cost, international pressure, the high reputation of organizations, etc. are some of the important drivers that would make organizations implement sustainable construction.

Solaimani and Sadighi [13] investigated the need for Lean construction practices while keeping in view the other aspects too, such as concerns of stakeholders, the concern of people, and preventing this planet from exploiting its resources.

Jat and Mane [14] worked basically toward the choice of clients while choosing a conventional approach of construction or green building approach because the choice of any customer would surely have a major impact on the price of construction. Though the green building is more expensive than the conventional buildings but in the long run green builds require less maintenance as compared to conventional buildings.

Gupta et al. [15] in their two-year research work focused on identifying the need, tools, obstacles, and limitations of mainstreaming sustainable social house building. Due to the constant pressure of the growing population, the need for timely completion and sustainable projects has taken a peek. So, it becomes necessary to make sustainable construction practices very common among clients.

Hirpara et al. [16] acknowledged the crucial factors affecting the culture of sustainable construction projects. Due to the rapid urbanization, the resources are utilized at a continual pace, which is going to lead to environmental depletion in the coming years of construction. Through a questionnaire survey, the data collected was used to identify the most important factors governing the sustainable construction approach.

Chourasia [17] worked on finding the possibility of using bamboo in construction needs while listing the various properties of bamboo-like easily available, its strength (tensile and bending), durable, etc. due to its engineering properties such as tensile strength, bamboo has been used in past also as a building material. In his work, the author has mentioned methods of improving the engineering properties of bamboo.

Patidar [18] researched and collected some data from some selected green buildings in India. These buildings tend to be GRIHA-certified buildings. Upon the findings, it was found that GRIHA-certified buildings had both environmental and economic benefits. The work of the author focuses on the effectiveness of GRIHA-certified architectures in comparison to contemporary architectures.

Goel et al. [19] reviewed and assessed the status of sustainable construction practices in India. With the help of inductive and qualitative analysis, three categories were formed viz: social, economic, and environmental. These categories unveiled huge deviation among the prevailing construction practices and the required construction practices for a sustainable construction project.

Manna and Banerjee [20] have put forth the green building movement and the criteria for the certification process of green buildings. The author has mentioned many green building rating systems in their work and elaborated on the role of these rating systems. Criteria like the selection of sustainable sites, water efficiency, energy and atmosphere, materials and resources, etc. are required for any building to get green building certification.

Mistri et al. [21] analyzed the lack of factors for a successful construction project management and observed the impact of these factors on achieving sustainable project management. The author highlights the skill shortage among artisans as the first lacking factor in achieving sustainable construction. Analytic Hierarchy Process (AHP) was used to divide the causes of skill shortage into different categories.

Nayak and Kayarkatte [22] carried out a comprehensive literature review to find state the status of sustainable green building construction in India. The author's works also rely on finding the role of rating systems in India in making India a green country along with finding the limitations of green buildings. In the end, the authors suggest some strategic policies to get Indio more into green building construction.

Gangwar et al. [23] to study India's rating system for green buildings also put an overview about the principles of design of sustainable housing in India. The systems like GRIHA, IGBC, and Eco-Housing Assessment Criteria were selected for the study.

Aghaegbuna et al. [24] carried out a study to find the obstacles faced by the construction project managers in achieving both the sustainability and success of a construction project. The work was carried out by circulating a questionnaire among the construction companies.

Akula Prakash et al. [25] defines a sustainable building as "the plan and development of structures utilizing strategies and materials that are asset productive and that will not bargain the wellbeing of climate or the related wellbeing and prosperity of the structure's inhabitants". In his work, he tries to mention the deterrents in attaining sustainable construction.

Nithya et al. [26] worked on finding a way to avoid wastage in construction industries in India. Their work also emphasizes the prevailing technology in India taking care of the waste generated from construction industries. Different types of wastes were identified by the author. This study also enlightens some of the initiatives taken by the government of India for infusing zero wastage policies in Indian construction industries to provide a sustainable future.

3 Conclusion

Keeping in view the existing literature, this article carried out an exploratory review on the importance and utilization of sustainable project management in the design for sustainability approach. This study aimed to find out the challenges faced by the construction companies and project managers in practicing sustainable construction project management and the methods and efforts to be taken to make sustainable construction project management a sound practice of management in the construction companies. The challenges such as labor-related challenges, work-related challenges, time-related challenges, etc. need to be taken care of. Further for the actual fieldwork, a survey questionnaire is to be prepared and circulated among the construction companies across India and get actual data for the research.

References

1. S. Marcelino-Sádaba, l.F. Gonzalez-Jaen, A. Excurdia (15 July 2015) Using project management as a way to sustainability. J. Cleaner. Prod. **99**
2. V. Sharma, H.K. Vinayak, B.M. Marwaha (6 July 2015) Enhancing sustainability of rural adobe houses of hills by addition of vernacular fiber reinforcement. Int. J. Sustain. Built. Environ.
3. A.B. Mokal, A.I. Shaikh, S.S. Raundal, S.J. Prajapati, U.J. Phatak (April 2015) Green building materials—a way towards sustainable construction. Int. J. Appl. Innov. Eng. Manage. (IJAIEM) **4**(2)
4. F. Ali, C. Boks, N. Bey (2016) Design for sustainability and project management literature—a review. *23rd CIRP Conference on Life Cycle Engineering*, CIRP, vol. 48, pp. 28–33
5. S. Banihashemi, M.R. Hosseini, H. Golizadeh, S. Sankaran (18 Jan 2017) Critical success factors (CSFs) for integration of sustainability into construction project management practices in developing countries. Int. J. Proj. Manage.
6. A.O. Ogunde, O. Olaolu, A. Afolabi, J. Owolabi, R. Ojelebi (2017) Challenges confronting construction project management system for sustainable construction in developing countries—a case study. J. Build. Perform. **8**(1)
7. A.S. Reddy, P.R. Kumar, P.A. Raj (2017) Sustainable construction—an Indian perspective. *Proceedings of Advances in Sustainable Materials, Construction and Technology (ASMCT) CBIT Hyderabad*
8. A. Gupta, Building a green home using local resources and sustainable technology in Jammu region—a case study. *International Conference Alternative and Renewable Energy Quest, AREQ 2017* (1–3 Feb 2017)
9. A.S. Reddy, P.A. Raj, R.K. Pancharathi (Dec 2017) Developing a sustainable building assessment tool (SBAT) for developing countries—case study of India. *Urbanization Challenges in Emerging Economies*
10. N. Agarchand, B. Laishram, Sustainable infrastructure development challenges through PPP procurement process—Indian perspective. Int. J. Managing. Projects. Bus. (6 June 2017)
11. V.K. Chawla, A.K. Chanda, S. Angra, G.R. Chawla, The sustainable project management—a review and future possibilities. J. Proj. Manage. **3**(3) (June 2018)
12. N. Syamimi, L.Y. Ling, Drivers in the implementation of sustainable construction management mong mainstream, contractors. Int. J. Eng. Technol. **7**(3.20):172–176 (2018)
13. S. Solaimani, M. Sadighi, Toward a holistic view on lean sustainable construction: a literature review. J. Cleaner. Prod. 119213 (Nov 2019, 2020)
14. A.K. Jat, P.D. Mane, Consumer's acceptance to green building concept for sustainable construction in India. Int. J. Adv. Res., Ideas Innovations Technol. **4**(1) (2018)

15. R. Gupta, S. Seth, Z. Niazi, J.S. Villanueva, S. Tuteja, M. Behal, P. Caleb, A. Banerjee, *Mainstreaming Sustainable Social Housing in India: Findings and Insights from the Mas-SHIP Project*. (Oxford Brookes University, TERI Development Alternatives and UN-Habitat, New Delhi, 2018)
16. R.J. Hirapara, N. Sharma, B. Kashiyani, Identification of crucial factors affecting to sustainable construction projects. Int. J. Eng. Technol. (IRJET) **5**(04) (April 2018)
17. D. Chourasia, Bamboo with reference to Indian context: potential sustainable building material and awareness. *AIP Conference Proceedings 2158*, (2019) p. 020004
18. S. Patidar, Sustainable architecture based on GRIHA norms in case of India. JETIR **6**(6) (June 2019)
19. A. Goel, L.S. Ganesh, A. Kaur, Sustain assessment of construction practices ibn India using inductive content analysis of research literature. Int. J. Constr. Manage. **21**(8) (2019)
20. D. Manna, S. Banerjee, A review on green building movement in India. Int. J. Sci. Technol. Res. **8**(10) (Oct 2019)
21. A. Mistri, C.G. Patel, J.K. Pitroda, Analysis of causes effects and impacts of skill shortage for sustainable construction through analytic hierarchy process. Int. J. Technical. Innov. Modern. Eng. Sci. (IJTIMES) **5**(5) (May 2019)
22. P. Nayak, N. Kayarkatte, Sustainability study of green building in India—through PESTLE and SWOC analysis. Int. J. Bus., Manage. Allied. Sci. (IJBMAS) **7**(3) (2020)
23. G. Gangwar, P. Kaur, I. Singh, Principles of design for sustainable group housing projects in India. Civil. Eng. Archit. **8**(6) (2020)
24. O. Aghaegbuna, C. Tasmiyah, B. Zanoxolo, M. Nikiwe (2020) Sustainability in project management practice. *MATEC Web of Conferences*, vol. 312, p. 02015
25. A. Prakash, Major barriers for sustainable development in Indian construction industry. Emerg. Res. Innovations Civil. Eng. (ERICE) (2021)
26. M. Nithya, M. Ramasamy, Sustainability in construction industry through zero wastage technology in India. Mater. Today Proc. Part 1 **46**:849–851 (2021)

A Sustainable Outlet for Canal Irrigation System

Pushpendra Kumar Sharma

Highlights
Outlets used in canal irrigation systems and their requirements.
Issues with Indian canal irrigation system.
Indian farmers' irrigation disputes and resulting ecological concerns.
A sustainable novel solution to farmers and recommendation to update Indian canal irrigation system.

1 Introduction

In irrigation systems modules are the outlets fitted in the banks of distributaries perpendicular to the direction of flow and connect parent channels, i.e. distributaries to water courses or field channels where from the farmers irrigate their fields. The maintenance of field channels is done by the cultivators and once the irrigation water out of the module the irrigation department has no control. Numerous outlets are used even in minor irrigation systems. Most of the Indian irrigation systems are using three types of modules such as; non-modular, semi-modular and modular type modules from ancient times.

Non-modular is a simple conduit constructed in bank and it discharges water directly proportional to the available head in parent channel. Being cheap, simple and long life it is widely used in various Indian irrigation systems but the main drawback is that these are tempered by the farmers as their own requirements [1]. Submerged Hume pipes, masonry sluices and orifices lie in this category and are commonly used

P. K. Sharma (✉)
School of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India
e-mail: p.sharmaji@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_30

in various states of India like; Madhya Pradesh, Uttar Pradesh, Bihar, Punjab and Haryana.

Semi-modular or flexible modules play in between non-modular and modular ones. They discharge independent of water level in field channel but depend on the water level in the parent channel. Crump's adjustable proportional module and Kennedy's semi-module fall in this category [1, 2].

Modular outlets which discharge independent of the available head in parent channel with a constant discharge to the farmers are of great use. These are also called the Rigid modules. Gibb's rigid module falls in this category. It is a very complex machine with a great head loss and very costly too. Once out of order it is only repairable under the supervision of a skilled engineer and that is why it does not suit to developing countries like India and Indian conditions of irrigation systems specifically. Undoubtedly it is better for equal discharge of water in equal slots/turns of the farmers [1, 2].

2 General Requirements

As far as the requirements of a perfect outlet are concerned it should be simple in design, economic, speedy constructible, able to work even at low available heads, draw proportionate silt, not likely tampered by the farmers, measurable discharge uniformly and easily repairable even by the unskilled labor when out of order.

3 Indian Scenario

In developing countries like India, it is not possible to afford a very expensive and smart canal system because neither government nor Indian farmers can pay for such a high-tech irrigation canal system. Usually, farmers take off water from irrigation canals turn by turn day wise and parent canal doesn't run full all the time. The farmers who are given water supply later are not satisfied because parent channels do not run at their full supply level all the time and simple Indian pipe outlets do not transmit water at their fullest in intermittent supply systems as existing in India.

4 Background

Most of the world researchers including India have their attention towards the increase of efficiency of existing outlets and none has paid attention to the real problem of Indian farmers regarding irrigation. The author from the rural background of Uttar Pradesh experienced that canal irrigation system plays a very important role and the villagers face numerous kinds of problems and quarrel for irrigation water on their turn. In villages, the water for crop irrigation is distributed by Indian Canal Irrigation System through the Roster (Warabandi) in which farmers as per their land ownership are allotted slots for their crop irrigation. But there is a problem in beginning and last day when water in the feeding channel rises or falls, respectively; as a result the farmers get lesser amount of water than their crops requirement and thus crops go to wilting point and in middle of the slots at full supply of water in feeding channel, the crops are over irrigated triggering flood or waterlogging.

Due to the above reasons most of the rich farmers are quitting canal irrigation systems and boring their own; using tube well irrigation systems. This is being over, especially in North Indian states; resulting in rapid fall in ground water table which is going to be a groundwater hazard in near future. The day is not very far when India will be facing water crisis. Really it is an eye opener for Indian government. The reason behind is inefficient and low-maintained Indian canal irrigation system only.

So the author identified the problem and experienced an urgent need of such a device that could supply a constant discharge even during variation in water supply levels in feeding minors. So, this problem motivated the author not only to help the poor farmers by providing solution to their problems but to spread awareness among rich farmers to re-adopt canal irrigation systems instead tube well also; so as to avoid rapid ground water table fall and shortly expected groundwater hazard. This idea of Indian approach towards the rigid modules clicked into mind which the author has already got its patent granted from Government of India.

5 The Sustainable Outlet

Keeping all the above-discussed points in mind like: outlet theme; its requirements in Indian scenario the author devised an indigenous technique based on rigid module called ‘The Sustainable outlet’. It is a combination of a masonry well-constructed in the bank of a parent channel connected with flow and a flexible neck tube attached with a floating object maintaining a constant head with respect to a parent channel and this way it maintains the constant discharge supplied to the farmers even in varying head getting rid of them of their usual problem of non-uniform distribution of water. This overcomes the problem of varying head in parent channel during intermittent supply, provides equal discharge to the farmers in their turn. It is very cheap, easily constructible, repairable and not likely to be tampered by the powerful farmers. In addition to the above advantages it is speedy constructed and can be maintained even by unskilled labour. So this novel idea meets all the international requirements of an ideal module.

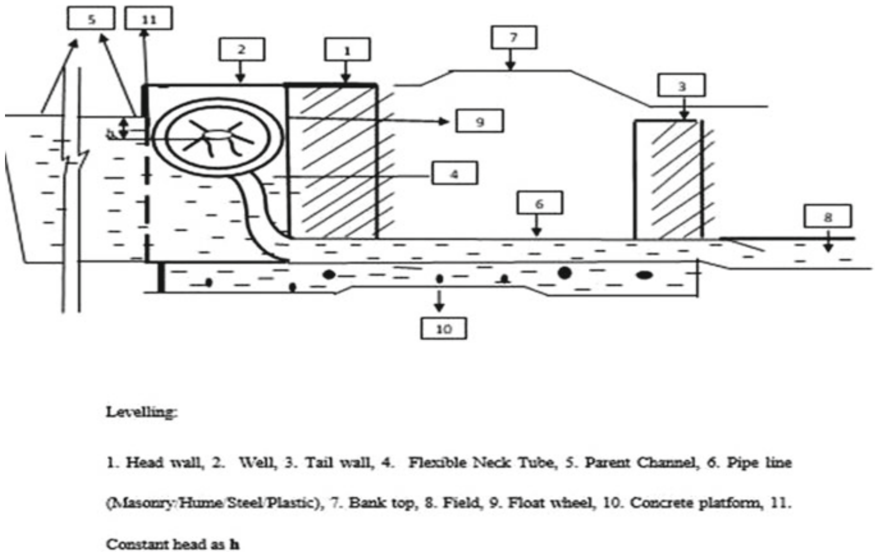


Fig. 1 Computer-aided model of the proposed novel outlet for Indian canal irrigation

6 Construction

The device consists of a flexible neck tube connecting parent channel head to a fixed masonry or steel constructed conduit in bank of parent channel to supply water into the field channel with a constant head independent of the varying head available in the feeding channel. The opening is circular only in shape. Figure 1 shows the longitudinal section of the Sustainable outlet; an Indian approach towards the rigid module. The diameter of the fixed connecting pipe may be from 100 to 300 mm laid on a lean concrete platform; so as not settle at all and perpendicular to the flow direction. The float head well must be clearly connected with varying water levels of feeding channel constructing a vertical open channel in well so as to record the water level in parent channel. The well can also be kept top covered and locked to avoid theft and tampering by the farmers or anybody else.

7 Laboratory Verification

The following Fig. 1 shows its computer-aided laboratory model/L-section of this module which was used to verify the discharge and head loss and it was found very near to the expected as per literature.

In case of discharge in air; an air vent pipe must also be instigated at the junction of flexible neck tube and fixed steel pipe otherwise need not to provide if discharge is submerged in field channel.

Following photographs show the actual mechanism of the device and its working. Figure 2 shows the theme idea of device construction, ingress tube and floating device maintaining constant head, respectively. Figure 3 shows that despite varying levels of water in water tank; same as that in feeding channel and float positions the flow remains constant. (Fig. 4)

Fig. 2 Theme idea, ingress tube and floating device maintaining constant head

Fig. 3 The various levels of water in water tank and float positions

Fig. 4 The various levels of water in water tank and float positions with constant discharge

8 Calculations

(a) Discharge

The discharge can be calculated by well-known equation as

$$Q = C_D A\sqrt{2gh} \quad (1)$$

where C_D is the Coefficient of discharge, A is area of cross-section of feeding flexible neck tube designed as per requirement and h is the head available above the neck tube upper mouth.

(b) Head Loss

The various kind of head loss like entry loss, friction head and the velocity at exit can be summed up to get the total head loss which is like:

$$H_L = \left(\frac{0.5v^2}{2g}\right) + \left(\frac{4flv^2}{2gd}\right) + \left(\frac{v^2}{2gh}\right) \quad (2)$$

9 Validation

The following observations were taken in the laboratory for the validation of the novel device as shown in Table 1.

Table 1 Discharge versus various water supply depths

Discharge versus various water supply depths			
Water depth (m)	Without device (l/s)	With device (l/s)	Desired (l/s)
0.30	0.046	0.0210	0.0225
0.35	0.047	0.0220	0.0225
0.40	0.052	0.0230	0.0225
0.45	0.054	0.0240	0.0225
0.50	0.056	0.0245	0.0225
0.55	0.060	0.0250	0.0225
0.60	0.062	0.0260	0.0225
0.55	0.060	0.0255	0.0225
0.50	0.057	0.0250	0.0225
0.45	0.053	0.0245	0.0225
0.40	0.052	0.0240	0.0225
0.35	0.048	0.0220	0.0225
0.30	0.046	0.0200	0.0225

The graph shown in Fig. 5 shows almost the constant discharge despite of water supply level in the tank/feeding channel. The results are very motivating and the errors are within permissible limits of experimentation and further trials for getting discharged without any variation are being made using different materials neck pipes of varying flexibility.

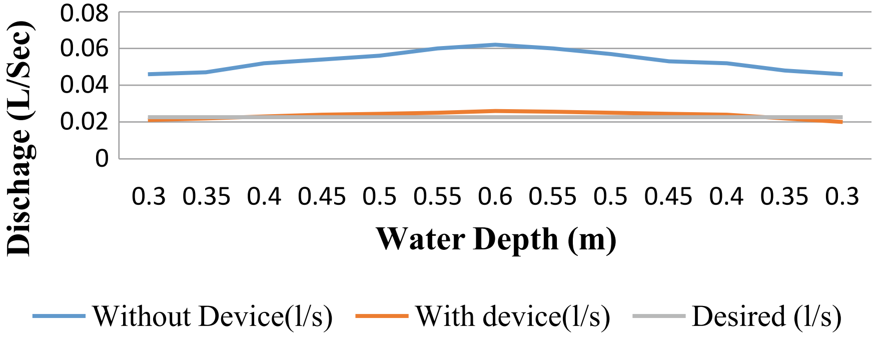


Fig. 5 Water depth versus discharge

10 Conclusion

This Indian approach is very near to the required standards of a rigid module. It is very simple, easy to construct and maintain. Being cheaper it best suits to the Indian canal irrigation system. This is better in all respects such as economy, societal and ecology. The author has recommended the module to be commercialized and to replace all the existing pipe outlets in Indian canal irrigation system by this novel device so as to come with a solution to the irrigation problems with Indian farmers and also to avoid future water crisis, rapid ground water table fall.

Acknowledgements The author acknowledges the support from the School of Civil Engineering, Lovely Professional University for providing laboratory to validate the innovation through prototype model which got a granted patent from Government of India. The author has already been granted Indian Patent Number: 359400 entitled as 'A NOVEL SYSTEM FOR CANAL IRRIGATION' dated 24.02.2021 via Application Number: 201811037216 filed on October 03, 2018 in the name of Lovely Professional University.

References

1. S.K. Garg, *Irrigation Engineering and Hydraulic Structures*, vol. 2 (Khanna Publishers, New Delhi, 2017)
2. G.L. Asawa, *Irrigation Engineering* (New Age International Publishers, Delhi, 2005)
3. P.K. Sharma, F. Ahmed, M. Manu, S. Kumar, A. Kumar, Sustainable canal irrigation through roster: an urgent need. Our Heritage **67**(7), 216–220 (2019)

Effect of Self-healing Concrete on Modular Structure

Gaurav Bharti, Atul Singh, Bishnu Kant Shukla, S. Varadharajan, S. V. Kirthanashri, Prasad Bishetti, and Amit Tripathi

1 Introduction

The Latin term 'concretus' means 'hardened' or 'condensed' is origin of concrete word. Self-healing concrete, also known as bio-concrete, is a name for cement-based materials that repair themselves after being injured by a degradation process [1]. Cement was first used twelve million years ago [2], whereas concrete-like construction materials were first used around 6500 BC [3]. However, it was made solid in later stage of Roman Empire. The world we live in is littered with structures made of traditional concrete. Portland cement, aggregates, and water make up conventional concrete. However, typical concrete has the drawback of water permeability, which causes seepage from roof slabs, columns, and other structures. Concrete's poor degree of sustainability is a global issue. Modern (lime-based) concrete, as revolutionary as it was and continues to be, has a limited usable life due to the creation of cracks, reducing the lifetime of a structure. Concrete can be replaced when it gets too weak in highly developed nations [4]. But, in this case. When concrete ages in underdeveloped nations like India, there isn't much money to repair or replace it. Concrete structures are frequently overlooked, and their inadequacy in poor nations can pose a hazard to the population and the environment.

Self-healing concrete may be made in two ways: biologically and chemically [5]. Biological concrete is just regular concrete with microorganisms and nutrients added to help it fill fractures on its own. When fractures form, bacteria create limestone to fill

G. Bharti · A. Singh · B. K. Shukla (✉) · S. Varadharajan · A. Tripathi
Department of Civil Engineering, JSS Academy of Technical Education, Noida 201301, India
e-mail: bishnukantshukla@gmail.com

S. V. Kirthanashri
AIMMSCR, Amity University, Noida 201301, India

P. Bishetti
School of Civil Engineering, KLE Technological University, Hubballi 580031, India

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_31

them in. This self-healing concrete now has the capacity to self-heal, increasing the concrete's long-term viability and durability. Bacterial concrete will have a greater level of resilience than regular concrete. A biotechnological technique based on calcite precipitation can improve the strength and durability of structural concrete [6].

The chemical technique is the second way to make self-healing concrete [7]. When micro-fractures appear, healing chemicals are injected into the capsule, which opens and rejoins the micro cracks. Each sort of healing substance has its unique method for self-healing. The processes are classified according to their design techniques.

1. Biological technique
2. Chemical procedure.

A. Direct application

   The bacteria and calcium lactate are added to the concrete as it is being manufactured.

B. The Law of Encapsulation

   The coarse aggregate is replaced with lightweight aggregate (LWA), which is impregnated with double the calcium lactate solution and bacterial spores when encapsulating in lightweight concrete. The concrete is created after the clay particles have been impregnated with 6% healing chemicals.

1.1 Biological Method

Researchers have discovered that specific bacteria may be mixed into concrete before it is poured, releasing self-healing chemicals. Until they die, these bacteria maintain the concrete healthy. The bacteria's main benefit is that it repairs the fractures by precipitating calcium carbonate in the calcite. Bacterial spores, nutrients, and calcium lactate have recently been utilised as self-healing agents in studies [8–10]. To prevent contact before cracks form, bacteria and calcium lactate are inserted in the capsules. Self-healing concrete, also known as bio-concrete, is concrete that has been treated with curative chemicals. The inclusion of these capsules, however, alters the composition of the mixture since the healing agent must replace a portion of it. 15 kg of curing agent must be added to every cubic metre of concrete, which means 15 kg of concrete must be removed each cubic metre. The concrete's strength will suffer as a result of this. Concrete may be infused with a variety of beneficial microorganisms. There are three reasons why components have been specified: (1) simplicity of use when formatting individual documents, (2) automated compliance with electronic requirements that allow the development of electronic goods concurrently or later, (3) consistency in style across a conference sessions. There are built-in margins, column widths, line spacing, and type styles; examples of type styles are supplied throughout this text and are identified in italic type, inside parentheses, after the example. The different table styles of text are given, components, such as multi-levelled equations, images, and tables, are not required. The formatter must construct these components while taking into account the following requirements. A common addition is Bacillus alkali nitrulicus, an alkali-resistant soil bacteria. Alkali-resistant microorganisms thrive in alkaline environments. The pH levels range from 9 to 11 on the scale. It ranges in temperature from 10 to 40 °C. There are additional microorganisms that may be introduced as well. This bacteria is psychrophilic. This bacteria likewise thrives in severe circumstances, with a pH range similar to that of the others but an optimal temperature around freezing [11–13].

Bacteria utilised in the manufacture of SHC Bacteria are generally single-celled, primitive creatures. Bacillus Pasteurii, Bacillus Cohnii, Bacillus Filla, and other Bacillus species are among the microorganisms utilised. In the presence of any carbonate source, this bacteria can create calcium carbonate. The bacteria is utilised for the same, and test pieces were seen to increase the resistances of concrete test specimens. Microbes are bacteria that are not dangerous to humans. Inorganic crystals precipitate, causing fissures to mend in the concrete, which can resist any temperature variation.

- The majority of bacteria in the Bacillus family satisfy the above-mentioned requirements.
- The best appropriate chemical precursor was discovered to be Calcium lactate $(C_3H_5O_2)_2$ is a good choice.

1.1.1 Bacterial-Based Healing Process

Process Due to continuous chemical, physical, and mechanical processes, concrete has a built-in healing mechanism already. The calcium carbonate precipitation is the most important (Edvardsen 1999). A width of crack of 0.2 mm is the average limit at which healing may occur. As shown in Eq. 1, the carbonation process, in which diffuse carbon dioxide reacts with calcium hydroxide to form calcium carbonate, is at the heart of calcium carbonate synthesis.

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \tag{1}$$

The precipitation of calcium carbonate is also a basis of microbial healing. The dormant bacteria are activated by the input water. Bacterial conversion of an embedded mineral precursor chemical produces dense layers of calcium carbonate [14]. The reaction happens in Eq. 2 in the case of calcium lactate when the bacteria merely serve as a catalyst.

$$Ca(C_3H_5O_2) + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O \tag{2}$$

Carbon dioxide is generated during the conversion of calcium lactate metabolically, which also interacts with the calcium hydroxide in the concrete matrix, creating

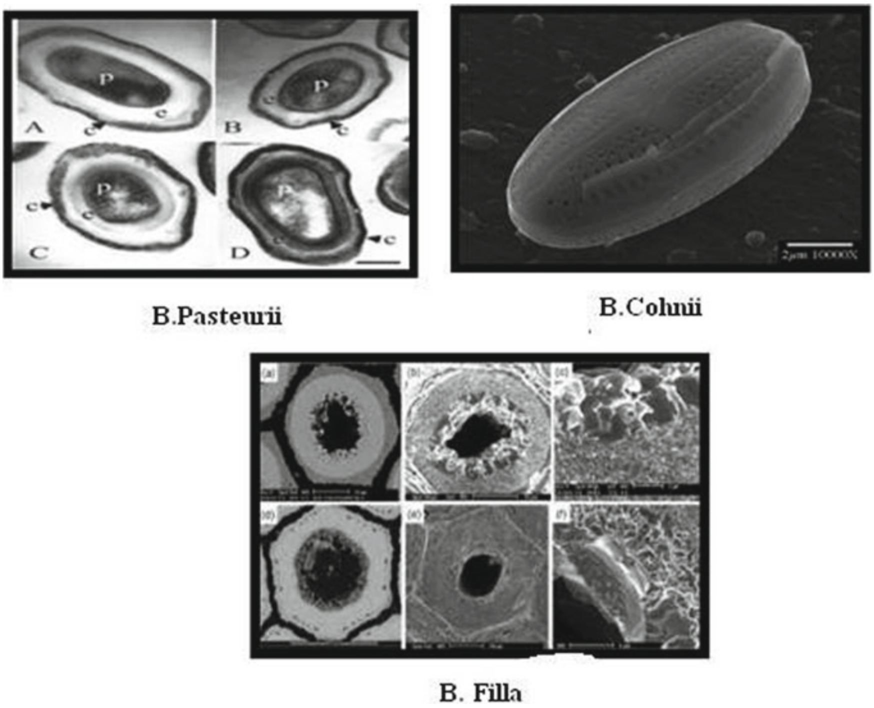


Fig. 1 Bacteria utilised in the research

more calcium carbonate, as shown in Eq. 1. The massive production of large crystalline calcium carbonate with a diameter greater than 100 m precipitates the sealing and blocking of cracks as shown in Fig. 1.

Bacteria generate urease, then the conversion of urea to carbonate and ammonium in the bacterial environment take place, resulting in pH increase and rise in carbonate concentration [15]. These components are then degraded, culminating in the creation of calcium carbonate from ammonia (NH_4^+) and carbonic acid (CO_3^{2-}). The following is the procedure for converting urea to carbonate (CO_3^{2-}) and ammonium (NH_4^+) using urease (hydrolysis of urea) ($CO(NH_2)_2$) (chemical reactions explained in Eqs. 3–7) [16].

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3 \quad (3)$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3 \quad (4)$$

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+ \quad (5)$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \quad (6)$$

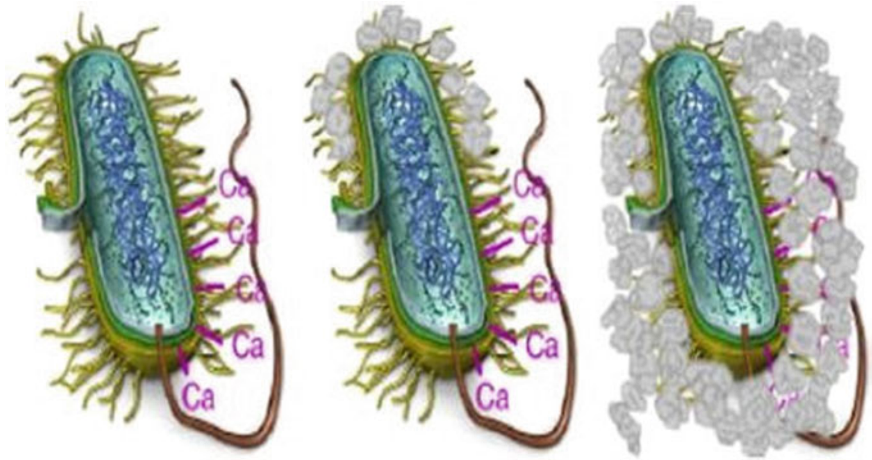


Fig. 2 Calcium carbonate formation on the bacterial cell wall

$$HCO_3^- + H^+ + 2NH_4^+ + 2OH^- \leftrightarrow CO_3^{2-} + 2NH_4^+ + 2H_2O \quad (7)$$

Bacteria take cations from the environment, including Ca^{2+}, to deposit on their cell surface because their cell wall is negatively charged. Calcium carbonate develops on the cell surface when Ca^{2+} ions mix with the CO_3^{2-} prime, acting as a nucleation site. Calcium carbonate precipitation in the bacterial cell wall is depicted in Fig. 1.

Calcium carbonate can be precipitated by a variety of bacteria based on urea analysis. A examination of the literature revealed bacterial applications. Using lightweight pebbles and graphite nanoplatelets, Subtilis bacteria can improve the strength of concrete [17]. When Aerius bacteria were tested in rice husk ash concrete, the durability of the concrete was shown to be improved [18]. The inclusion of Bacillus Megaterium bacteria in concrete resulted in a 24% increase in compressive strength [19]. Bacillus Sphaericus improves the durability of concrete by depositing calcium carbonate [20]. Sporoscarcina Pasteurii, a self-healing bacteria used in fly ash concrete, has enhanced the concrete's strength and lifespan [21]. The self-healing action of the bacterium Sporoscarcina Pasteurii, which is used in silica fume concrete, has improved the strength and longevity of the material [22] (Fig. 2).

1.2 Chemical Method

When two chemicals, methacryloxypropyl certain polydimethylsiloxane and benzoyl isobutyl ether, are combined in the presence of sunshine, they convert into an impermeable polymer that clings to concrete, according to Chan-Moon Chung's recent experiment. The chemical combination is kept isolated from sunlight when this balm is put within small capsules comprised of urea and formaldehyde. The capsule opens and the balsam spills out when it fractures due to external factors. These capsules are produced by combining water, urea, ammonium chloride, and resorcinol, a benzene derivative that promotes capsule production. The mixture is then heated for 4.5 h at 55 °C with a methacryloxypropyl terminated group, polydimethylsiloxane, benzoin isobutyl ether, and formaldehyde. The urea and formaldehyde are then combined to produce capsules containing the two concrete curing ingredients, as required. The mixture is then combined with polymer (liquid) and put onto concrete blocks weighing two-thirds of a kg apiece, with the resultant film being allowed to harden. He then used force to shatter each block one at a time, then set the blocks in the sun for four hours.

2 Observations

The fissures in the concrete extended to the capsules' polymer coating, which opened some of the capsules and spilled their contents. The blocks are then put in a waterproof layer when exposed to the sun, a fact that can be verified by submerging the blocks in water. He weighed the blocks after 24 h of soaking to assess how much water they had absorbed. The raw concrete collected 11.3 g of water on average. Without capsules, the polymer-coated concrete weighed 3.9 g. However, the concrete that had been coated with a layer of polymer containing capsules barely absorbed 0.4 g (Fig. 3).

3 Advantages and Dısadvantages

When compared to conventional concrete, bio-concrete has a higher compressive and flexural strength. It is capable of repairing cracks without the need for external assistance. Bacillus bacteria are non-pathogenic to humans, thus they may be utilised to make bio-concrete. One disadvantage of self-healing concrete is that two ammonium ions are created concurrently for each carbonate ion, potentially resulting in excessive nitrogen loading in the environment. Additionally, the cost of bacterial concrete is double that of normal concrete.

4 Results

In the bio-concrete test findings, the bio-concrete and conventional concrete test results revealed a clear distinction. The graph provides detailed information on Compressive strength, split tensile strength, and flexural strength are all factors to

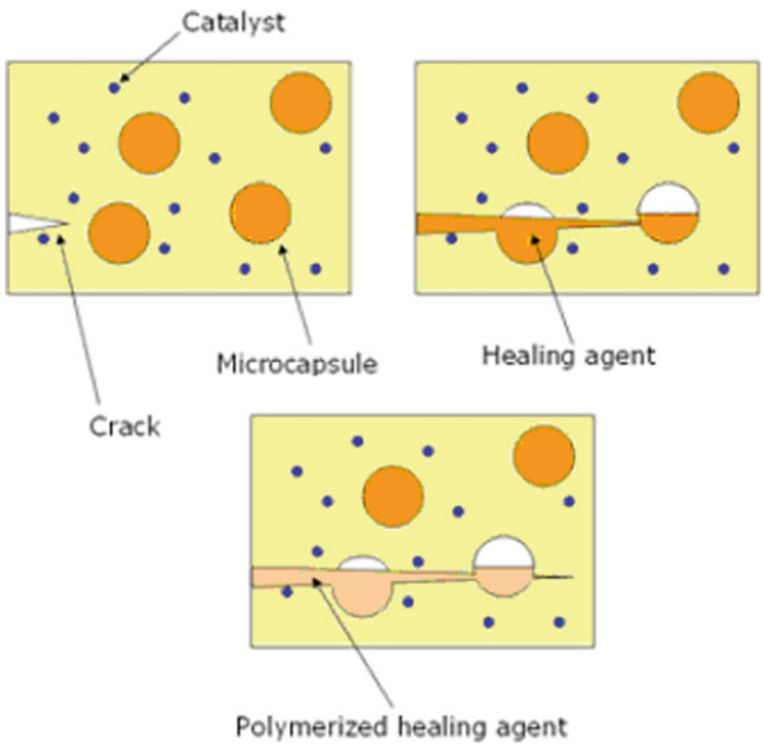


Fig. 3 Concept of healing agent embedded microcapsules, based on White et al. figure's microstructure with embedded catalyst and healing agent microcapsules (polymer precursor)

consider of M20 conventional concrete and M20 bio-concrete made with various bacteria (Figs. 4 and 5).

5 Conclusions

Although the majority of healing agents utilised in bio-concrete are chemical-based, the application of bacteria has been studied for their self-healing properties. In some studies, the presence of healing agent bacteria can lead to the enhancement of its durability by precipitating calcite or limestone on the surface.

In bio-concrete, microorganisms consume oxygen from concrete matrix, which can prevent steel reinforcement corrosion. However, this procedure has not been proven to work and more research is needed to quantify this potentially helpful procedure in real terms.

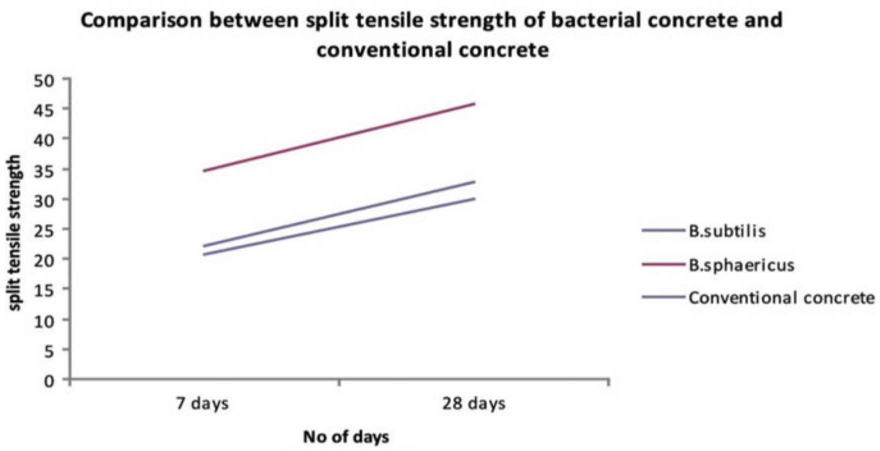


Fig. 4 Comparison between flexural strength of bacterial concrete and conventional concrete

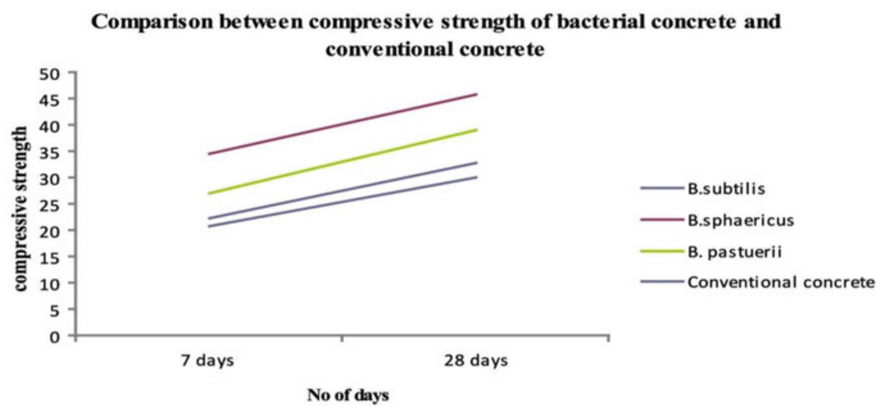


Fig. 5 Comparison between split tensile strength of bacterial concrete and conventional concrete

References

1. H. M. Jonkers, in *Self-Healing Concrete: A Biological Approach*, ed. by S. van der Zwaag. Self Healing Materials: An Alternative Approach to 20 Centuries of Materials Science (Springer, The Netherlands, 2007), pp. 195–204
2. H.M. Jonkers et al., Application of bacteria as self-healing agent for the development of sustainable concrete. Ecol. Eng. **36**(2), 230–235 (2010)
3. E. Tziviloglou, V. Wiktor, H.M. Jonkers, E. Schlangen, Bacteria-based self-healing concrete to increase liquid tightness of crack. Constr. Build. Mater. **122**, 118–125 (2016)
4. W. De Muynck, D. Debrouwer, N. De Belie, W. Verstraete, De Verstraete, Bacterial carbonate precipitation improves the durability of cementitious materials. Cem. Concr. Res. **38**, 1005–1014 (2008)
5. R. Siddique, K. Singh, M. Kunal, S.V. Corinaldesi, A. Rajor, Properties of bacterial rice husk ash concrete. Constr. Build. Mater. **121**, 112–119 (2016)

6. R. Andalib, Abd Majid, M. Z. Hussin, Optimum concentration of Bacillus megaterium for strengthening structural concrete. Constr. Build. Mater. **118**, 180–193 (2016)
7. J. Wang, J. Dewanckele, V. Cnudde, S. Van Vlierberghe, W. Verstraete, N.D. Belie, X-ray computed tomography proof of bacterial-based self-healing in concrete. Cem. Concr. Compos. **53**, 289–304 (2014)
8. J. Wang, D. Snoeck, Van Vlierberghe S., W. Verstraete, N. De Belie, Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. Constr. Build. Mater. **68**, 110–119 (2014)
9. N. Chahal, R. Siddique, A. Rajor, Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. Constr. Build. Mater. **28**, 351–356 (2012)
10. N. Chahal, R. Siddique, A. Rajor, Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume. Constr. Build. Mater. **37**(1), 645–650 (2012)
11. L. Lakshmi, Durability and self-healing behaviour of bacterial impregnated concrete. Int. J. Innov. Res. Sci. Eng. Technol. **5**, 148–152 (2016)
12. P. Ghosh, S. Mandal, B. Chattopadhyay, S. Pal, Use of microorganism to improve the strength of cement mortar. Cem. Concr. Res. **35**(10), 1980–1983 (2005)
13. P. Ghosh, S. Mandal, S. Pal, G. Bandyopadhyaya, B. Chattopadhyay, Development of bioconcrete material using an enrichment culture of novelthermophilic anaerobic bacteria. Indian J. Exp. Biol. **44**(4), 336 (2006)
14. S.J. Park, Y.M. Park, W.Y. Chun, W.J. Kim, S.Y. Ghim, Calcite-forming bacteria for compressive strength improvement in mortar. J. Microbiol. Biotechnol. **4**, 782–788 (2010)
15. J. Dick et al., Bio-deposition of a calcium carbonate layer on degraded limestone by Bacillus species. Biodegradation **17**(4), 357–367 (2006)
16. S.K. Ramachandran et al., Remediation of concrete using micro-organisms. ACI Mater. J. **98**(1), 3–9 (2001)
17. V. Wiktor, H.M. Jonkers, Quantification of crack-healing in novel bacteria based self-healing concrete. Cement Concr. Compos. **33**(7), 763–770 (2011)
18. K. Paine, in *A Design and Performance of Bacteria-Based Self-Healing*. Concrete, the 9th International Concrete Conference — pp. 6–8. (2016).
19. F. B. Silva, N. De Belie, N. Boon, W. Verstraete, Production of non-axenicureolytic spores for self-healing concrete applications. Constr. Build. Mater., 150–156 (2015)
20. H.M. Jonkers, A. Thijssen, G. Muyzer, O. Copuroglu, E. Schlangen, Application of bacteria as self-healing agent for the development of sustainable concrete. Ecol. Eng. **6**(2), 230–235 (2010)
21. N. De Belie, J. Wang, *Bacteria-Based Repair and Self-Healing of Concrete*, vol. 373 (2015)
22. V. Kunamineni, M. Meena, V. D. Shirish, Bacteria based self healing concrete—a review. Construct. Build. Mater. **152**, 1008–1014 (2017)

Evaluation of Domestic Wastewater Treatment Plant in Rural Areas

Jaspreet Singh and Janaki Ballav Swain

1 Introduction

One of the most essential things on the earth for life is water. As the population is increasing, the requirement of fresh water is also increasing day by day. The wastewater spawn from the isolated/rural areas is generally directly disposed off openly which further cause serious diseases. Disposing wastewater directly can have negative impact on irrigation, recreational process and to aquatic life [1]. The other way to deal with such wastewater is to be collected at a single point (collection chamber) and further it can be treated through sewerage treatment plants. The sewerage treatment plant is used to deal with removal of harmful contaminants from the gray water and which can be further reused. In India, the considerable amount of sewerage treatment plants is consisting of mechanical processes in which the process of biological waste purification, sludge treatment, etc. are used which can prove efficient in isolated/rural areas [1]. For the efficient processing of wastewater the considerable contact time, i.e., retention time should be given so that the chemical process can be taken place [2, 3]. Variations in flow rate can be there due to chemical composition and pH and atmosphere [4]. As most of the Indian population lives in rural areas, it becomes very important to deal with wastewater.

There are lot of opportunities in rural areas of India where the wastewater can easily be reused despite of lack of resource's availability like improper design, running cost of sewerage treatment plan, etc. [5]. One of the best and cheap way to deal with domestic wastewater is to construct the sewerage treatment plants [6]. In this research paper, the evaluation of the domestic wastewater treatment plant has been

J. Singh (✉) · J. B. Swain
Lovely Professional University, Phagwara, Punjab, India
e-mail: Jaspreet.kaler025@gmail.com

J. B. Swain
e-mail: Janaki.22747@lpu.co.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_32

carried out to check the effectiveness of the traditional sewerage treatment plants. Moreover, the chances of microbial growth in India is high which will be helpful for treatment of gray water [7]. The domestic wastewater consists of essential nutrients that can be used for additionally biological activities [8]. The management opportunities are revisited for the reuse of the treated water as the environmental issues in India are growing at fast rate [9]. The detergent present in domestic wastewater can cause serious diseases like cancer and kidney damage [10, 11].

It has been well-known fact that water used in isolated/rural areas is considerably less for internal utilization. Hence there is notable water that is used for external work and the treated water can be utilized for purpose like farming, stable, etc.

It is recognized that there are serious water pollution problems in Punjab and other parts of India, mainly due to untreated wastewater. Rivers like Satluj, Beas, Ganga, etc. which cross very densely populated areas, are polluted. 85% of wastewater in India is not treated and flows directly into the country's rivers, polluting the main sources of drinking water. Indian cities together produce about 40 billion liters of wastewater per day, and only 20% is processed through treatment plants. Therefore, the treatment and reuse of wastewater is an urgent in growing countries. Treatment of water become more and more important in country like India due to massive increase of population.

By taking care of the above scenario, the samples for the domestic waste are taken from Sewage treatment plant town "Bambianwali, Jalandhar which comes under the Government of Punjab with capacity of 10 MLD. The area is located 16 km away from Phagwara and 14 km away from Jalandhar. The "Bambianwali" sewerage treatment plant mostly received the water which belongs to domestic area. After the treatment of wastewater has been discharged into Sutlej River. Surrounding land belongs to agriculture hence there is not much industry in said area. The testing has been done in Government approved lab near treatment and fulfills the norms (permissible limits) of Central Pollution Control Board (CPCB).

The "Bambianwali" Sewerage Treatment Plant consists of the following steps of treatment.

- Inlet Chamber
- Screen Channel
- Mechanical Chamber
- SBR Basins
- MEP/Blower Room
- Chlorine Contact Tank
- Chlorination Room
- Tonner Shed
- Sludge Sump
- Sludge Pump House (Fig. 1).

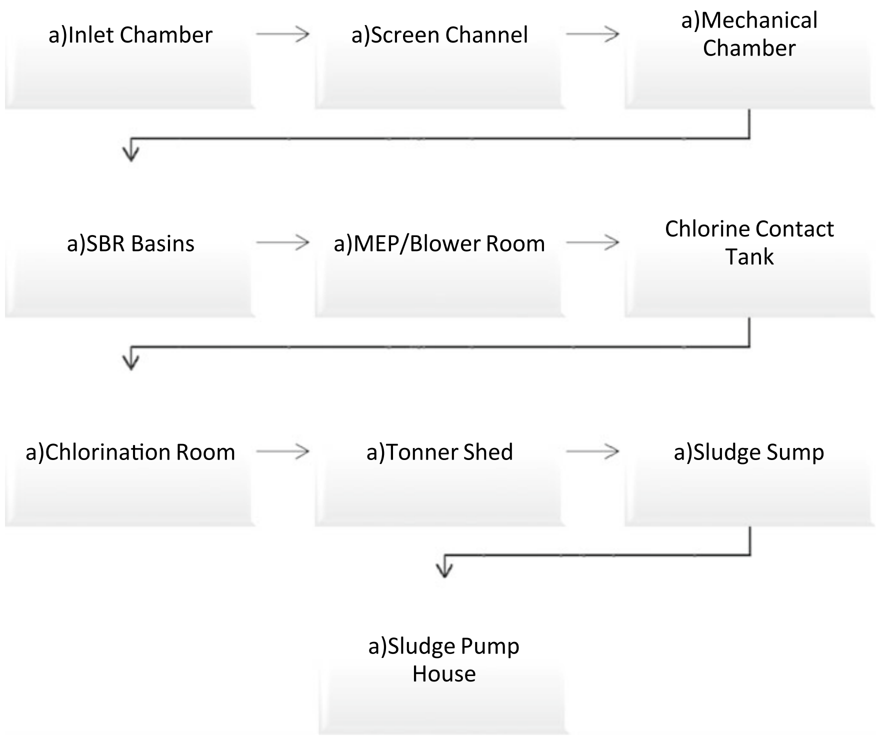


Fig. 1 Flow chart of process of sewerage treatment plant

2 Results and Discussion

Characteristics used for the study of sewerage treatment plant has been mentioned in Table 1. As we can see in Table 1, there is no significant relation in temperature between the data which is taken before monsoon and after monsoon. In case of pH, there is not much impact of the temperature.

Table 1 Pre-monsoon test data

Parameter	Before treatment	After treatment	Permissible limits as per CPCB
pH	7.06	7.1	6.5–9.0
Temp. C	23.2	23.29	<30
TSS	309.14	16.37	20
COD	313.81	39.81	50
BOD	111.4	7.18	10

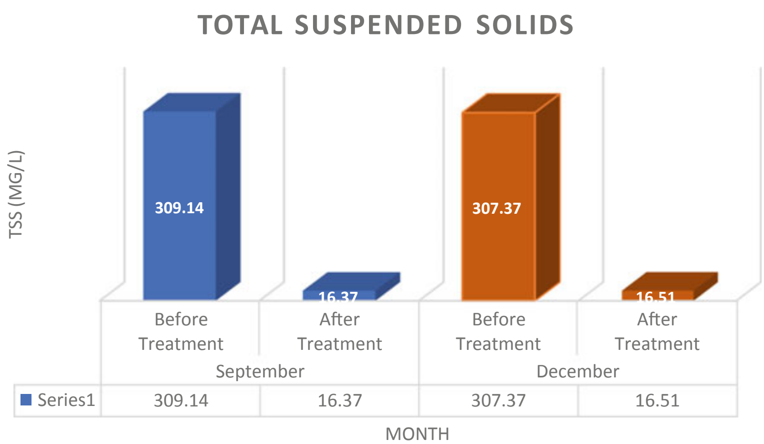
Table 2 Post-monsoon test data

Parameter	Before treatment	After treatment	Permissible limits as per CPCB
pH	7.13	7.12	6.5–9.0
Temp. C	21.07	21.42	<30
TSS	307.37	16.51	20
COD	309.9	39.92	50
BOD	111.4	7.25	10

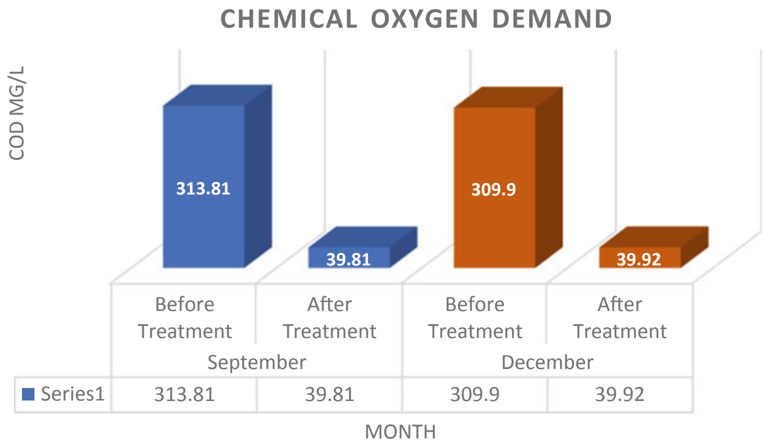
Table 2 shows the data which is taken post-monsoon which reflects that impact of temperature is almost negligible. This has happened since the wastewater always remain in motion during the discharge as well as during the treatment. The table reflecting that there is not much impact on the pH since it is already under permissible limit and does not require any treatment.

Graph 1 reflects the domestic method on treatment is very effective in case of Total Suspended Solids. Before the treatment, average value has shown as 309.14 mg/l which is very high and has to be processed before disposal of wastewater. After treatment results show value of TSS is 16.37 mg/l which under the permissible limit of Central Pollution Control Board (CPCB). The methods seem appropriate and effective during summer season as well as winter season.

Graph 2 shows the sustainable use of technology where the wastewater before treatment is completely contaminated and required treatment before it gets disposed of into natural water body or under the ground. Before treatment, Chemical oxygen demand is appearing 313.81 mg/l which is very harmful for the environment. After the treatment through sewerage treatment value shows 39.81 mg/l which is under



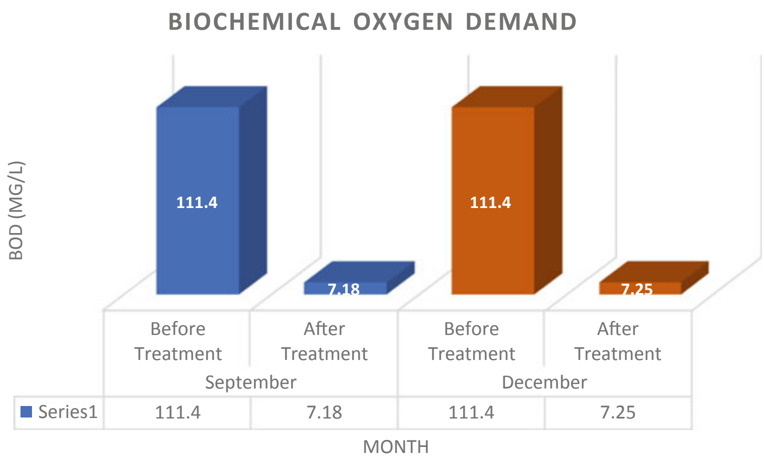
Graph 1 Test result of total suspended solids



Graph 2 Test result of chemical oxygen demand

permissible value of 50 mg/l hence the treatment plants work effectively and water is safe to be disposed of.

Considering Graph 3 wastewater sample results, the enhancement is water quality has been found. Before the treatment of sewerage, biochemical oxygen demand showing 111.40 mg/l which is almost 10 times higher than permissible limit hence the sewerage cannot be directly put into natural water bodies. After the process in treatment plant, BOD comes down to 7 mg/l which is under the permissible limit of 10 mg/l as per Central Pollution Control Board (CPCB).



Graph 3 Test result of biochemical oxygen demand

3 Summary

There has been considerable amount of work has been done in the field of domestic sewerage treatment plants. The work in this path is related to reuse of gray water in such a way that freshwater requirements can be decreased. The advantage which can be brought is primarily to reduce the use of potable water by using the treated water. Woefully, people in isolated/rural areas are not carrying good knowledge about the use of treated water. As far as competent authorities are concerned, they are agreeing to conserved and reuse the water where ever possible. The is major concern on public health as well as on environmental conditions which are rapidly degrading. The design of sewerage treatment plants can be made better so that the cost of processing wastewater can be decreased.

References

1. B. Ahansazan, H. Afrashteh, N. Ahansazan, Z. Ahansazan, Activated sludge process overview. Int. J. Environ. Sci. Develop. **5**(1), 81 (2014)
2. Biological Wastewater Treatment. [Online]. Available: http://www.engineering.dartmouth.edu/Cushman/…/BioTreatmentTypes.pdf
3. M.H. Esparza, M.C. Doria-Serrano, G. Acero-Salinas, F.A. Ruiz-Trevino, Removal of high phenol concentrations with adapted activated sludge in suspended form and entrapped in calcium alginate/cross- linked poly(N-vinyl pyrrolidone) hydrogels. Biotechnol. Process. **22**, 1552–1559 (2006)
4. W. P. C. F. Apha Awwa, *Standard Methods for the Examination of Water and Wastewater*, 20th edn. (American Public Health Association, American Water Work Association, Water Environment Federation, Washington, DC, 1998)
5. D. Konnerup, T. Koottatep, H. Brix, Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with Canna and Heliconia. Ecol. Eng. **35**(2), 248–257 (2009)
6. J.A. Álvarez, C. Ávila, P. Otter, R. Kilian, D. Istenič, M. Rolletschek, C.A. Arias, Constructed wetlands and solar-driven disinfection technologies for sustainable wastewater treatment and reclamation in rural India: SWINGS project. Water Sci. Technol. **76**(6), 1474–1489 (2017)
7. R. Kaur, S. P. Wani, A. K. Singh, K. Lal, in *Wastewater Production, Treatment and Use in India.* National Report Presented at the 2nd Regional Workshop on Safe Use of Wastewater in Agriculture (2012), pp. 1–13
8. A.K. Kivaisi, The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. Ecol. Eng. **16**(4), 545–560 (2001)
9. R. Kadlec, S. Wallace, *Treatment Wetlands* (CRC, Boca Raton, 2009)
10. M.V. Vijay, J.S. Sudarsan, S. Nithiyanantham, Sustainability of constructed wetlands using biochar as effective absorbent for treating wastewaters. Int. J. Energy Water Resour. **3**(2), 153–164 (2019)
11. A. Leura-Vicencio, A.J. Alonso-Castro, C. Carranza-Álvarez, R. Loredo-Portales, M.C. Alfaro-De la Torre, R.F. García-De la Cruz, Removal and accumulation of As, Cd and Cr by Typha latifolia. Bull. Environ. Contam. Toxicol. **90**(6), 650–653 (2013)

Evaluation of Mechanical and Durability Properties of Concrete Using Metakaolin: A Review

Nirvesh Singh, Kanish Kapoor, Mudasir Nazeer, and Paramveer Singh

1 Introduction

In the building business, cement concrete is the most often used construction material. Aggregate, cement, and water are the main ingredients of concrete. There are several formulations with various characteristics [1]. The aggregate consists of coarse gravel or broken rocks like limestone or granite, as well as a fine aggregate like sand. It is almost as popular as water as the most commonly ingested material. The aggregate is bound together with cement (often Ordinary Portland Cement) and other cementitious materials such as Fly Ash (FA), metakaolin (MK), Silica Fume (SF), and slag cement. Concrete must acquire chemical and physical characteristics, as well as mechanical strength, during the hydration and hardening process. Concrete has a relatively high compressive strength but a significantly lower tensile strength, which means it invariably breaks when subjected to tensile pressures. As a result, steel bar or fibre reinforcement is frequently used in the construction of concrete. Compaction is required during the casting of conventional concrete to guarantee

N. Singh · K. Kapoor · M. Nazeer (✉) · P. Singh
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology Jalandhar, Punjab, India
e-mail: mudasirn.ce.18@nitj.ac.in

N. Singh
e-mail: singhnirvesh496@gmail.com

K. Kapoor
e-mail: kapoork@nitj.ac.in

P. Singh
e-mail: paramveers.ce.19@nitj.ac.in

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_33

adequate strength and durability. When concrete is designed and compacted incorrectly, voids develop, resulting in poor quality concrete [2]. The need for high-strength and high-performance concretes has risen dramatically in recent years as a result of the building industry's demands.

One of the high-quality compounds is metakaolin. Calcinations of kaolinitic clay are used in the production of metakaolin. At 8000 degrees Celsius, pure kaolinitic is calcined. There has been a growing interest in using MK as a mineral additive to increase the strength and durability of concrete in recent years. Metakaolin is made by heating mineral kaolin and produces stronger concrete and mortar. Because its particle size is larger than silica fume but smaller than cement, it resists sulphate attack and improves workability [3].

The physical and chemical characteristics of metakaolin were first discussed, followed by its application and benefits. After then, metakaolin was used to improve the mechanical and durability qualities of concrete. The goal of this study was to look at the mechanical characteristics and durability of concrete with a metakaolin replacement rate.

2 Properties of Metakaolin

Metakaolin is a chemical phase that occurs when kaolinite is heated. Al_2O_3:$2SiO_2$.$2H_2O$ is the chemical composition of kaolinite. Metakaolin had a mean particle size of around 3 μm and 99.9% of the particles were smaller than 16 μm. Tables 1 and 2 show typical physical characteristics and chemical compositions, respectively.

2.1 *Use of Metakaolin*

Metakaolin is used to make a high performance, high strength, and lightweight concrete and used to precast concrete for architectural, civil, industrial, and structural purposes [17]. It is also used in fibre cement, ferrocement products, and glass fibre reinforced concrete and mortars, stuccos, repair material, and pool plasters [18].

Table 1 Physical properties of metakaolin

Research study	Property	Value
[4, 5]	Specific gravity	2.53–2.60
[6]	Bulk density (g/cm^2)	0.3–0.4
[7, 8]	Physical form	Powder
[3, 9]	Colour	Light creamy white
[10, 11]	Loss on ignition, %	0.67–0.70

Table 2 Chemical composition of metakaolin

Research study	Oxides (%)										
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	P_2O_5	SO_3	Na_2O	TiO_2	LOI
[12]	0.03	57.37	38.63	0.77	0.07	0.49	0.61	0.15	0.39	0.40	1.04
[13]	0.09	51.6	41.3	4.64	0.16	0.62	–	–	0.01	0.83	–
[14]	0.78	52.68	36.34	2.14	0.16	0.62	–	–	0.26	–	0.98
[9]	0.05	51.2	45.3	0.6	–	0.16	–	–	0.21	–	0.51
[15]	0.07	52.1	41	4.32	0.19	0.63	–	–	0.26	0.81	0.6
[6]	2.4	56	37	2.4	0.3	1	–	–	1	0.2	–
[16]	–	51.5	44.7	0.4	–	–	–	–	–	2.1	–
[16]	–	52.5	44.5	0.9	–	–	–	–	–	1.7	–

2.2 Advantages of Using Metakaolin

MK helps to increase the compressive strength, flexural strength, reduced permeability, and increased durability of concrete [19, 20]. MK increases resistance to chemical attack, reduced effects of alkali-silica reactivity (ASR) and reduced shrinkage due to particle packing, making concrete dense [21]. It also enhanced the workability, finishing of concrete, reduced potential for efflorescence, and improved finish ability, colour, and appearance [22].

3 Fresh Properties of Concrete Using Metakaolin

Reduction in the slump values and increase in the setting times of concrete with the inclusion of MK were reported by [23]. Reduction in the slump values and increase in the setting times of concrete with the inclusion of MK were reported by [13] as given in Table 3.

Ramlochan et al. [23] used neural networks to predict workability of concrete incorporating metakaolin (up to 15%) and 40% fly ash. The models were reliable and accurate and illustrated how neural networks can be used to predict the workability parameters of slump, compacting factor and Ve-be time across a wide range of Portland Cement Fly ash Metakaolin compositions.

Table 3 Fresh properties of SCC having metakaolin [13]

Mixes	0% MK	10% MK	20% MK	30% MK
Slump flow	690 mm	720 mm	710 mm	680 mm
V-funnel test	6.65 s	6.60 s	6.76 mm	6.47 s
L-Box test	0.88	0.9	0.92	0.89

Table 4 Properties of metakaolin cements [24]

Sample	Metakaolin (% mass)	Water demand (% mass)	Setting time (min)	
			Initial	Final
PC	–	27.5	105	140
MK1-10	10	29	75	130
MK2-10	10	29	85	130
MK3-10	10	32	105	160
MK4-10	10	32.5	155	180
MKC-10	10	31	95	130
MK1-20	20	32	105	160
MK2-20	20	31.5	110	165
MK3-20	20	38.5	120	160
MK4-20	20	41	205	230
MKC-20	20	37.5	140	170

Bai et al. [24] reported the results of water demand and setting times of cements containing five metakaolins. The metakaolinite contents in metakaolins MK1, MK2, MK3, and MK4 (derived from poor Greek kaolins) were 36, 37, 71, and 49% but 95% in a commercial metakaolin (MKC) of high purity. The authors concluded that (i) blended cements demanded significantly more water than the relatively pure cement, and (ii) the initial and final setting time of metakaolin cements were affected by the metakaolin content. Cements with 10% metakaolin, generally, exhibited similar setting times to that of PC, while for 20% metakaolin content there was a delay in the setting. MK4 showed the greatest effect on the setting delay of the cements (Table 4).

4 Mechanical Properties of Hardened Concrete

4.1 Pore Size Distribution

When metakaolin percentage was less than 20%, the porosity of the cement paste decreased [25]. More than 30%, an increase in porosity was notice which could be attributed to the 'filler effect' of fine metakaolin particles and also because of enhancing w/b ratios with increasing metakaolin content. At 90 days curing, the pore volume of mortar and the threshold diameter decreased in the presence of metakaolin. Bredy et al. [26] finds the inclusion of metakaolin in cement paste guided to refinement of the pore structure. The threshold value for paste decreased with the enhance in metakaolin content. The proportion of pores with radius smaller than 20 μm enhanced with the increase in metakaolin content. Total intruded pore volumes increased between the ages of 14 and 28 days for metakaolin paste. Wild et al. [27] concludes the porosity decreases up to 28–56 days of curing time. The values came

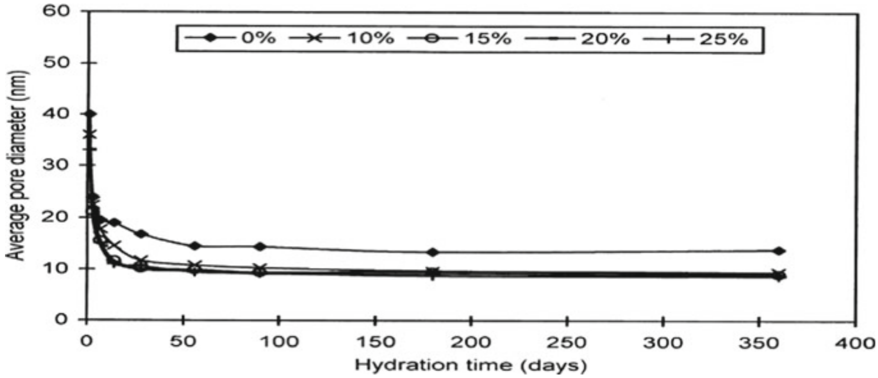


Fig. 1 Average pore diameter [27]

for MK mixes with respect to OPC mix. Between 7 and 90 days, the porosity of MK mixes increases, while the OPC mix remains constant, the necessity of addition of at least 15–20% of MK to achieve important improvement in the porosity and reducing the average pore diameter (Fig. 1).

4.2 *Compressive Strength*

Inclusion of MK as partial replacement of cement enhanced the compressive strength of concrete, but the optimum replacement level of OPC by MK to give maximum long-term strength enhancement was about 20% [15]. Cabera [28] has concluded that the compressive strength of concrete using metakaolin is higher at 10% of replacements and showed relatively high values of modulus of elasticity. Splitting tensile and elastic modulus results are also followed same trends. Dinkar et al. [29] finds that the compressive strength of recycled concrete increased with the increase of metakaolin content, but the increasing trend gradually became slower. The compressive strength of the recycled concrete fully regenerated aggregate replacement rate increased. When metakaolin was 7%, the 28-day compressive strength increased by 27.1% (Table 5).

Table 5 Compressive strengths of concrete with use MK at 28 days

Research study	Content of MK (%)	Optimum doze (%)	Compressive strength increment (%)
[15]	0–30	20	24.09
[30]	0–15	7.5	8.05
[31]	0–25	20	50.0
[31]	0–40	15	25.0

4.3 Splitting and Flexural Tensile Strength

Patil et al. [31] MK (15%% M/C) increased the tensile strength and resulted in the maximum splitting and flexural strengths at virtually all ages, demonstrating that both splitting and flexural strengths grew with age. Concrete's flexural tensile strength is proportional to its compressive strength; the higher the compressive strength, the higher the tensile strength [30]. The tensile strength of concrete improves when the amount of cement replaced with metakaolin is increased. The value improves as the proportion of cement replaced with metakaolin is increased, up to a maximum of 15%. The highest increase in split tensile strength occurs when 15% of the cement is replaced with metakaolin. The flexural strength of ferrocements containing metakaolin is up to 15% greater than the flexural strength of the control ferrocement. It may be the best substitute for metakaolin since it has the maximum strength at 10% substitution.

5 Durability Properties of Concrete

5.1 Creep and Shrinkage

Drying shrinkage is a significant property of concrete that impacts the structure's long- term mechanical and durability qualities [14]. MK decreases concrete shrinkage from the first set time, with the reduction being larger at higher replacement levels. MK concrete, in comparison with control mix, is mostly made up of self-induced shrinkage, with drying shrinkage accounting for a lower portion [13]. The addition of MK significantly reduced drying shrinkage strain while increasing concrete strength in various degrees, depending on the amount of MK replaced, the w/c ratio, and the age of the concrete mix being tested.

5.2 Water Absorption

According to the previous findings, there is a significant variation in water absorption between the top and bottom surfaces of cast concrete. Reference [8] at 28 days and 14 months, the water absorption of concrete mix increased as the MK concentration rose. Observations similar to this are also made by [4]. Metakaolin and silica fume significantly reduced the initial surface absorption, water absorption, and sorptivity of concrete in different ways.

5.3 Chemical Resistance

Chemicals from various acids (acidic, hydrochloric, and nitric) as well as a mixture of magnesium sulphate, sodium sulphate, and sulphuric acid are used in the durability test [10]. Discovered chemical imperviousness as the quantity of the metakaolin replacement increased. Xie et al. [30] has discovered that adding 7.5% high reactivity metakaolin to cement improves its resistance to chloride attack.

6 Conclusion

Because of future needs for environmental protection and sustainable building, the utilisation of by-products such as rice husk ash, granulated blast furnace slag silica fume, fly ash, and metakaolin in cement and concrete has gained considerable relevance.

The utilization of metakaolin (MK) as partial substitution of concrete in mortar, and concrete has been broadly explored lately. The literature checked on obviously shows that MK is an effective pozzolan.

1. In the case of strength and durability, the concrete using MK shows better results than normal mixes.
2. The partial replacement of cement with MK reduces the water penetration into concrete by capillary action.
3. MK modifies the pore structure of the cement, mortar, and concrete and significantly reduces the permeability resulting in resistance of transportation of water and dispersing of harmful ions which showed to the deterioration of the matrix.
4. Replacement of metakaolin as a partial cement between 10 and 15% may be sufficient to control deleterious expansion due to alkali-silica reaction and enhancing the mechanical properties in concrete, depending on the nature of the aggregate.
5. When compared with cement, metakaolin may be uneconomical due to its high cost, whereas it is economical in the aspects of durability and mechanical properties.

References

1. S. Piggin, *The properties of concrete*, vol. 65, no. 4 (2006)
2. W. Sha, G.B. Pereira, Differential scanning calorimetry study of ordinary Portland cement paste containing metakaolin and theoretical approach of metakaolin activity. Cem. Concr. Compos. **23**(6), 455–461 (2001). https://doi.org/10.1016/S0958-9465(00)00090-1
3. M. Beulah, M. C. Prahallada, Effect of replacement of cement by metakalion on the properties of high performance concrete subjected to acid attack. i-Manager's J. Civ. Eng. **2**(3), 14–21 (2012). https://doi.org/10.26634/jce.2.3.1934

4. H.A. Razak, H.K. Chai, H.S. Wong, Near surface characteristics of concrete containing supplementary cementing materials. Cem. Concr. Compos. **26**(7), 883–889 (2004). https://doi.org/10.1016/j.cemconcomp.2003.10.001
5. A. A. Ramezanianpour, H. Bahrami Jovein, Influence of metakaolin as supplementary cementing material on strength and durability of concretes. Constr. Build. Mater. **30**, 470–479 (2012). https://doi.org/10.1016/j.conbuildmat.2011.12.050
6. H.S. Kim, S.H. Lee, H.Y. Moon, Strength properties and durability aspects of high strength concrete using Korean metakaolin. Constr. Build. Mater. **21**(6), 1229–1237 (2007). https://doi.org/10.1016/j.conbuildmat.2006.05.007
7. H. Paiva, A. Velosa, P. Cachim, V.M. Ferreira, Effect of metakaolin dispersion on the fresh and hardened state properties of concrete. Cem. Concr. Res. **42**(4), 607–612 (2012). https://doi.org/10.1016/j.cemconres.2012.01.005
8. L. Courard, A. Darimont, M. Schouterden, F. Ferauche, X. Willem, R. Degeimbre, Durability of mortars modified with metakaolin. Cem. Concr. Res. **33**(9), 1473–1479 (2003). https://doi.org/10.1016/S0008-8846(03)00090-5
9. J.-T. Ding, Effects of metakaolin and silica fume on properties of concrete. Accessed: April 10, 2021. [Online]. Available: https://www.researchgate.net/publication/279902244
10. B. Ayobami, A. Joseph, D. Bamidele, Strength and durability properties of concrete using metakaolin as a sustainable material: review of literatures. Int. J. Civ. Eng. Technol. **10**(1), 1893–1902 (2019). Accessed: April 11, 2021. [Online]. Available: http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=1httxp://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1http://www.iaeme.com/IJCIET/index.asp1894
11. M.S. Nadesan, P. Dinakar, Permeation properties of high strength self-compacting and vibrated concretes. J. Build. Eng. **12**, 275–281 (2017). https://doi.org/10.1016/j.jobe.2017.06.003
12. Q. Li, H. Geng, Y. Huang, Z. Shui, Chloride resistance of concrete with metakaolin addition and seawater mixing: a comparative study. Constr. Build. Mater. **101**, 184–192 (2015). https://doi.org/10.1016/j.conbuildmat.2015.10.076
13. J. J. Brooks, M. A. Megat Johari, Effect of metakaolin on creep and shrinkage of concrete. Cem. Concr. Compos. **23**(6), 495–502 (2001). https://doi.org/10.1016/S0958-9465(00)00095-0
14. E. Güneyisi, M. Gesoğlu, S. Karaoğlu, K. Mermerdaş, Strength, permeability and shrinkage cracking of silica fume and metakaolin concretes. Constr. Build. Mater. **34**, 120–130 (2012). https://doi.org/10.1016/j.conbuildmat.2012.02.017
15. S. Wild, J. M. Khatib, A. Jones, Relative strength, pozzolanic activity and cement hydration in superplasticised metakaolin concrete. Cem. Concr. Res. Theme Sustain. Infrastr. Eng. **26**(10), 1537–1544 (1996). https://doi.org/10.1016/0008-8846(96)00148-2
16. B. J. Mohr, *Comparison of Two Metakaolins and a Silica Fume Used as Supplementary Cementitious Materials the Effect of Alkali Cation on the Structure of Alkali-Silica Reaction Gel View Project Utilizing Zinc Oxide Nanoparticles in Portland Cement Concrete as a Thermoelectric Material View Project* (2005). Accessed: April 10, 2021. [Online]. Available: https://www.researchgate.net/publication/237619177
17. B. Sabir, S. Wild, J. Bai, Metakaolin and calcined clays as pozzolans for concrete: a review. Cem. Concr. Compos. **23**(6), 441–454 (2001). https://doi.org/10.1016/S0958-9465(00)00092-5
18. R. Siddique, J. Klaus, Influence of metakaolin on the properties of mortar and concrete: a review. Appl. Clay Sci. **43**(3–4). 392–400 (2009). https://doi.org/10.1016/j.clay.2008.11.007
19. J. Ambroise, S. Maximilien, J. Pera, Properties of Metakaolin blended cements. Adv. Cem. Based Mater. **1**(4), 161–168 (1994). https://doi.org/10.1016/1065-7355(94)90007-8
20. C. S. Poon, S. C. Kou, L. Lam, Compressive strength, chloride diffusivity and pore structure of high performance metakaolin and silica fume concrete (2005). https://doi.org/10.1016/j.conbuildmat.2005.07.001
21. N.M. Al-Akhras, Durability of metakaolin concrete to sulfate attack. Cem. Concr. Res. **36**(9), 1727–1734 (2006). https://doi.org/10.1016/j.cemconres.2006.03.026
22. O. Karahan, K.M.A. Hossain, E. Ozbay, M. Lachemi, E. Sancak, Effect of metakaolin content on the properties self-consolidating lightweight concrete. Constr. Build. Mater. **31**, 320–325 (2012). https://doi.org/10.1016/j.conbuildmat.2011.12.112

23. T. Ramlochan, M. Thomas, K.A. Gruber, Effect of metakaolin on alkali- silica reaction in concrete. Cem. Concr. Res. **30**(3), 339–344 (2000). https://doi.org/10.1016/S0008-8846(99)00261-6
24. J. Bai, S. Wild, J.A. Ware, B.B. Sabir, Using neural networks to predict workability of concrete incorporating metakaolin and fly ash. Adv. Eng. Softw. **34**(11–12), 663–669 (2003). https://doi.org/10.1016/S0965-9978(03)00102-9
25. E. Badogiannis, G. Kakali, G. Dimopoulou, E. Chaniotakis, S. Tsivilis, Metakaolin as a main cement constituent. Exploitation of poor Greek kaolins. Cem. Concr. Compos. **27**(2), 197–203 (2005). https://doi.org/10.1016/j.cemconcomp.2004.02.007
26. P. Bredy, M. Chabannet, J. Pera, Microstructure and porosity of metakaolin blended cements. MRS Proc. **136**(1), 275–280 (1988). https://doi.org/10.1557/proc-136-275
27. S. Wild, J.M. Khatib, L.J. Roose, Chemical shrinkage and autogenous shrinkage of Portland cement-metakaolin pastes. Adv. Cem. Res. **10**(3), 109–119 (1998). https://doi.org/10.1680/adcr.1998.10.3.109
28. J. Cabrera, *Pore Size Distribution and Degree of Hydration of Metakaolin* ± *Cement Pastes*, vol. 30 (2000), pp. 561–569
29. P. Dinakar, P. K. Sahoo, G. Sriram, Effect of metakaolin content on the properties of high strength concrete. https://doi.org/10.1007/s40069-013-0045-0
30. J. Xie et al., Effect of nano metakaolin on compressive strength of recycled concrete. Constr. Build. Mater. **256**, 119393 (2020). https://doi.org/10.1016/j.conbuildmat.2020.119393
31. B. B. Patil, P. D. Kumbhar, Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin, vol. 2, no. 3 (2012), pp. 1099–1104
32. M. Narmatha, T. Felixkala, Analyse the mechanical properties of metakaolin using as a partial replacement of cement in concrete. Artic. Int. J. Civ. Eng. **4**(1) (2017). https://doi.org/10.14445/23488352/IJCE-V4I1P103

Utilization of Agricultural Waste for the Sustainable Production of Clay Bricks

Yaksh Kakkar, Rajwinder Singh, and Mahesh Patel

1 Introduction

In the construction sector, brick is one of the most significant materials. Clay due to its unique property of plasticity is the primary material used for making burnt bricks. For construction needs, bricks are sufficiently sturdy and long-lasting. They are heat resistant, corrosion resistant, and fire resistant. Because of its strength, durability, loading, compactness, and lightweight, brick is the most commonly used building material. After China, India is the world's 2nd largest brick producer. In India, it is estimated that over 1,45,000 registered and unregistered brick-making enterprises exist, producing over 236 billion bricks and directly employing over 8 million people [1]. The traditional way of producing bricks has kept this vital material away from progressing. Because of the high demand for building materials, particularly in the previous decade as a result of the rising population, more and more natural resources are being consumed. As a result, experts are working to create and develop sustainable alternative construction material factors like resource depletion, protection of non-renewable resources, advancements in public health and society, and low-cost Garbage disposal has led many nations toward recycling industrial/agricultural waste as raw materials [2]. Wastes such as rice husk, rice husk ash [3–6], fly ash [7–9], sugarcane bagasse ash [10, 11], wastewater treatment plant sludge [12–14], cigarette butts [15], and sawdust [16, 17]. have been utilized in making clay-based bricks, while certain waste materials produced excellent results, others resulted in a loss of some brick qualities. However, the final product provides good sustainable waste management [15, 18].

Rice is a primary food in Asia and the Pacific regions, and over 90% of the world's rice is produced and consumed in these areas [14]. Rice straw and rice husk together

Y. Kakkar (✉) · R. Singh · M. Patel
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab 144011, India
e-mail: kakkar2313@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_34

form the paddy residue that occupies large areas causing harm to the environment. Rice straw ash is produced as a byproduct of rice straw combustion. A huge amount of rice straw is generated around the world (annual production 731 million tons), but it can't be recycled in soil due to the short time (20–25 days) before growing subsequent crops [19]. Every year, a massive amount of rice straw is burned to get rid of this waste as the easiest method of disposal [20, 21]. In many rice-growing countries, field burning of rice straw produces atmospheric pollution, which is responsible for early deaths, health hazardous to the animal and human beings [22].

The literature review revealed no previous studies on the direct integration of rice straw ash in clay bricks as a partial replacement material for clay. No comparison of conventional and rice straw ash-based clay bricks has been published yet. The current study aims to reduce the problem connected with rice straw and its byproducts while focusing on the sustainable utilization of this waste in clay-based bricks for use in construction.

2 Environmental Impact of Rice Straw

Rice by-product management has become a concern as well as an opportunity as crop yields and cropping intensity have increased [21]. The commonly opted methods for managing rice straw by almost all farmers include open burning, soil integration, animal feed, and removal from the field. In one way or another, each strategy has some influence on the environment. The most opted rice straw management approach is to burn it. Even though farmers and paddy field owners benefit from this technique, it is tremendously damaging to the environment. This practice contributes to air pollution, global warming, and energy waste by igniting atmospheric pollution and causing nutrient losses from the soil [23]. Overall, emissions from field burning activities deteriorate local air quality and have been reported to cause high personal exposure and result in adverse health effects [24]. Fine particles, one of the major pollutants emitted from the field burning are considered as a major cause of concern due to their harmful effects on human health [25] and the earth's climate [26]. This activity emits a large number of toxic air pollutants (particles, inorganic, and organic gases) and greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxides (NOx), and sulfur dioxide (SO_2) [27].

3 Materials

This section consists of the details of the materials used in the study. Their basic properties and technique of processing these materials before brick production are also presented in this section.

3.1 Clay

Clay has been collected from a nearby brick manufacturing unit (BLS brick plant, Kartarpur, Punjab). Any sort of coarser impurities or decayed matter present were removed at the time of collection [28].

3.2 Rice Straw Ash

Rice straw ash (RSA) was collected from the "Green Planet Energy Private Limited" facility in Garhshanker, tehsil, Binjon, where rice straw is used for energy generation and rice straw ash is produced as a waste product. Ash was subjected to grinding in the ball mill for about 15–20 min until it is reduced to a fine powder and ash passed through a 300-micron sieve have been used for the production of bricks. Figure 1 shows clay and rice straw ash (RSA) samples prepared after processing.

Tables 1 and 2 show the physical properties and chemical composition of both the materials used [14].

The chemical composition of rice straw ash indicates the presence of a high amount of SiO_2 which shows that it can perform as a very good raw material for brick manufacturing.

Fig. 1 **a** Clay and **b** rice straw ash

Table 1 Physical properties of clay

Characteristics	Clay	Rice straw ash (RSA)
Specific gravity	2.48	2
Color	Brown	Black

Table 2 Chemical composition of clay

Chemical compound	Clay wt%	RSA wt%
SiO_2	59.56	71.96
Al_2O_3	21.01	5.72
Fe_2O_3	4.55	2.37
MgO	–	5.46
CaO	2.81	3.40
SO_3	0.79	1.53
LOI	6.67	3.43

3.3 Water

Normal tap water has been used to mix all the ingredients in the right consistency before molding bricks. Water having a pH of around 7 has been used in the current study [10, 14].

4 Methodology

This section contains the detailed procedure followed for carrying out the study. The details about the manufacturing process of bricks and tests to be conducted on the mix and bricks are also discussed.

Following the procurement of all required materials, basic preliminary tests were performed on the raw materials and different mix proportions with varying percentages of RSA (2, 4, 6, 8 and 10%) to analyze basic properties. Tests such as specific gravity, standard proctor tests, and consistency limits were conducted on the clay having different amounts of rice straw ash in it [29, 30].

After conducting the preliminary tests and analyzing their results, the process of the production of bricks with varying percentages of rice straw ash has been carried out at the brick manufacturing plant. Each mix had twenty bricks and the six different batches of 90 kg of clay were used for the production of bricks. The quantity of clay and RSA used in different mix designs are shown in Table 3.

Table 3 Mix design for the production of bricks

Mix	Mix proportions	Clay (kg)	RSA (kg)
1	100:0	90	0
2	98:2	88.2	1.8
3	96:4	86.4	3.6
4	94:6	84.6	5.4
5	92:8	82.8	7.2
6	90:10	81	9

Rice straw ash (passing 300-μm sieve) in right proportion mixed thoroughly with clay. Tempering of the mix was performed, followed by the addition of water. Water was added according to the optimum moisture content of each mix. With the addition of water, kneading of the mix was carried out for 24 h with slow mixing at regular intervals. For molding purposes, the table molding technique was adopted. Steel mold is used for casting brick of size 9″ × 4.5″ × 3″ with a frog of depth 10 mm. Molded bricks were then kept for 48 h in an open atmosphere for surface drying. Followed by that step, the bricks were placed in the kiln for carrying out the burning procedure of bricks to a temperature of around 1000 °C. Continuous burning of bricks has been carried for 3–4 days and after a cooling period of 10 days, bricks were extracted from the kiln. Bricks were then transported to the laboratory and stacked in six different groups were tested accordingly.

4.1 Tests Performed on Manufactured Bricks

After completion of the manufacturing process, various tests such as compressive strength test, water absorption test, shape, size, soundness, and hardness test were carried out on the bricks specimens manufactured [31]. The results of these tests were then compared with those of clay bricks (with 0% ash) to analyze the quality of bricks manufactured.

5 Results and Discussion

The brick samples prepared with varying percentages of rice straw ash and the conventional bricks were tested according to the Indian Standard code. The results of rice straw ash based-bricks were compared with the conventional clay bricks.

Preliminary tests such as specific gravity, compaction test, and consistency limit were carried out on the raw material (clay + RSA) and aids to understand the behavior of the addition of RSA in clay.

5.1 Weight of Bricks

The measurement of weight of the bricks samples manufactured using different percentages of rice straw ash was conducted, and the average result of three test specimens has been considered. Conventional brick with 0% ash weighed 3.30 kg, and bricks with 2% ash incorporated weighed 2.86 kg, resulting in a 13.3% reduction in weight. Furthermore, when the ash content has been increased to 4%, around 16.7% reduction in weight of brick has been observed (2.75 kg). Reduction in weight of bricks has been observed with increasing RSA content as depicted in Fig. 2, because

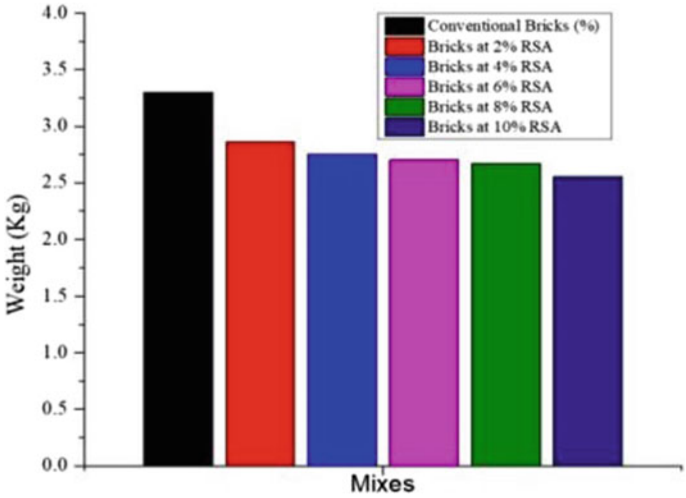


Fig. 2 Weight of bricks versus % rice straw ash in bricks

of the introduction of a low-density material in clay. Ash particles being lighter in weight in comparison to the clay, resulting in the overall reduction in the weight of rice straw ash- based bricks specimens. Moreover, when the content of rice straw ash has been increased the porosity of bricks gets increased, eventually, causing the production of the light weight of bricks in comparison to the conventional bricks [18].

5.2 *Compressive Strength*

The strength of bricks manufactured with different percentages of rice straw ash has been compared with the strength of conventional clay bricks. Bricks with 0% of rice straw ash produced the compressive strength of around 13.88 MPa, whereas at 2% replacement of clay with rice straw ash (RSA) showed the compressive strength around 11.10 MPa, that is, a 20% decrease in strength as compared to the strength of conventional bricks. Further increase in the amount of rice straw ash in the clay mix led to cause a reduction in the compressive strength of bricks as illustrated in Fig. 3. Bricks with 10% RSA produced a minimum strength of 3.12 MPa. Up to the 4% replacement of clay with RSA, the strength of the specimens satisfies the prescribed standard of first-class and second-class brick. The compressive strength of specimens depends on the density, porosity, and pore size distribution. The decrease in the density and increase in the porosity of the mix has been noticed as the amount of rice straw ash has been increased which results in the decrease in the compressive strength. The trend of decrease in the compressive strength of brick with an increase

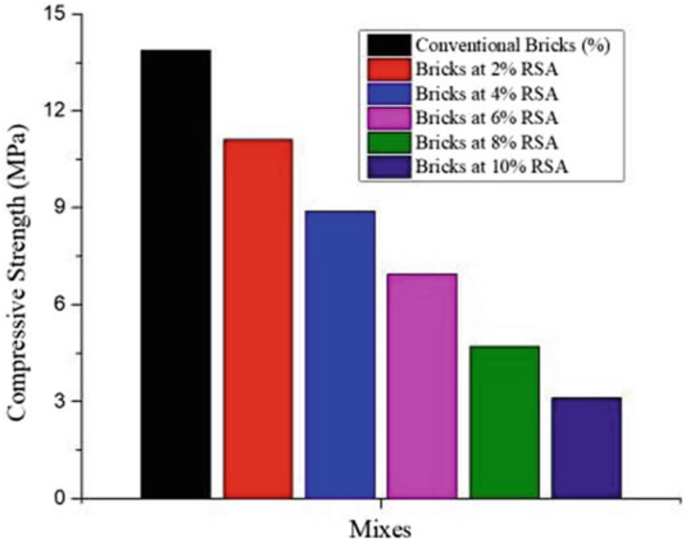


Fig. 3 Compressive strength versus % rice straw ash in bricks

in the content of waste material in the clay matrix is in line with the studies reported in the literature [10, 14, 15].

5.3 *Water Absorption*

The effect on water absorption with the incorporation of rice straw ash in bricks has been analyzed by conducting the test on each mix. The variation in the water absorption of bricks specimens of all the mixes is presented in Fig. 4. The conventional bricks showed a minimum water absorption of 3.5%, whereas when 2% of clay is replaced by RSA, a significant increase in the water absorption has been increased. Bricks specimens prepared with 2% and 4% of RSA presented water absorption around 12% and 14.4%, respectively. Whereas, it has also been noticed that the samples prepared at 2% and 4% addition of ash, satisfies the water absorption limit for first-class bricks i.e., <15%. The main reason behind the increase in the water absorption capacity of the bricks with the increase in the amount of pozzolanic material is due to the high-water absorbing nature of RSA and the formation of more pores/voids in the specimen [32, 33].

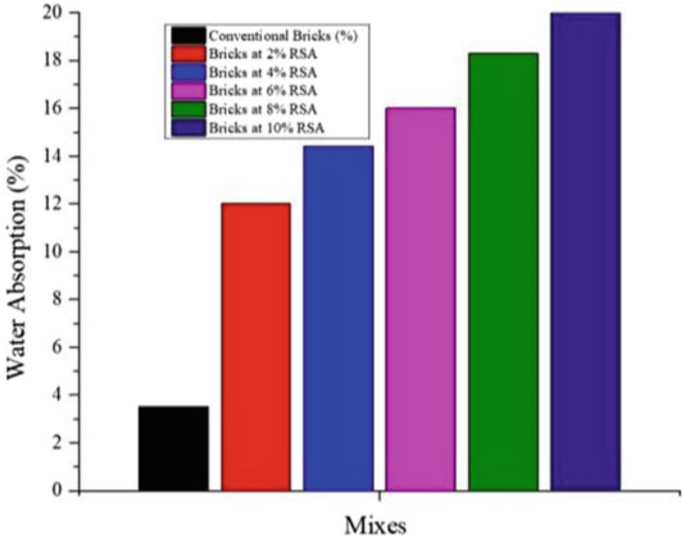


Fig. 4 Water absorption versus % RSA in different bricks

5.4 Hardness

All the brick samples prepared with and without the different proportions of rice straw ash were subjected to scratching the surface of the bricks with the fingernail and a metal ruler to test the hardness of bricks. It has been observed that conventional bricks and bricks prepared at 2, 4 and 6% ash content did not show any scratches, whereas slight indentations were observed in the case of bricks prepared at 8 and 10%. Figure 5 shows the testing procedure of the hardness test of bricks along with the scratches formed on the surface of bricks made at 8 and 10%. The manufactured bricks satisfy standards of hardness [34].

5.5 Shape and Size

All manufactured bricks possess proper rectangular shape with corners intact and no signs of warping of bricks were observed. The bricks prepared with and without the addition of rice straw ash were of proper shape and size of 9″ × 4.5″ × 3″. Results of the study were found to be in line with the similar study found in the literature [34].

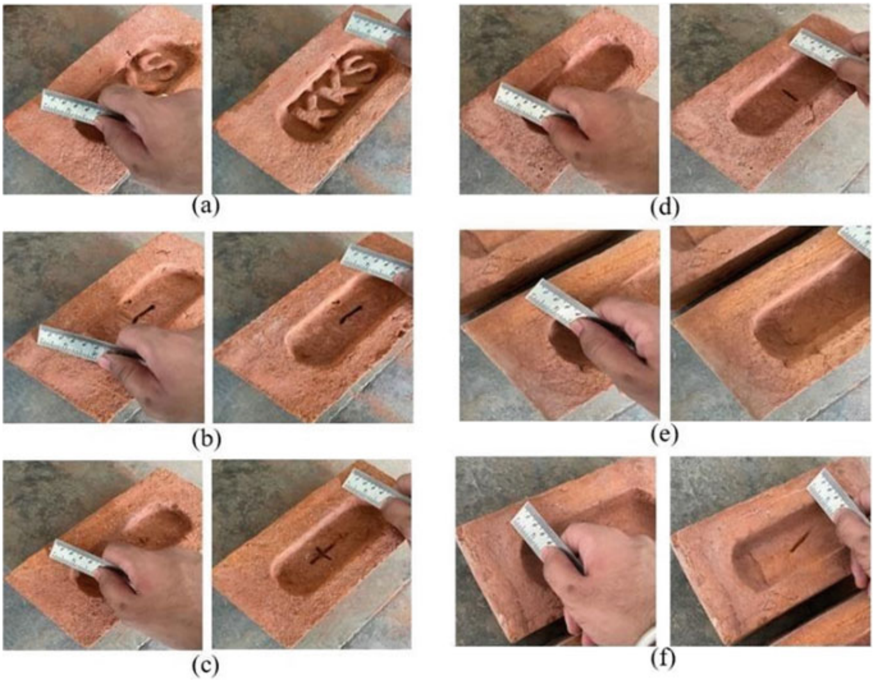


Fig. 5 Hardness test results **a** conventional clay bricks with 0% RSA, **b** brick with 2% RSA, **c** bricks with 4% RSA **d** brick with 6% RSA, **e** brick with 8% RSA, **f** brick with 10% RSA

5.6 Soundness

To conduct the soundness test on the bricks, two bricks of each mix were selected at random and stuck to one another to check the clear bell ringing sound. It has been noticed that the bricks manufactured at each mix showed that sound, resulting in meeting the standards of soundness test [35].

6 Conclusions

Based on the results of the bricks manufactured with and without the rice straw ash, it has been noticed that the performance of bricks has been improved in terms of lighter weight with satisfactory strength values and durability qualities along with providing an effective method for sustainable waste management of rice straw.

The results of preliminary tests conducted on raw materials and different mix proportions indicate that with the introduction of RSA, the specific gravity and plasticity of the mix gets decreases, whereas the optimum moisture content of each mix gets increased. Moreover, the properties of the bricks such as water absorption, compressive strength, and weight were found to be affected by the addition of rice straw ash in comparison to the conventional bricks. The physical properties such as shape, size, and hardness were found to be unaffected by the addition of rice straw ash and presented satisfactory results. In the current study, the best results have been obtained by the bricks prepared with the 2% replacement of clay has been done with the rice straw ash as all the results were found to be comparable with the results of conventional bricks and satisfying the prescribed limits according to the Indian standard. The bricks manufactured with the addition of rice straw ash at 2% are recommended for the practical application as this approach not only results in satisfying the prescribed standard but also leads to cause the sustainable management of rice straw. The author anticipates that further findings can be obtained while using rice straw ash along with the other pozzolanic materials such as rice husk ash, fly ash, and sugarcane bagasse ash for the production of bricks. The effects of these waste materials on the mechanical and durability aspects of bricks can also be evaluated.

References

1. S. K. Jain, P. S. Singh, Manual and information brochure on the brick (2009)
2. R.R. Menezes, H.S. Ferreira, G.A. Neves et al., Use of granite sawing wastes in the production of ceramic bricks and tiles. J. Eur. Ceram. Soc. **25**, 1149–1158 (2005)
3. J. Sutas, A. Mana, L. Pitak, Effect of rice husk and rice husk ash to properties of bricks. Proc. Eng. [Internet] **32**, 1061–1067 (2012). https://doi.org/10.1016/j.proeng.2012.02.055
4. M.A. Rahman, Properties of clay-sand-rice husk ash mixed bricks. Int. J. Cem. Compos. Light. Concr. **9**, 105–108 (1987)
5. D. Eliche-Quesada, M. A. Felipe-Sesé, J. A. López-Pérez, et al., Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks. Ceram. Int. [Internet] **43**, 463–475 (2017). https://doi.org/10.1016/j.ceramint.2016.09.181
6. M.S. Sultana, M.I. Hossain, M.A. Rahman et al., Influence of rice husk ash and fly ash on properties of red clay. J Sci Res. **6**, 421–430 (2014)
7. S. Abbas, M. A. Saleem, S. M. S. Kazmi, et al., Production of sustainable clay bricks using waste fly ash: mechanical and durability properties. J. Build. Eng. [Internet] **14**, 7–14 (2017). https://doi.org/10.1016/j.jobe.2017.09.008
8. O. Kayali, *High Performance Bricks from Fly Ash* (2005), pp. 1–13
9. .ASP, Engineering properties of clay bricks with use of fly ash. Int. J. Res. Eng. Technol. **03**, 75–80 (2014)
10. S. M. S. Kazmi, S. Abbas, M. J. Munir, et al., Exploratory study on the effect of waste rice husk and sugarcane bagasse ashes in burnt clay bricks. J. Build. Eng. [Internet] **7**, 372–378 (2016). https://doi.org/10.1016/j.jobe.2016.08.001
11. K. C. P. Faria, R. F. Gurgel, J. N. F. Holanda, Recycling of sugarcane bagasse ash waste in the production of clay bricks. J. Environ. Manage. [Internet] **101**, 7–12 (2012). https://doi.org/10.1016/j.jenvman.2012.01.032
12. J. A. Cusidó, L. V. Cremades, C. Soriano, et al., Incorporation of paper sludge in clay brick formulation: ten years of industrial experience. Appl. Clay. Sci. [Internet] **108**, 191–198 (2015). https://doi.org/10.1016/j.clay.2015.02.027

13. C. M. F. Vieira, R. M. Pinheiro, R. J. S. Rodriguez, et al., Clay bricks added with effluent sludge from paper industry: technical, economical and environmental benefits. Appl. Clay Sci. [Internet], 132–133:753–759 (2016). https://doi.org/10.1016/j.clay.2016.07.001
14. A. M. Heniegal, M. A. Ramadan, A. Naguib, et al., Study on properties of clay brick incorporating sludge of water treatment plant and agriculture waste. Case Stud. Constr. Mater. [Internet] **13**, e00397 (2020). https://doi.org/10.1016/j.cscm.2020.e00397
15. S. P. Raut, R. V. Ralegaonkar, S. A. Mandavgane, Development of sustainable construction material using industrial and agricultural solid waste : a review of waste-create bricks. Constr. Build. Mater. [Internet] **25**, 4037–4042 (2011). https://doi.org/10.1016/j.conbuildmat.2011.04.038
16. L. Barbieri, F. Andreola, I. Lancellotti, et al., Management of agricultural biomass wastes: preliminary study on characterization and valorisation in clay matrix bricks. Waste Mana. [Internet] **33**, 2307–2315 (2013). https://doi.org/10.1016/j.wasman.2013.03.014
17. P.A. Kumar, P. Rinku, Comparative study of compressive strength of bricks made with various materials to clay bricks. Int. J. Sci. Res. Publ. **2**, 7–10 (2012)
18. D. Tonnayopas, P. Tekasakul, S. Jaritgnam, in *Effects of Rice Husk Ash on Characteristics of Lightweight Clay Brick*. Technology and Innovation for Sustainable Development Conference (Khon Kaen University, 2008), pp. 28–29
19. M. Kapoor, D. Panwar, G. S. Kaira, Bioprocesses for enzyme production using agroindustrial wastes: technical challenges and commercialization potential [Internet]. Agro-Indust. Wastes as Feed. Enzym. Prod. Appl. Expl. Emerg. Valuab. Use Opt. Waste Biomass. (2016). https://doi.org/10.1016/B978-0-12-802392-1.00003-4
20. R. Singh, A. K. Sodhi, N. Bhanot, Investigation on the potential use of EAF dust and RSA for sustainable concrete production. Lect. Notes Civ. Eng. [Internet], 127–135 (2019). https://doi.org/10.1007/978-981-137017-5_15
21. J. Logeswaran, A.H. Shamsuddin, A.S. Silitonga et al., Prospect of using rice straw for power generation: a review. Environ. Sci. Pollut. Res. **27**, 25956–25969 (2020)
22. C.A.M. Moraes, I.J. Fernandes, D. Calheiro et al., Review of the rice production cycle: by products and the main applications focusing on rice husk combustion and ash recycling. Waste Manag. Res. **32**, 1034–1048 (2014)
23. F.A. Abdel-Mohdy, E.S. Abdel-Halim, Y.M. Abu-Ayana et al., Rice straw as a new resource for some beneficial uses. Carbohydr. Polym. **75**, 44–51 (2009)
24. C.F. Wu, J. Jimenez, C. Claiborn et al., Agricultural burning smoke in Eastern Washington: Part II. Expos. Assess. Atmos. Environ. **40**, 5379–5392 (2006)
25. C.A. Pope, M. Ezzati, D.W. Dockery, Fine-particulate air pollution and life expectancy in the United States. N. Engl. J. Med. **360**, 376–386 (2009)
26. T.C. Bond, D.G. Streets, K.F. Yarber et al., A technology-based global inventory of black and organic carbon emissions from combustion. J. Geophys. Res. Atmos. **109**, 1–43 (2004)
27. H. Van Nguyen, C. D. Nguyen, T. Van Tran, et al., Energy efficiency, greenhouse gas emissions, and cost of rice straw collection in the mekong river delta of vietnam. F. Crop. Res. [Internet] **198**, 16–22 (2016).https://doi.org/10.1016/j.fcr.2016.08.024
28. Z. A. Ahmad, Physical Performance of Fired Clay Brick Containing Two Types Of Rice Husk (2012), pp. 2–5
29. Bureau of Indian Standards. Methods of test for soils, determination of water content dry density relation using light compaction. IS 2720 (Part VII-1980), 1–16 (2011)
30. E.A. Siebel, A.E. Kott, Determination of specific gravity. J. AOAC Int. **20**, 535–542 (1937)
31. Bureau of Indian Standards, *IS 3495 Parts 1–4 : Methods of Tests of Burnt Clay Building Brick*. IS 3495 (1992), pp. 1–7
32. S. M. S. Kazmi, S. Abbas, M. A. Saleem, et al., Manufacturing of sustainable clay bricks: utilization of waste sugarcane bagasse and rice husk ashes. Constr. Build. Mater. [Internet] **120**, 29–41 (2016). https://doi.org/10.1016/j.conbuildmat.2016.05.084
33. O. T. Maza-Ignacio, V. G. Jiménez-Quero, J. Guerrero-Paz, et al., Recycling untreated sugarcane bagasse ash and industrial wastes for the preparation of resistant, lightweight and ecological fired bricks. Constr. Build. Mater. [Internet] **234**, 117–314 (2020). https://doi.org/10.1016/j.conbuildmat.2019.117314

34. R. Kumar, N. Hooda, An experimental study on properties of fly ash bricks. Int. J. Res. Aeronaut. Mech. Eng. **2**, 56–67 (2014)
35. A.R. Dar, S.K. Verma, D.K. Ashish et al., Investigation on the properties of non conventional bricks. J. Struct. Eng. **3**, 26–35 (2015)

Future of Sustainable Landfilling Through Bioreactor Landfills: A Review

Kamran Ilahi and Arvind Kumar Agnihotri

Abbreviations

BL	Bioreactor Landfill
BLT	Bioreactor Landfill Technology
EPA	Environmental Protection Agency
ETPS	Effluent Treatment Plant Sludge
IWM	Integrated Waste Management
IMD	Indian Meteorological Department
LL	Landfill Leachate
LRS	Leachate-Recycle System
MBR	Membrane Bioreactor
MLD	Million Liters Per Day
MSW	Municipal Solid Waste
MSWLF	Municipal Solid Waste Landfill
MSWM	Municipal Solid Waste Management
N	Nitrogen
NH_3–N	Ammonia Nitrogen
RO	Reverse Osmosis
TDR	Time Domain Reflectometry
TFFBR	Photocatalytic Detoxification with the Thin-Film Fixed-Bed Reactor

K. Ilahi (✉) · A. K. Agnihotri
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India
e-mail: kamranilahisbl@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_35

1 Introduction

Waste management is a critical issue worldwide because the potential of environmental pollution associated with municipal solid waste management (MSWM) is tremendous. This is undoubtedly a matter of concern for developing countries, where the total amount of municipal solid waste (MSW) has expanded erratically due to accelerated industrialization, rapid urbanization, and rise in community living standards [1–3]. With increasing population and lack of awareness in the developing nations, traditional indiscriminate methods of managing MSW are still being operated such as open dumping, informal recycling, and open incineration [4–10]. The deferred realization by developing nations after identifying negative impacts of inappropriate MSWM practices on public health, water bodies and atmosphere has forced them to address this issue with some concern [5, 11]. This has also forced all nations worldwide to come up with fresh policies and develop accurate MSWM techniques. Aforementioned can help them to deal with the negative impacts of MSW on the ecosystem [12, 13].

Bioreactor landfill (BL) concept has gained tremendous attention from the last three decades because of its suitability for achieving greater environmental sustainability and is considered as a way forward in integrated waste management techniques. According to the EPA, a bioreactor landfill is a municipal solid waste landfill (MSWLF) in which liquids are added to help bacteria break down the waste at a faster rate. Bioreactor landfills do not only decompose the waste rapidly but also provide an opportunity to convert this waste mass into usable energy by capturing landfill gases (LFGs) [14–17] and thus improving the viability of gas-to-energy options. On the foremost, bioreactor landfills provide higher flexibility to reduce risks, related to highly sensitive and numerous environmental pollution issues, such as soil contamination by leachate and rise of global temperature due to release of greenhouse gases in open dumps, traditional landfills and dry tombs [18, 19]. A schematic image of a bioreactor landfill showing its important components is presented in Fig. 1.

Parameters that make bioreactor landfills economical to implement most significantly are savings resulting from reduced leachate treatment costs [20], rapid settlement of waste (airspace recovery), and the economy raised by electricity generated through landfill gases (LFGs) [21–23]. The latest reports on bioreactor landfill design are trying to make it a more efficient system. However, bioreactor landfill design is an open meaningful concept that is yet to be equipped by developing and many developed nations. The possible reason for such delay may be interrelated complex parameters such as socio-cultural, economic, political, legal, environmental, and available resources [24, 25]. Such parameters can heavily influence the MSWM in a country, for example, India, where the 12th schedule of the 74th constitution amendment act (1992), clearly formulates urban local bodies (ULBs) as the institution for MSWM in cities and towns. However, ULBs in India lack competent institutional capacity, financial resources, and a political will for a sustainable MSWM system. In India, it accounts for more than 90% of the total MSW generated, which is directly applied on land in an indiscriminate manner [26]. The achievement of a sustainable

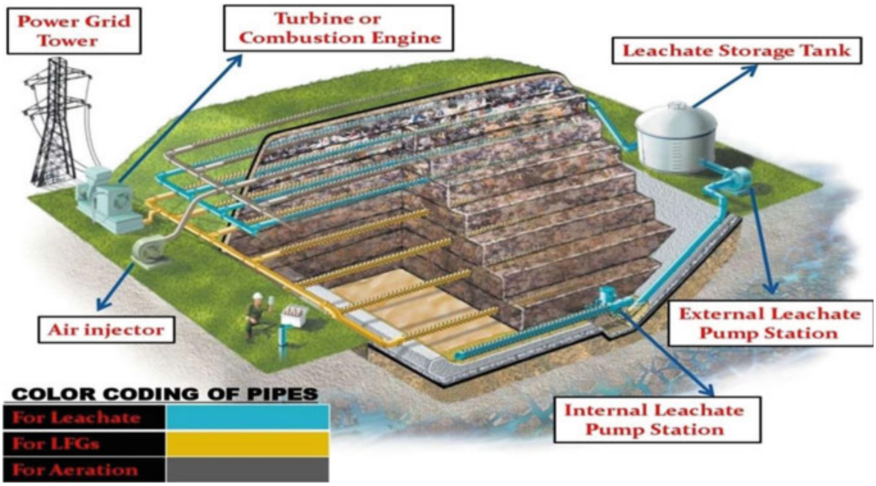


Fig. 1 A detailed framework of bioreactor landfill design

MSWM solution is definitely possible when such issues are addressed. Fourie [27], reported that enforcement of environmental legislation is very weak in developing countries. Such factors have resulted in the devastation of human and environmental health on a large scale.

Presently, more factors for the delay of bioreactor landfill construction in MSWM on a global scale can be realized through various scientific and technical concerns associated with it. Bioreactor landfill design is still in its development phase and also being a novel technology, it is mostly studied at laboratory scale. However, the United States, Canada, and Australia are the countries where many bioreactor landfill projects are in operation. Pilot scale projects for bioreactor landfills are showing promising results and such projects have been started in different parts of the world. Currently, there are no standardized operational procedures, recommended designs, or approved guidelines in operating bioreactor landfills. Thus, its critical analysis is necessary to find out the various challenging issues which the scientific community has to address in future.

2 Waste Degradation Behavior in Bioreactor Landfills

Bioreactor landfills can be classified as anaerobic, aerobic, semi-aerobic, and hybrid based on their operational distinctiveness [28]. However, the basic concept of leachate recirculation is the same in all types of bioreactor landfills. They have evolved with time under distinct designs, operational procedures, and waste degradation mechanisms. The attainment of specific objectives such as energy recovery from LFGs and leachate quality improvement drives the choice of the BL type. Moreover, the choice is also heavily influenced by MSW characteristics, climate of the location, and socio-economic situation of the area. However, global sustainability in landfilling should be the common principle in the BL design for achieving rapid waste stabilization [29]. A detailed analysis of different types of bioreactor landfills is presented in Table 1.

A special modification in BLs has been reported in the form of flushing bioreactor. In a flushing BL, a large quantity of supplementary liquid is injected and recirculated along with leachate so that organic compounds, ammonium, salts, and hard COD can be flushed out of the bioreactor landfill system. This in turn accelerates the waste degradation process. The most critical factor in the flushing BLs is the flushing rate [37], which depends upon the liquid/solid (L/S) ratio, where L denotes the cumulative quantity of liquids recirculated in m^3 and S denotes the quantity of waste mass in tons. However, various studies have indicated the inhibition of methanogenic phase under flushing operations. Such inhibition can decrease the potential of LFGs to energy conversion. Moreover, [38] suggested a modified form of flushing BLs in which they performed flushing operations with the help of leachate alone and combined it with in-situ aeration in order to remove the organic content effectively from the BL. The

Table 1 Overview of various types of bioreactor landfills

Types	Aerobic	Anaerobic	Hybrid	Facultative
Basic properties	(a) Air and leachate, both are recirculated (b) Accelerated waste degradation by aerobes (c) Removal of moisture by air stripping (d) Nitrification and denitrification occur simultaneously	(a) Conditions are made favorable for anaerobic bacteria (b) Optimal moisture content is important (c) Ballooning and tearing of plastic surface liners can occur	(a) Partial oxygen-deficient conditions (b) Volatile organic acids are destroyed in-situ (c) Methanation, hydrolysis, and fermentation are operated in parallel	(a) Aerobic-anaerobic type (b) Controlled leachate input (c) Mitigates risks of high ammonia-nitrogen levels
Waste degradation rate	Rapid	Medium	High	Medium
LFG to energy potential	Low (CO_2 mainly)	High (CH_4 mainly)	Medium (mixture of CO_2 and CH_4)	High
Distinctive feature	Quick removal of COD and BOD, space is regained in real-time	High odors, improved leachate quality	Complete in-situ removal of nitrogen can be accomplished	Leachate is nitrified in an external treatment system prior to recirculation
Flammability and explosion risks	Low	High	Medium	High
References	[20, 30, 31]	[32, 33]	[28, 31, 34]	[35, 36]

leachate was treated with Fenton's reagent outside the cell after each flushing cycle. However, they assumed hydraulic conductivity of waste as a constant parameter, which is not true in reality. Hydraulic conductivity of waste decreases as the waste mass stabilizes with time under recirculation operations of leachate. Furthermore, the Fenton's reagent particles should have clogged the pores, thus reducing the hydraulic conductivity to a further extent. Note that Fenton's reagent has been reported to remove the organic content effectively from the mature landfill leachate due to the presence of hydroxyl free radical (HO*) [39–41].

During the past thirty years, there has been a surge in research on several aspects of the BL design framework, such reports have indicated the potential advantages of bioreactors and have demonstrated the rise in MSW decomposition and gas production at various landfills [17]. Due to potential advantages of BLs as well as more frequent regulatory acceptance, a number of full-scale bioreactor and leachate recirculation operations have been started in the US [23]. Entire world is showing considerable interest in developing strategies to accelerate the decomposition of municipal solid waste (MSW) in landfills. Sustainable landfilling has recently inspired scientific community about MSWM and can be attained by incorporating a long-term strategy for the control of emissions and climate change issues into bright aspects of traditional landfilling technology and achieve environmental equilibrium over a long period of time, as indicated by [50].

The rapid waste decomposition executed by BLs can have colossal advantages which include quick settlement of the waste which in turn increases the volume of waste that can be disposed of in a given landfill footprint, a superior rate of gas production which can upgrade the economics of the valuable use of landfill such as methane. It can also reform leachate character through recognition of the waste mass as a treatment medium, thus reducing leachate treatment costs. Furthermore, rapid waste decomposition helps greatly in stabilization of the waste mass prior to final cover placement which cuts down long-term maintenance requirements for a final cover and finally, a reduction in overall environmental risk can be accomplished by achieving enhanced sustainability as indicated by [16, 21, 43, 51, 52]. In addition to the above-discussed advantages, bioreactor landfill allows a flexible landfill management by recognizing the biological, chemical, and physical processes involved in a landfill ecosystem [53]. BLs are designed to improve the inefficiencies of traditional landfills, reducing the prolonged stabilization periods [54].

3 Future Challenges Associated with Bioreactor Landfills

Various researchers showed increased levels of waste degradation in relatively wet areas during shorter spans of time as verified by an increase in percentage of fines up to 50–75% as compared with 35–40% in relatively dryer areas worked out in Delaware by [55], Georgia by [56] and in Maryland by [57]. Such results were also verified by using biological methane potential tests carried out at landfill sites located in the UK and Florida indicated, respectively by [58] and [43]. Thus, it is necessary to claim here that solid evidence has been put forward in multiple phases of time by a series of studies for achievement of enhanced degradation rates of organic biodegradable waste fractions in leachate recirculation landfills. However, the long-term fate of many other waste constituents is still unidentified and assessment and reckoning of the fate of these components have proved challenging to researchers. For instance, with the passage of time, in the presence of moisture, sulfides and humic substances are expected to bind with heavy metals more frequently and are subjected to continued anaerobic processes within the landfill. In such a scenario oxygen and water may help in mobilizing metals within the landfill and flush surviving inorganic contaminants out of the landfill. Flushing BLs offer probable solutions to the early exclusion of soluble inorganic contaminants. Various studies have shown that the accelerated introduction of two to four liquid bed volumes decreases the ammonia levels significantly as indicated by [59], however application of these tools gives rise to many scientific and economic issues. Such situations pose difficult questions on ultimate environmental sustainability of BLs, which the current study has tried to figure out, such as; can such a system be adopted in developing nations to achieve global scale sustainability? Can traditional landfills and open dumped sites be converted into BLs? What elements to consider while implementing a sustainable bioreactor (based on critical appraisal of the published literature)? Can environmental conditions develop in such a way that will assimilate these contaminants within tolerable levels of risk to human well-being or the environment itself? Moreover, can the reactor perform to pull out ample resources, such as LFGs, within a logical time period? The various other critical issues related to bioreactors remain unanswered, which we are highlighting in subsequent sections. For example; [58] investigated the effect of anaerobic co-landfilling in simulated BLs on leachate strength obtained from a mixture of paper mill-based ETPS (effluent treatment plant sludge) and MSW. The results indicated considerable reduction in leachate strength and enhancement in biogas production compared to the solo MSW digestion. They also carried the simulation of co-landfilling reactors through the gompertz growth equation to develop a sigmoid kinematic model for methane production. However, in their model, they neglected the effect of various parameters in the numerical formulations such as thermal conductivity and viscosity of leachate subjected to co-landfilling, gas pressure, and biodegradation parameters such as methane diffusion properties. Furthermore, pulverized MSW samples were used in their analysis in very small prismoidal-shaped lysimeters having dimensions $1.15\ \text{m} \times 0.6\ \text{m} \times 0.4\ \text{m}$, such conditions cannot conform to the real field conditions of a complex bioreactor landfill system where heterogeneity and anisotropy play a major part to control gas production and leachate quality.

3.1 Settlement

A clear distinction between the secondary compressibility corresponding to settlement of landfill waste under sustained action of load and the biological secondary compressibility, which represents the settlement achieved due to accelerated biological waste degradation in bioreactor landfills is yet to be explained and may be helpful in achieving long-term goals.

3.2 Sustainable Airspace Recovery

As it is now well understood that the vertical airspace is recovered due to rapid degradation and significant settlement of waste mass, but the effective utilization of this recovered airspace in real frames of time should be addressed. This will help us in saving utilization of areas under landfill sites and the economy as well. For example, a floating dome concept may be helpful in such cases, which are designed for growing space and meeting space requirements. One of the future design elements of BL should accommodate the fresh incoming MSW instantly into its recovered airspace without causing trouble to the overall efficiency of the system.

3.3 Sampling Challenges at Bioreactor Landfill Sites

Significant research is required to establish methodologies for performing tests on real waste samples in an undisturbed state, while obtaining hydraulic properties in a disturbed sample, the structure of waste changes drastically, even in pressure plate tests such as a modified tempe cell [59, 60]. Thus, the results obtained for the structural and hydraulic properties will not represent in-situ conditions of waste as it is believed that the disparity in particle size, density, amount of organic matter with respect to landfill life and depth modifies unsaturated hydraulic parameters. The major research till date known to us has focused on leachate production, collection, elimination, or its recirculation for justifying accelerated degradation of the waste mass. The optimization of important parameters such as non-homogeneous and anisotropic nature of waste mass has been ignored. A frequent drawback of the testing methods used for investigation of the hydraulic conductivity is its presumptions of considering waste as a homogeneous waste mass with equal vertical and horizontal hydraulic conductivities. Therefore, the obtained hydraulic conductivity value is ambiguous to a larger extent and when such uncertain parameters are used in correlations and data equations, it may result in higher disparities. However, some researchers tried back calculations for both vertical and horizontal hydraulic conductivities of paper sludge, conducted on a two-stage setup of borehole permeameter. However, TSB tests have not been reported on MSW nor recommended.

3.4 Challenges with Testing Procedures on Waste Mass

The tests, techniques, and equipment's which have been adopted in established research for evaluation of various properties of municipal solid waste mass in bioreactors and also previously in traditional landfills can be roughly categorized into direct procedures (giving results directly) such as borehole for direct unit weight, dilatometer, CPT, SPT, pressuremeter for measuring (strength, stiffness, lateral earth pressure, etc.) directly and indirect procedures (results obtained after back analysis or inversion of data, modifications, regression) such as electrical and nuclear surveys, strong ground motions, stratigraphy, etc. For the measurement of properties of waste, if the setup is required to penetrate into the waste, it may be referred to as Intrusive procedures and non-Intrusive vice versa, such as evaluation of ambient vibrations (e.g., REMI), seismic refraction surveys, spectral analysis of surface waves (SASW). Non-intrusive procedures mostly provide indirect measurements of MSW properties and are preferred over Intrusive methods by researchers in the perspective of being faster, cheaper, and associated benefits of health and safety, but possess a variety of drawbacks such as wide variations in data. There are various parameters in MSW where tests and methodologies developed so far cannot be applied with ample reliability. For example, several researchers in their studies that it is difficult to measure the shear strength of MSW. In addition, the elements for inversion, modifications, and regression of data techniques do not follow a common principle. Hence, the variation in data obtained is certain. The inconsistency in measured properties may be attributed to the interdependence of multiple types of deformations caused by secondary compression without change in waste mass, secondary biological compression, and due to creep combined with the anisotropic and heterogeneous nature of waste properties and biological decomposition processes within the landfill. Thus, it is difficult to figure out a particular test or procedure as an approved or recommended procedure in this current frame of time, however for achieving a sustainable solution research on this important aspect of bioreactors should be encouraged and funded.

4 Recommendations for Developing Countries

More efforts are required to address the persisting challenges associated with BLs which are highlighted in this paper. However, the current state of bioreactor landfills is implementable to cure the damages aimed at our biosphere through unplanned and haphazard waste management practices. One of the key challenges is "How do we equip the bioreactor landfills worldwide, particularly in developing nations?" or in other words, we should conceptualize a road map to switch from open dumping to BLs. Various reports have highlighted random waste disposal practices such as open dumping even in developed countries. These practices at global level are posing significant threats to the environment. The challenges on ground are highly resilient to a sustainable integrated waste management policy.

However, a global level sustainability can be attained by implementing BLs as the ultimate solution for MSWM challenges with the help of sustainability science, by using its tools such as the concept of nature-society systems and co-production. Co-production is one of the most vital ideas in the theory, practice, and governance for global sustainability. Moreover, also indicated that the perception of co-production can be the foundation to achieve global sustainability. Furthermore, co-production provides the key framework for critically evaluating the society and implementing use of sustainability knowledge in global affairs [61], and guiding the design and implementation of international sustainability research and action. Table 2 presents a comprehensive approach for effective bioreactor landfill initiation as a viable tool for developing countries and also for developed ones where bioreactor landfill strategy is in planning phase.

Indiscriminate disposal of MSW in absence of necessary provisions such as daily cover and leachate prevention facility is recognized as a dangerous practice in integrated waste management at the global level. The unscientific management of a sustainable policy framework by many developing nations has resulted in informal recycling and disposing activities that are regularly in conflict with recommended and sound waste management practices [12]. However, BLT can be implemented by retrofitting these open dumpsites and there are three scenarios that may solve the problem:

(a) **Scenario 1 (An economic solution)**
In economically weaker countries, such as India, implementing BLT, a new trend in waste management practices will require new investments. However, there are more long-term benefits associated with BLT, as discussed earlier. Keeping such a factor in mind, land costs can be avoided by constructing bioreactor landfills at the vacant spaces of dumpsites. This should be designed for holding the daily fresh incoming MSW after proper segregation at source. The choice of BL may vary after consideration and optimization of various site constraints. Co-production should be the common goal between the political organization and the scientific community in attaining sustainable solutions through BLT. At present, provisions for leachate collection and recirculation facilities can also be planned on these waste dumping sites to enhance their biodegradation in order to recover the airspace for future planning of BLT. This can indeed prove to be a viable economic solution for a step toward IWM.

(b) **Scenario 2 (Minimizing environmental pollution)**
The waste mass at the dumps exhibits varying properties along the depth. We may classify it with respect to its leachability. For e.g., the waste mass dumped two years before will be more leachable than the one dumped six months ago. As the waste mass is dumped and subjected to landfill conditions, it starts degrading and leaching out the various harmful contaminants with the percolating liquid. When the BLT has operated near the waste dumping sites, it is more appropriate

Table 2 Roadmap for equipping/retrofitting BLs in developing countries

Site constraints	Design elements
Select a retrofit site/cell size and optimize MSWM bioreactor planning elements [52]	Optimize landfill geometry, including interim height and final elevations
Optimize land use elements	Optimize design/configuration elements of overlapping cells with integrated liner and cover systems
Keep the record of climate, precipitation, and hydrology of the location, see also [51, 52]	Optimize liner systems (such as natural clay or man-made geomembranes) and liner chemical compatibility
Optimize risk elements such as fault areas, seismic impact zones, airports, explosions, etc.	Optimize design/capacity of leachate collection and removal system (LCRS) for uniform distribution
Optimize political, social, legal and stakeholders' concerns	Optimize design/capacity of gas collection and control elements
Optimize elements for availability of haulage vehicles	Optimize elements to control PH, temperature, and odor
Prepare plans for assisting structures such as buildings for control facility	Carry out discretization of space and for storage capacity and those of a final cover system at the top of the landfill [62]
Set a provision of buffer areas and Prepare/plan elements for construction of access roads toward bioreactor site	Optimize surface water drainage system elements
Set a provision for availability of cover material such as large quantities of soil	Optimize elements to minimize groundwater contamination
Optimize elements of protection for environmentally sensitive areas/issues	Check the serviceability and overall stability of various design elements
Optimize elements of fencing and Landscaping	Optimize elements for groundwater and landfill gas monitoring
Set a provision for a potential beneficial end-use after the closure of a bioreactor and post-closure plan	Optimize the overall geotechnical stability of the system
Plan/optimize liquid addition and management methods as per location suitability, e.g., [63]	Carry out the cost–benefit analysis for a given location of bioreactor, e.g., [20]

and sustainable to design the BLs for the waste having more leachability potential. This can also help in starting the post-closure monitoring in a short span of time, as the waste mass having higher leachability potential is abundantly present in waste dumping sites. The overall environmental pollution will be reduced by preventing potential contaminants such as heavy metals, aliphatic hydrocarbons etc. reaching underground water tables. The revenue can also be generated by collecting the methane at an early stage.

(c) **Scenario 3 (A sustainable solution)**
An IWM scheme can be outlined worldwide when operating BLs designed for capacity to hold refuse generated on a daily basis as well as waste disposed

of in open dumpsites. This can lead to a revolution by reducing all negative impacts on the biosphere and a vital economy generation system. This can be achieved by optimizing various aspects of BLs and encouraging research on the promising BLT.

The improvement and response to the mismanaged landfilling operations, an organized rehabilitation program must be outlined and executed such as the elements of optimization prepared by this paper. This program must consider the various benefits of retrofitting and operating dumpsites as bioreactors and must be conceptualized accordingly during the planning phase. Further studies must be conducted at pilot and lab scales in such developing nations for global environmental sustainability.

5 Conclusions and Future Scope

This paper gives an overview about dynamic aspects of bioreactor landfill systems. Furthermore, various geotechnical challenges associated with BL systems are investigated. Technical and scientific factors affecting proper understanding of moisture and its dynamic behavior of flow through spatial-temporal varied waste mass is reviewed. This study provides an opportunity to understand the impedance between LL flow and waste mass inside bioreactor landfill design. Since Landfilling lingers to be the most crucial part of an IWM system, the need for improved testing procedures is also investigated and research urgency on bioreactor landfills for modifications in IWM policies are also reviewed in order to reach a sustainable BL scheme. This can help also in outlining a proper post-closure monitoring program. Furthermore, recommendable guidelines can be outlined for developing countries by optimizing various site constraints. The co-production of such a roadmap provides an opportunity to attain sustainability in MSWM through research in its technical aspects and cost-benefit realization of such a new technology at global scale. Investigations are needed to set up definitive guidance charts for standardization of layout of leachate injection network. This paper opens the scope for implementation of bioreactor landfills at global level. Moreover, following important points are concluded by the current study and are important for further research and sustainable development of MSWM through BL acquisition:

a. More investigations are required on Facultative type BLs where leachate is nitrified in an external treatment system prior to recirculation, in order to mitigate risks of toxic ammonia-nitrogen levels effectively through proper reliability methods.
b. Limited studies have focused on reducing flammability and explosion risks in anaerobic BL systems. High odor emissions from anaerobic BLs due to hydrogen sulfide and methane are also a concern to human health and should be addressed with further extensive studies.
c. The fate of various contaminants such as sulfides and humic substances having a tendency to bind with heavy metals should be clearly understood.

d. Factors controlling anisotropic and heterogeneous properties of waste should be properly reviewed and a proper decision support and expert system must be obtained.
e. Proper analytical and rational methods are required to calculate the hydraulic conductivity of waste mass in BLs having greater reliability than the existing methods.
f. A unified system for proper in-situ leachate treatment plan capable of eliminating the toxic levels of all contaminants during leachate injection processes without disturbing the optimal levels of pH and temperature for methane extraction is need of the hour.
g. Parameterization of time involved in different settlement stages through accurate simulation studies can be helpful for effective utilization of recovered airspace in real frames of time.
h. Optimization of socio-political constraints in developing nations is one of the key elements in BL acquisition. In cases of retrofitting, flexibility in BL design must be investigated to counter persisting heavy leachate-pollutant load in open dumpsites.
i. While retrofitting existing landfills such as open dumps or LRS into BL systems, provisions for handling existing waste at site must be planned in accordance with the design elements discussed in various sections of this paper in order to reduce contaminant load and pollution impact on the biosphere.
j. Significant research is required to establish methodologies for performing tests on real waste samples in an undisturbed state. Improved testing procedures will help to access the holistic performance of the BL system. Sustainability science should come forward for addressing issues in BL acquisition worldwide.

References

1. S. Seo, T. Aramaki, Y. Hwang, K. Hanaki, Environmental impact of solid waste treatment methods in Korea. J. Environ. Eng. **130**(1), 81–89 (2004). https://doi.org/10.1061/(asce)0733-9372(2004)130:1(81)
2. S. Sakai et al., World trends in municipal solid waste management. Waste Manage. **16**(5–6), 341–350 (1996). https://doi.org/10.1016/S0956-053X(96)00106-7
3. X. Chen, Y. Geng, T. Fujita, An overview of municipal solid waste management in China. Waste Manage. **30**(4), 716–724 (2010). https://doi.org/10.1016/j.wasman.2009.10.011
4. L. Zhen-shan, Y. Lei, Q. Xiao-Yan, S. Yu-mei, Municipal solid waste management in Beijing City. Waste Manage. **29**(9), 2596–2599 (2009). https://doi.org/10.1016/j.wasman.2009.03.018
5. S.A. Batool, M.N. Ch, Municipal solid waste management in Lahore city district, Pakistan. Waste Manage. **29**(6), 1971–1981 (2009). https://doi.org/10.1016/j.wasman.2008.12.016
6. S.S. Chung, C.W.H. Lo, Local waste management constraints and waste administrators in China. Waste Manage. **28**(2), 272–281 (2008). https://doi.org/10.1016/j.wasman.2006.11.013
7. A. Imam, B. Mohammed, D.C. Wilson, C.R. Cheeseman, Solid waste management in Abuja, Nigeria. Waste Manage. **28**(2), 468–472 (2008). https://doi.org/10.1016/j.wasman.2007.01.006
8. M. Berkun, E. Aras, S. Nemlioglu, Disposal of solid waste in Istanbul and along the Black Sea coast of Turkey. Waste Manage. **25**(8), 847–855 (2005). https://doi.org/10.1016/j.wasman.2005.04.004

9. E. Metin, A. Eröztürk, C. Neyim, Solid waste management practices and review of recovery and recycling operations in Turkey. Waste Manage. **23**(5), 425–432 (2003). https://doi.org/10.1016/S0956-053X(03)00070-9
10. S.A. Ahmed, M. Ali, Partnerships for solid waste management in developing countries: linking theories to realities. Habitat Int. **28**(3), 467–479 (2004). https://doi.org/10.1016/S0197-3975(03)00044-4
11. M. Sharholy, K. Ahmad, G. Mahmood, R.C. Trivedi, Municipal solid waste management in Indian cities—a review. Waste Manage. **28**(2), 459–467 (2008). https://doi.org/10.1016/j.wasman.2007.02.008
12. C.R. Bartone, Economic and policy issues in resource recovery from municipal solid wastes. Resour. Conserv. Recycl. **4**(1–2), 7–23 (1990). https://doi.org/10.1016/0921-3449(90)90030-8
13. I. A. Al-Khatib, M. Monou, A. S. F. Abu Zahra, H. Q. Shaheen, D. Kassinos, Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district—Palestine. J. Environ. Manage. **91**(5), 1131–1138 (2010). https://doi.org/10.1016/j.jenvman.2010.01.003
14. R.E. Klink, R.K. Ham, Effects of moisture movement on methane production in solid waste landfill samples. Resour. Conserv. **8**(1), 29–41 (1982). https://doi.org/10.1016/0166-3097(82)90051-7
15. A. Findikakis, C. Papelis, C. Halvadakis, J. Leckie, Modelling gas production in managed sanitary landfills. Waste Manage. Res. **6**(2), 115–123 (1988). https://doi.org/10.1016/0734-242x(88)90056-0
16. M.A. Barlaz, R.K. Ham, D.M. Schaefer, Methane production from municipal refuse: a review of enhancement techniques and microbial dynamics. Crit. Rev. Environ. Control **19**(6), 557–584 (1990). https://doi.org/10.1080/10643389009388384
17. R. Mehta, M.A. Barlaz, R. Yazdani, D. Augenstein, M. Bryars, L. Sinderson, Refuse decomposition in the presence and absence of leachate recirculation. J. Environ. Eng. **128**(3), 228–236 (2002). https://doi.org/10.1061/(ASCE)0733-9372(2002)128:3(228)
18. N. Sutthasil et al., Comparison of solid waste stabilization and methane emission from anaerobic and semi-aerobic landfills operated in tropical condition. Environ. Eng. Res. **19**(3), 261–268 (2014). https://doi.org/10.4491/eer2014.S1.003
19. X. Wu et al., Spatio-temporal variation of landfill gas in pilot-scale semi-aerobic and anaerobic landfills over 5 years. J. Environ. Sci. (China) **54**, 288–297 (2017). https://doi.org/10.1016/j.jes.2016.09.015
20. N.D. Berge, D.R. Reinhart, E.S. Batarseh, An assessment of bioreactor landfill costs and benefits. Waste Manage. **29**(5), 1558–1567 (2009). https://doi.org/10.1016/j.wasman.2008.12.010
21. F. G. Pohland, S. J. Kang, *Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment*. (Cincinnati, Ohio, 1975)
22. F.G. Pohland, Leachate recycle as landfill management option. J. Environ. Eng. Div. **106**(6), 1057–1069 (1980)
23. D.R. Reinhart, P.T. McCreanor, T. Townsend, The bioreactor landfill: Its status and future. Waste Manage. Res. **20**(2), 172–186 (2002). https://doi.org/10.1177/0734242X0202000209
24. V. Kum, A. Sharp, N. Harnpornchai, Improving the solid waste management in Phnom Penh city: a strategic approach. Waste Manage. **25**(1), 101–109 (2005). https://doi.org/10.1016/j.wasman.2004.09.004
25. H. A. Abu Qdais, Techno-economic assessment of municipal solid waste management in Jordan. Waste Manage. **27**(11), 1666–1672 (2007). https://doi.org/10.1016/j.wasman.2006.08.004
26. D. Das, M. Srinivasu, M. Bandyopadhyay, Solid state acidification of vegetable waste. Indian J. Environ. Health **40**(4), 333–342 (1998)
27. A. Fourie, Municipal solid waste management as a luxury item. Waste Manage. **26**(8), 801–802 (2006). https://doi.org/10.1016/j.wasman.2006.05.005
28. Z. Han, D. Zeng, Z. Mou, G. Shi, Y. Zhang, Z. Lou, A novel spatiotemporally anaerobic/semi-aerobic bioreactor for domestic solid waste treatment in rural areas. Waste Manage. **86**, 97–105 (2019). https://doi.org/10.1016/j.wasman.2019.01.034

29. R. Cossu, Technical evolution of landfilling. Waste Manage. **30**(6), 947–948 (2010). https://doi.org/10.1016/j.wasman.2010.03.003
30. A. Giannis, G. Makripodis, F. Simantiraki, M. Somara, E. Gidarakos, Monitoring operational and leachate characteristics of an aerobic simulated landfill bioreactor. Waste Manage. **28**(8), 1346–1354 (2008). https://doi.org/10.1016/j.wasman.2007.06.024
31. M. Ahmadifar, M. Sartaj, M. Abdallah, Investigating the performance of aerobic, semi-aerobic, and anaerobic bioreactor landfills for MSW management in developing countries. J. Mater. Cycles Waste Manage. **18**(4), 703–714 (2016). https://doi.org/10.1007/s10163-015-0372-0
32. R. Valencia, W. van der Zon, H. Woelders, H.J. Lubberding, H.J. Gijzen, Anammox: an option for ammonium removal in bioreactor landfills. Waste Manage. **31**(11), 2287–2293 (2011). https://doi.org/10.1016/j.wasman.2011.06.012
33. G.A. Price, M.A. Barlaz, G.R. Hater, Nitrogen management in bioreactor landfills. Waste Manage. **23**(7), 675–688 (2003). https://doi.org/10.1016/S0956-053X(03)00104-1
34. Y. Long, L. fang Hu, D. S. Shen, Nitrogen transformation in the hybrid bioreactor landfill. Bioresour. Technol. **100**(9), 2527–2533 (2009). https://doi.org/10.1016/j.biortech.2008.11.036
35. Y. Long, Y.Y. Long, H.C. Liu, D.S. Shen, Degradation of refuse in hybrid bioreactor landfill. Biomed. Environ. Sci. **22**(4), 303–310 (2009). https://doi.org/10.1016/S0895-3988(09)60060-X
36. R. C. de Abreu, E. J. La Motta, K. L. McManis, Facultative landfill bioreactors (FLB): results of a pilot-scale study, 1–13 (2005). https://doi.org/10.1061/40789(168)49
37. T.H. Christensen, S. Manfredi, K. Knox, Landfilling: reactor landfills. Solid Waste Technol. Manage. **2**, 772–787 (2010). https://doi.org/10.1002/9780470666883.ch49
38. E.S. Batarseh, D.R. Reinhart, N.D. Berge, Sustainable disposal of municipal solid waste: post bioreactor landfill polishing. Waste Manage. **30**(11), 2170–2176 (2010). https://doi.org/10.1016/j.wasman.2010.06.015
39. C. Walling, Fenton's reagent revisited. Acc. Chem. Res. **8**(4), 125–131 (1975). https://doi.org/10.1021/ar50088a003
40. Y. Deng, J.D. Englehardt, Treatment of landfill leachate by the Fenton process. Water Res. **40**(20), 3683–3694 (2006). https://doi.org/10.1016/j.watres.2006.08.009
41. A. Lopez, M. Pagano, A. Volpe, A.C. Di Pinto, Fenton's pre-treatment of mature landfill leachate. Chemosphere **54**(7), 1005–1010 (2004). https://doi.org/10.1016/j.chemosphere.2003.09.015
42. T.G. Townsend, W.L. Miller, H.-J. Lee, J.F.K. Earle, Acceleration of landfill stabilization using leachate recycle. J. Environ. Eng. **122**(4), 263–268 (1996). https://doi.org/10.1061/(asce)0733-9372(1996)122:4(263)
43. D. R. Reinhart, T. G. Townsend, *Landfill Bioreactor Design and Operation* (Lewis Publishers, New York, NY, 1998). https://doi.org/10.1201/9780203749555
44. F.G. Pohland, J.C. Kim, In situ anaerobic treatment of leachate in landfill bioreactors. Water Sci. Technol. **40**(8), 203–210 (1999). https://doi.org/10.1016/S0273-1223(99)00627-7
45. M. El-Fadel, S. Shazbak, E. Saliby, J. Leckie, Comparative assessment of settlement models for municipal solid waste landfill applications. Waste Manage. Res. **17**(5), 347–368 (1999). https://doi.org/10.1034/j.1399-3070.1999.00059.x
46. A. Aromolaran, M. Sartaj, Enhancing biogas production from municipal solid waste through recirculation of blended leachate in simulated bioreactor landfills. Biomass Conv. Biorefin. 19–26 (2021). https://doi.org/10.1007/s13399-020-01260-5
47. R. Cossu, L. Morello, R. Raga, G. Cerminara, Biogas production enhancement using semi-aerobic pre-aeration in a hybrid bioreactor landfill. Waste Manage. **55**, 83–92 (2016). https://doi.org/10.1016/j.wasman.2015.10.025
48. R. Cossu, From triangles to cycles. Waste Manage. **29**(12), 2915–2917 (2009). https://doi.org/10.1016/j.wasman.2009.09.002
49. C.A. Bareither, C.H. Benson, M.A. Barlaz, T.B. Edil, T.M. Tolaymat, Performance of North American bioreactor landfills. I: leachate hydrology and waste settlement. J. Environ. Eng. **136**(8), 824–838 (2010). https://doi.org/10.1061/(asce)ee.1943-7870.0000219

50. T. Abichou, M.A. Barlaz, R. Green, G. Hater, The outer loop bioreactor: a case study of settlement monitoring and solids decomposition. Waste Manage. **33**(10), 2035–2047 (2013). https://doi.org/10.1016/j.wasman.2013.02.005
51. M. Warith, Bioreactor landfills: experimental and field results. Waste Manage. **22**(1), 7–17 (2002). https://doi.org/10.1016/S0956-053X(01)00014-9
52. L. Morello et al., The S. An.A.® concept: semi-aerobic, anaerobic, aerated bioreactor landfill. Waste Manage. **67**, 193–202 (2017). https://doi.org/10.1016/j.wasman.2017.05.006
53. D. A. Germain, A. Vogt, W. Gregory, Fluman, in *Waste Characterization Study for Excavated Test Cells Central Solid Waste Management Center*. Proceedings of the Second Annual Landfill Symposium SWANA (Sacramento, CA, USA, 1997)
54. J. Johnson, W. Baker, in *Operation Characteristics and Enhanced Bioreduction of Municipal Waste Landfill Mass By a Controlled Aerobic prOcess.* Proceedings from SWANA's 4th Annual Landfill Symposium (Denver, CO., 1999)
55. J. Kilmer, W. Kenneth, Tustin, in *Rapid Landfill Stabilization and Improvements in Leachate Quality By Leachate Recirculation.* SWANA Proceedings of the Fourth Annual Landfill Symposium (Denver, CO, 1999)
56. N. C. Blakey, K. Bradshaw, P. Reynolds, K. Knox, in Bio-Reactor Landfill-A Field Trial of Accelerated Waste Stabilisation. Sardinia 97, Proceedings of the Sixth International Landfill Symposium (1997), pp. 375–385
57. Institute of Wastes Management (Great Britain). in *Sustainable Landfill Working Group, The Role and Operation of the Flushing Bioreactor* (IWM Business Services, 1999)
58. A.N. Srivastava, S. Chakma, Investigating leachate decontamination and biomethane augmentation through co-disposal of paper mill sludge with municipal solid waste in simulated anaerobic landfill bioreactors. Biores. Technol. **329**, 124889 (2021). https://doi.org/10.1016/j.biortech.2021.124889
59. Y. K. Kazimoglu, J. R. McDougall, I. C. Pyrah, Moisture retention curve in landfilled waste. Unsaturated Soils Experim. Stud., 59–67 (2006). https://doi.org/10.1007/3-540-26736-0_5
60. H. Wu, H. Wang, Y. Zhao, T. Chen, W. Lu, Evolution of unsaturated hydraulic properties of municipal solid waste with landfill depth and age. Waste Manage. **32**(3), 463–470 (2012). https://doi.org/10.1016/j.wasman.2011.10.029
61. M. Beck, S. Forsyth, T. Kohler, P. M. Lahsen, M. Mahony, *The Making of Global Environmental Science and Politics* (MIT Press, 2016)
62. W. Gao, W. Xu, X. Bian, Y. Chen, A practical approach for calculating the settlement and storage capacity of landfills based on the space and time discretization of the landfilling process. Waste Manage. **69**, 202–214 (2017). https://doi.org/10.1016/j.wasman.2017.07.048
63. H.D. Sharma, A. De, Municipal solid waste landfill settlement: postclosure perspectives. J. Geotech. Geoenviron. Eng. **133**(6), 619–629 (2007). https://doi.org/10.1061/(ASCE)1090-0241(2007)133:6(619)

Smart Dynamic Concrete as Pavement Material

Bhupati Kannur and H. S. Chore

1 Introduction

Smart dynamic concrete flows under its own weight, it is easily and quickly workable into different structures and is as strong as a conventional concrete. It conserves the natural resources and time and requires less maintenance, thus overall carbon footprint reduces drastically. Smart dynamic concrete is beneficial in cost, energy, and in lowering carbon footprint as there is no need for vibrators. It also improves the quality and lowers the deterioration of the pavement due to the elimination of mechanical vibrations which will cause the over-consolidation. The study aimed at strength characterization of SDC as pavement material, with fly ash (FA) as supplementary cementitious material.

Yogananda et al. [1] reported that SDC has been successfully used in Sobha Indhraprastha, Bengaluru (India), and completed monolithic high-rise concrete structure of 37 floors. It also eliminates the cement consumption with the use of different cement replacing materials. Ravindrarajah [2] concludes that up to 30% ultra-fine slag can be used as replacement to cement in production of HS-SCC. SCC is one among the most recent and very significant advances in construction industry due to its numerous benefits both in the fresh and hardened state [3, 4]. SCC fills all the corners of the formwork without honeycombing and subsequently improves the quality of the concrete structures [5]. SCC can be produced with the use of industrial discards such as slag, fly ash, metakaolin, etc. [6–10]. Tattersall [11] opined that the mass cement replacement with fly ash reduces yield stress of the mixtures. Laskar and Talukdar [12] found no change in the yield stress and plastic viscosity by replacing the cement with fly ash up to 50%.

B. Kannur (✉) · H. S. Chore
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India
e-mail: bhupati.kmt@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_36

Rheology of SDC mixes with various mineral admixtures, crushed sand, industrial wastes, various supplementary cementitious materials (SCM), and polycarboxylate ether (PCE) have been studied by many researchers [13–15]. Few studies depicted out effect of admixture in SCC by using the dispersing admixtures [16–18]. Ayobami et al. [19] studied the strength properties of SCC using different brands of cement for pavement application, and concludes that SCC with cement not less than 42.5 grade can be used in pavement construction as SCC with cement grades above 42.5 shows highest compressive strengths at 3 days and above. Also, the flexural strength at 28 days is of about 4.54 MPa which is more than the specified value of 4.5 MPa for pavement construction. Study was restricted on the selected brands of cement.

The SDC mix design is unique with optimization of binder content (low fines). There are many studies on the effect of mineral and chemical admixtures along with the different types of aggregates on the rheological behavior of SCC. However, the studies with respect to the smart dynamic concrete (SDC) are less. It can be observed from the literature review that relatively less research is reported on the strength of the SDC, especially in a view to use it in the pavement construction. On this backdrop, the present study reports the laboratory investigation on fresh and hardened properties of smart dynamic concrete with the use of fly ash as a partial to cement to validate SDC as a pavement construction material.

2 Materials and Mix Proportion

The matrix of concrete included OPC 43 confirming to of IS 8112: 2013 [20], Fly ash (FA) class F confirming to IS: 3812 (Part-I)—2003 [21] as supplementary cementitious material (Fig. 1). Natural aggregates with maximum size of 12.5 mm good quality well graded natural (river) sand (NS) are used as coarse and fine aggregates, respectively.

(a) OPC (b) Flyash

Fig. 1 Cementitious materials used in the study

Table 1 SDC mix proportion

Mix ref.	OPC (kg/m^3)	FA (kg/m^3)	SP (%)
OP	420	0	0.62
F2	336	84	0.60
F3	294	132	0.56
F4	252	168	0.53
F5	210	210	0.50

(OP-100% OPC, FA 2–20% FA, FA 3–30% FA, FA 4–40% FA, FA 5–50% FA)

Physical analysis of aggregate obtained following systematic laboratory investigations carried out. A specially formulated Polycarboxilate ether-based TamSem 53SP, high range water reducer was used in this study.

Five different smart dynamic concrete mixes have been developed. The OPC has been replaced by various percentages of Fly ash, maintaining volume of the mix paste (35%), w/b ratio 0.39, and constant flow of concrete (650 ± 10). The details of the mixes are presented in Table 1. The volume of aggregates has been determined by subtracting the volume of paste from the total volume of the mix. The weights of contents have been determined by using the specific gravity and mass relationship.

3 Results and Discussion

3.1 Fresh Properties of SDC

The mixes thus developed were tested for their fresh properties such as slump flow, V- funnel time, L- box ratio, and T50 time. The results are in line with the EFNARC [22] guidelines.

The flow values are in the range of 640–660 mm. The flow values increased with increased percentages of fly ash. The V-funnel (in sec) values are in the range of 9–12 s. The L—box ratio varies from 0.84 to 0.86 and T50 (in sec) values range from 7 to 9. All the fresh properties ensure the required range of workability to achieve the compaction without the use of external vibratos which is critical for the Smart dynamic concrete.

From the fresh properties of the SDC it can be stated that this type of concrete can effectively be used for the construction of the rigid pavements with edge supports or the form work as it flows freely and it has less shape stability in the fresh state. Thus it can be used on the plane terrain with negligible change in the grade change and camber.

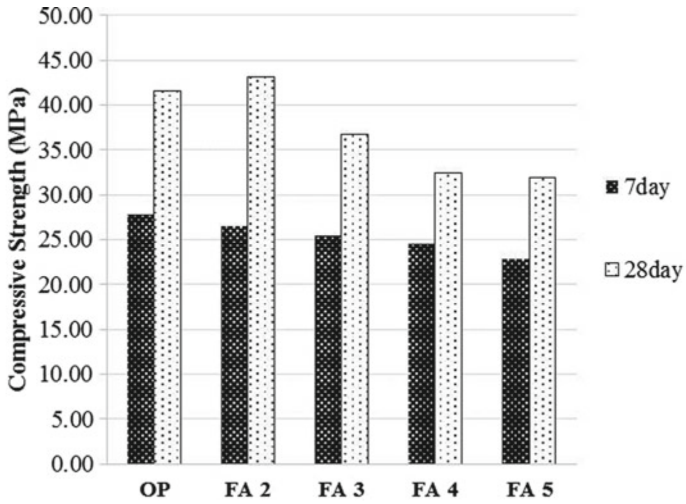


Fig. 2 Compressive strength of SDC with FA

3.2 Mechanical Behavior of FA-Treated SDC Mixes

3.2.1 Compressive Strength

Compressive strength of all the five mixes is determined as per IS: 516-1959 [23] corresponding to curing intervals of 7 and 28 days. Addition of fly ash into the OPC reduced the compressive strength at early age. The results of compressive strength test at curing periods of 7 and 28 days are as presented in Fig. 2. It shows that the strength of control SDC and F20 mixes are above 40 MPa at 28 days of curing. On the other hand all the SDC mixes with FA up to 50% have got 28 days of strength above 30 MPa. Up to 20% addition of FA the strength results were found to increase. Further, above 20% the addition of FA reduced the strengths at both 7 and 28 days of curing periods.

Thus, all the mixes with strengths above 30 MPa can be used in rural road pavements, and above 40 MPa strengths can be used for normal (urban) road pavement construction as per the recommendations of IRC: 44—2008 [24].

4 Conclusion

Based on the laboratory investigation on the strength of the SDC mixes with addition of fly ash as cement replacing material in view of its applicability as pavement material findings can be summarized as follows.

1. The use of fly ash solves not only the problem of waste disposal, it saves the natural resources and thus proves to be sustainable technique.
2. Addition of fly ash up to 20% provides compressive strength above 40 MPa. Thus, the mixes can be used as rigid pavement material for all normal roads.
3. All other combinations result in minimum 30 MPa of 28 days compressive strength. All the mixes can be used in the rigid pavements in rural roads (low traffic roads).
4. Thus, smart dynamic concrete which is an easy and cost economic technique can be used in the rigid pavement construction either in urban or low-volume village roads.

References

1. M. V. Yogananda, L. R. Manjunatha, V. Kallappa, H. M. Madhukar, S. Anvekar, Utilization of GGBS in smart dynamic concrete to construct sustainable and durable tall structure a case study on Sobha Indhraprastha, Bengaluru, India. Int. J. Res. Eng. Technol. **5**(20), 276–281 (2016)
2. R. Sri Ravindrarajah, in *High-Strength Self-Compacting Concrete for Sustainable Construction*. Conference: 22nd Australasian Conference on the Mechanics of Structures and Materials at: Sydney, Australia (2012)
3. P. Nanthagopalan, M. Santhanam, Fresh and hardened properties of selfcompacting concrete produced with manufactured sand. Cem. Concr. Compos. **33**, 353–358 (2011)
4. H.Y. Wang, W.L. Huang, A study on the properties of fresh selfconsolidating glass concrete (SCGC). Constr. Build. Mater. **24**, 619–622 (2010)
5. K.H. Khayat, Workability, testing, and performance of self-consolidating concrete. ACI Mater. J. **96**(3), 346–353 (1999)
6. A.A.A. Hassan, K.M.A. Hossain, M. Lachemi, Behavior of full-scale selfconsolidating concrete beams in shear. Cem. Concr. Compos. **30**(7), 588–596 (2008)
7. A.A.A. Hassan, K.M.A. Hossain, M. Lachemi, Strength, cracking and deflection performance of large-scale self-consolidating concrete beams subjected to shear failure. Eng. Struct. **32**(5), 1262–1271 (2010)
8. M. Uysal, K. Yilmaz, Effect of mineral admixtures on properties of selfcompacting concrete. Cem. Concr. Compos. **33**(7), 771–776 (2011)
9. M. Hubertova, R. Hela, *The Effect of Metakaolin and Micro Silica on the Properties of Lightweight Self-Consolidating Concrete* (American Concrete Institute ACI Publication SP-243-3, 2007), pp 35–48
10. S. D. Bauchkar, H. S. Chore, Rheological properties of self consolidating concrete with various mineral admixtures. Struct. Eng. Mech. Int. J. (Techno Press) **51**(1), 1–13 (2014). https://doi.org/10.12989/sem.2014.51.1.001
11. G. H. Tattersall, *Workability and Quality-Control of Concrete* (London, 1991)
12. A.I. Laskar, S. Talukdar, Rheological behavior of high-performance concrete with mineral admixtures and their blending. Constr. Build. Mater. **22**(12), 2345–2354 (2008)
13. S. D. Bauchkar, H. S. Chore, in *Rheological Properties Self Consolidating Concrete Containing Different Mineral Admixtures (with Mumbai Crushed Sand as fine aggregate)*. Proceeding 3rd International Conference on Quality Upgradation in Engineering, Science and Technology (IC-QUEST 2014) (B.D.C.E. Sewagram, Wardha, (Maharashtra), 2014)
14. S.D. Bauchkar, H.S. Chore, S.K. Mukherjee, Rheological properties of smart dynamic concrete (SDC) containing different supplementary cementitious materials', *Journal of Structural*

Engineering (JoSE). J. Struct. Eng. (JoSE) Struct. Eng. Res. Centre, Chennai. **44**(6), 1–12 (2017)
15. S. D. Bauchkar, H. S. Chore, in *Effect of Poly Carboxylate Ether (PCE), Increase in water Contents and Paste Contents on Rheological Properties of Smart Dynamic Concrete*. Proceedings National Conference on Advanced Structures, Materials and Methodology in Civil Engineering (ASMMCE-2018) (Department of Civil Engineering, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, 2018), pp. 78–87
16. C.F. Ferraris, K.H. Obla, R. Hill, The influence of mineral admixtures on the rheology of cement paste and concrete. Cem. Concr. Res. **31**(2), 245–255 (2001)
17. C. Hu, F.R. de Larrard, The rheology of fresh high-performance concrete. Cem. Concr. Res. **26**, 283–294 (1996)
18. P. F. G. Banfill, *The Rheology of Fresh Cement and Concrete—A Review* (British Society of Rheology, UK, 2006), pp. 61–130
19. J. Y. Yoon, J. H. Kim, in *Adsorption Characteristics of PCEs and its Effect on Rheological Properties of Cement Paste*. SCC 2016 8 th International RILEM Symposium on Self-Compacting Concrete, Flowing toward Sustainability (Washington DC, USA, 2016), pp. 165–173
20. IS: 8112-2013, *Indian Standard for "Ordinary Portland Cement 43 Grade—Specification"*, Second Revision (Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, 2013)
21. IS: 3812 (Part I)-2003, *"Pulverized Fuel Ash—Specification" Part I, For Use As Pozzolana in Cement, Cement Mortar and Concrete*, Second Revision (Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, 2003)
22. EFNARC, *European Guideline for Self-Compacting Concrete (SCC):Specification for Production and Use*, vol. 68 (2005)
23. IS: 516-1959, Indian Standard, *Methods of tests for Strength of Concrete* (Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi, 110002, 1959)
24. IRC: 44-2008, *Guidelines for cement concrete mix Design for Pavements*, Second Revision (2008)

Strength Evaluation of Fly Ash-Based Geopolymer Mortar by Using Ground-Granulated Blast Furnace Slag and Ordinary Portland Cement

Abhishek Sharma, Kanish Kapoor, and Paramveer Singh

1 Introduction

Geopolymers are ceramic-like materials formed by the reaction of aluminosilicate source materials with the presence of alkaline activators [1]. They are environmentally friendly materials since the manufacturing of raw materials for geopolymers needs less energy consumption than Portland cement (PC). The production of PC includes the use of a considerable amount of fuel, which results in significant CO2 emissions [2]. In the past few years, there has been a surge in interest in research into the production of geopolymers concrete. When we compared the cement concrete, with the geopolymer concrete, it shows equivalent mechanical properties and good durability properties [3, 4]. Geopolymer is a new cement-free binder that claims to be a more sustainable and environmentally friendly and sustainable alternative to OPC. It is made from geological resources, like Metakaolin (MK) or industrial by-products, for example, FA and GGBS, which are high in silica and alumina with the help of alkaline activators [5, 6]. According to the study, the manufacture of FA-based geopolymer consumes around 60% less energy and produces at least 80% less CO2 than the production of OPC [7]. The various researcher utilized FA, MK, and GGBS as the main aluminiosilicate source of geopolymer concrete [8]. Sodium and potassium-based alkaline solutions are the most commonly utilized, as they activate the base materials. Sumajouw et al. [9] have done a lot of research on FA-based geopolymer concrete. They stated that concretes may be made by combining FA with sodium silicate and sodium hydroxide solution. Geopolymer concretes demonstrated optimal engineering characteristics after 24 h of heat curing at 60C. It is critical to emphasize that the geopolymerization process is dependent on the curing procedure.

A. Sharma (✉) · K. Kapoor · P. Singh
Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, India
e-mail: abhisharma1216@gmail.com

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_37

The geopolymerization process accelerates as the temperature rises, and the strength of the products improves as the curing time increases [10]. This study is focused on the strength improvement of the FA-based geopolymer mortar in ambient curing conditions in the presence of Ca-rich materials. For the activation of FA, GGBS and OPC were used in small doses 0%, 10%, 20%, respectively.

2 Experimental Program

2.1 Materials

Fly ash, GGBS, and OPC

In this study, FA was used as the main binder for making GPM. Along with the FA, GGBS and OPC were also used as additive materials. The FA, GGBS, and OPC were collected from Rajpura thermal plant Punjab India. The physical and chemical composition of FA, GGBS, and OPC was shown in Table 1. Locally available river sand was used as natural fine aggregates (NFAs). The water absorption and specific gravity of NFA are 1.5% and 2.53, respectively. The fineness modulus of the NFA is 2.34.

Alkali activator

In this study, the sodium hydroxide and sodium silicate solution are used as alkali activators. For making a solution of sodium hydroxide, the molarity was kept constant at 12 M. However, the ratio of sodium silicate to sodium hydroxide was fixed at 2. In the sodium silicate solution, the ratio of SiO_2 and Na_2O was 3.02. The property of the alkali activator was shown in Table 2.

Table 1 Chemical composition of fly ash, GGBS, and OPC

Properties	FA (%)	GGBS (%)	OPC (%)
SiO_2	56.50	33.1	22
Al_2O_3	17.70	18.2	7
Fe_2O_3	11	0.31	5
CaO	3.20	35.3	61
MgO	2.30	7.6	3
Loss of ignition	1.20	0.26	1.2

Table 2 Property of alkali activator

Property	Sodium hydroxide	Sodium silicate
Molecular formula	NaOH	Na_2SiO_3
Na_2O content (%)	–	9
SiO_2 content (%)	–	27.2
H_2O content (%)	–	63.8

2.2 Mix Proportion

The cube specimens having a size 70.6 mm were caste at various proportions of FA with GGBS and OPC. The GGBS and OPC were partially replaced with FA at 10 and 20% in the GPM mixes. The alkali (Al) by binder (bi) ratio (Al/bi) was kept constant at 0.45 for all the mixes. The sodium hydroxide was prepared one day before mixing. The sodium silicate and sodium hydroxide were mixed one hour before mixing at 2 ratios 1. In the initial stage of the mixing, the binder and NFA were mixed in the dry state for 5 min; after that alkali activator was poured into the mixture and further mixed for 2 min. In the final stage, the mortar was then poured into the cube mold having a size 70.6 mm. To avoid the water evaporation of the specimens, it was sealed with a vinyl polyethene bag during the initial stage of curing. In the experiment, two different curing conditions were taken into use, i.e., ambient curing and heat curing. For heat curing, the curing temperature was fixed at 60 °C. The mix proportion for all the mixes was shown in Table 3.

Table 3 Mix proportion of the mixes

Mix notation	Mix description	Mortar mixture quantity (Kg/m^3)					
		FA	CGBS	OPC	NFA	NAOH	Na_2Sio_3
F100	100% FA	500	–	–	1500	150.4	75.22
F90G10	90% FA + 10% G	450	68.35	–	1500	150.4	75.22
F80G20	80% FA + 20% G	400	136.92	–	1500	150.4	75.22
F90C10	90% FA + 10% C	450	–	75.54	1500	150.4	75.22
F80C20	80% FA + 20% C	400	–	151.42	1500	150.4	75.22

3 Experimental Program

3.1 Flow Value

The flow value of the GPM mixture is determined in accordance with IS code: 5512-19,383 [11]. The flow value of the GPM is determined right after the mixing is done.

3.2 Compressive Strength

The compressive strength of GPM is done in accordance with IS 4031-7 1998 [12]. For calculating the compressive strength of GPM mixes, a cube of having a size 70.6 mm is used. The compressive strength is calculated after the 3, 7, and 28 days of curing periods.

3.3 Water Absorption

The water absorption of all the GPM mixes was calculated as per ASTM C642-13 [13]. For calculating the water absorption, 70.6 mm cube specimens were used at 28 days of curing periods. Three identical specimens were oven-dried at 105 °C for 24 h, and their weight was measured as initial weight. After that, the specimens were submerged in water for 24 h, and their weight was measured as the final weight.

3.4 Acid Attack

The acid attack test was conducted in accordance with ASTM C267 (2012) [14] at 28 days of the curing period. The acid attack test was investigated on a sample by immersing the specimens in 5% sulfuric acid solutions. To check the acid resistance of the mixes, we use cube specimens were used having sizes 70.6 mm.

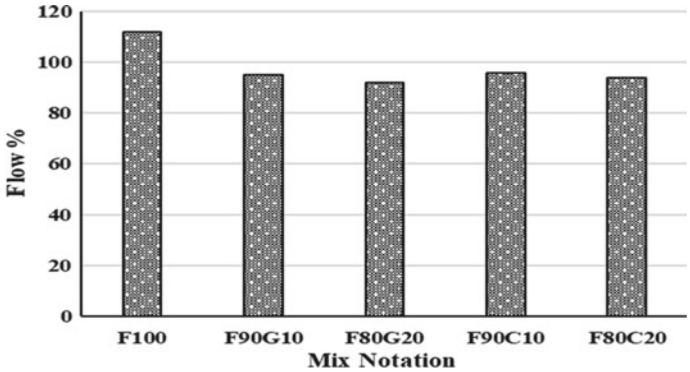


Fig. 1 Effect of various GGBS and OPC percentages on the workability of geopolymer mortar mixes

4 Result and Discussion

4.1 Fresh Properties

The effect of GGBS and OPC on the workability of GPM is shown in Fig. 1. The result shows that the inclusion of GGBS and OPC at various amounts reduces the workability of the geopolymer mortar. FA contains spherical particles, which give a lubricating effect when combined with the alkaline activator and tend to give better workability, while GGBS has angular particles, which have an impact on workability. Figure 1 depicts that the inclusion of OPC and GGBS 0, 10, 20% show a reduction in the workability of the geopolymer mortar. The highest slump flow value of 112 mm was obtained for the control mix F100 which contains 100% FA content, while the lowest slump flow value of 92 mm was obtained for the mix F80G20, having 20% GGBS content. Similarly, the inclusion of 10% and 20% OPC content also showed a reduction in slump flow value of 5% and 10%, respectively.

4.2 Effect of GGBS and OPC on Compressive Strength

The compressive strength result of ambient and heat curing was shown in Fig. 2a and b. Figure 2a shows the compressive strength results at 3, 7, and 28 days of ambient curing. The results revealed that for mix F100, having 100% FA, the compressive strength of the geopolymer mortar was substantially low. However, the addition of GGBS and OPC content from 0 to 20% shows a considerable increment in compressive strength. For mix F90G10, having 10% GGBS, the percentage increment of compressive strength was 212, 188, and 170% for 3, 7, and 28 days of curing. Similarly, for mix F80G20 containing 20% GGBS content, the compressive strength

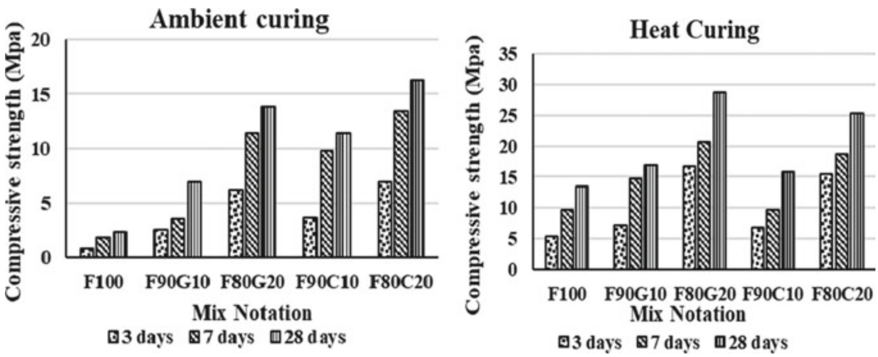


Fig. 2 Compressive strength of GPM at different curing **a** ambient curing **b** heat curing

showed 675, 553, and 500% increment as compared to the control mix. Similarly, mix F90C10 and F80C20 shows the strength variation of geopolymer mortar when FA content was replaced by OPC content from 10 to 20%. The compressive strength of mix F90C10 having 10% OPC was replaced by the FA shows the 350, 444, and 395% increment at 3, 7, and 8 days of curing. Furthermore, mix F80R20 containing 20% substitution of OPC in FA shows 762.5, 644, and 608%. However, the strength achievement is due to the addition of OPC and GGBS in the FA-based GPM. The addition of OPC and GGBS helps to accelerate the geopolymer reaction which is responsible for the strength achievement [15, 16].

Similarly, Fig. 2b shows the result of compressive strength results at 3, 7, and 28 days of heat curing at temperature 60 °C. The compressive strength of the control mix was reported as 5.4, 9.61 and 13.4 MPa at 3, 7, and 28 days of curing. For mix F90G10 having 10% GGBS substitution, the compressive strength increment was 31, 52, and 25.37%. Similarly, for mix F80G20 having 20%, GGBS content was added; the percentage increment was 209.25, 115, and 114% at 3, 7, and 28 days of curing as compared to control mixes. However, the mix F90C10 and F80C20 having 10 and 20% OPC content also shows a similar trend of increment of compressive strength. For example, mix F90C10 having 10%, OPC shows 27.7, 6.13, and 18% increment in strength at 3, 7, and 28 days of curing as compared to control mix. Similarly, mix F80C20 shows the 185, 93, and 90% increment in strength at 3, 7, and 28 days of curing as compared to the control mix.

4.3 Water Absorption

The water absorption of the mixes was done after 28 days of curing. Figure 3 shows the result of water absorption of ambient and heat curing mixes. The result reveals that the ambient curing mixes show more water absorption as compared to heat curing mixes. Furthermore, the increased percentage of GGBS and OPC content in the mixes

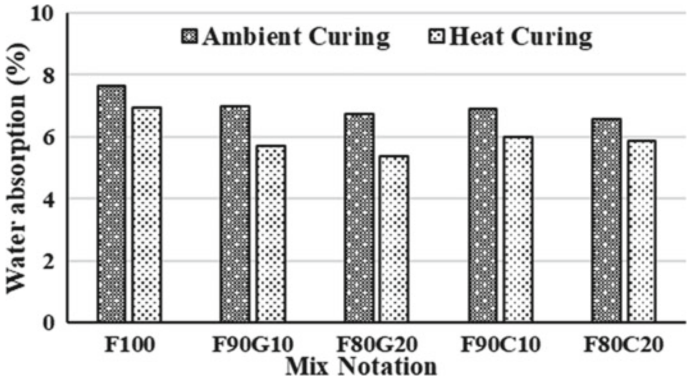


Fig. 3 Water absorption

shows a decrease in the water absorption value. For example, mix F90G10 having 10% GGBS shows the 8.77% decrement in the water absorption. Mix F80G20 having 20% GGBS shows the 11.65% decrement in the water absorption as compared to control mixes. However, the mix F90C10 having 10% OPC shows the 9% decrement in the water absorption as compared to control mixes. Similarly, mix F80C20 having 20% OPC shows a 13.87% decrement in water absorption. The decrement in the water absorption is due to the microstructure of mixes being improved with the addition of GGBS and OPC [17, 18]. The dense structure of concrete absorbed less water and increases the durability properties of concrete [19].

Similarly, heat curing with the addition of 10% GGBS shows a 17.89% decrement in water absorption as compared to the control mix. Furthermore, mix F80G20 having 20% GGBS shows the 22.37% decrement in the water absorption as compared to the control mix. However, mix F90C10 and F80C20 having 10 and 20% OPC content shows a 13.71% and 15.15% decrement in water absorption as compared to the control mix.

4.4 Acid Attack

Figure 4 shows that the weight change in the specimens after being exposed to the acidic solution after 28 days in 5% concentrated H2SO4. The result depicts that it was no significant change in weight was observed in both ambient and heat curing specimens after 28 days of exposure. The result also shows that with the increase in the OPC and GGBS content in the mixes the weight loss is marginally increased. Furthermore, the mixes having 10% and 20% OPC show more loss in weight as compared to the mixes having 10% and 20% GGBS, respectively. Weight losses in the mix containing 20% OPC were mostly driven by the interaction of the calcium hydroxide which is present in the mixes and the acid [20].

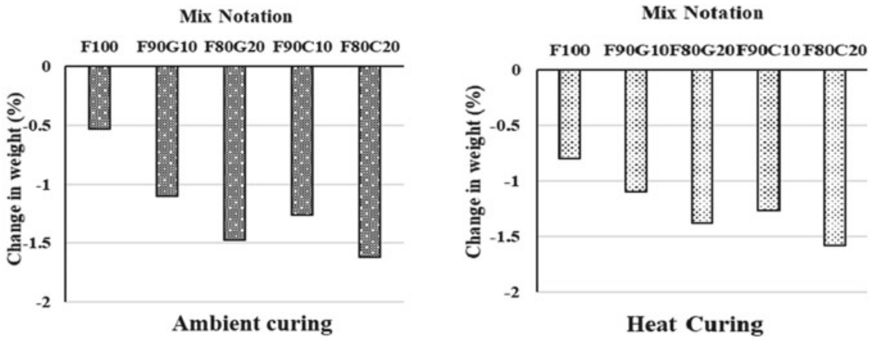


Fig. 4 Weight loss in geopolymer concrete

5 Conclusion

- The substitution of the GGBS and OPC in the FA-based GPM enhanced both the early and later-age properties.
- With the inclusion of GGBS and OPC, the slump flow decreases marginally.
- The substitution of 20% GGBS and OPC is showing the good mechanical properties of the GPM. With the inclusion of GGBS and OPC in the mixes, the water absorption decreases significantly.
- The result of the acid attack shows that with the inclusion of GGBS and OPC the GPM mixes show more weight loss.

References

1. J. Davidovits, Geopolymers—inorganic polymeric new materials. J. Therm. Anal. **37**(8), 1633–1656 (1991). https://doi.org/10.1007/BF01912193
2. D. Hardjito, S. E. Wallah, D. M. J. Sumajouw, B. V. Rangan, Factors influencing the compressive strength of fly ash-based geopolymer concrete. Civ. Eng. **6**(2), 88–93 (2004), [Online]. Available: http://www.freepatentsonline.com/article/Civil-Engineering-Dimension/170455954.html
3. A. Bouaissi, L. yuan Li, M. M. Al Bakri Abdullah, Q. B. Bui, Mechanical properties and microstructure analysis of FA-GGBS-HMNS based geopolymer concrete. Constr. Build. Mater. **210**, 198–209 (2019). https://doi.org/10.1016/j.conbuildmat.2019.03.202
4. M. D. J. Sumajouw, B. V. Rangan, Low-calcium fly ash-based geopolymer concrete : reinforced beams and columns by Faculty of Engineering Curtin University of Technology. GC3, Fac. Eng. Curtin Univ. Technol., 1–120 (2006)
5. M.I. AbdulAleem, P.D. Arumairaj, A review of seismic assessment of reinforced concrete structure using pushover analysis. Int. J. Eng. Sci. Emerg. Technol. **1**(2), 118–122 (2011). https://doi.org/10.7323/ijeset/v1
6. N.B. Singh, M. Kumar, S. Rai, Geopolymer cement and concrete: Properties. Mater. Today Proc. **29**, 743–748 (2019). https://doi.org/10.1016/j.matpr.2020.04.513

7. P. Duxson, J.L. Provis, G.C. Lukey, J.S.J. van Deventer, The role of inorganic polymer technology in the development of 'green concrete.' Cem. Concr. Res. **37**(12), 1590–1597 (2007). https://doi.org/10.1016/j.cemconres.2007.08.018
8. C. Yi, Y. Boluk, V. Bindiganavile, Enhancing alkali-activation of metakaolin- based geopolymers using dry water. J. Clean. Prod. **258** (2020). https://doi.org/10.1016/j.jclepro.2020.120676
9. D.M.J. Sumajouw, D. Hardjito, S.E. Wallah, B.V. Rangan, Fly ash-based geopolymer concrete: study of slender reinforced columns. J. Mater. Sci. **42**(9), 3124–3130 (2007). https://doi.org/10.1007/s10853-006-0523-8
10. C. Ng, U.J. Alengaram, L.S. Wong, K.H. Mo, M.Z. Jumaat, S. Ramesh, A review on microstructural study and compressive strength of geopolymer mortar, paste and concrete. Constr. Build. Mater. **186**, 550–576 (2018). https://doi.org/10.1016/j.conbuildmat.2018.07.075
11. IS 5512-1983, Specification for flow table for use in tests of hydraulic cements and pozzolanic materials. Bur. Indian Stand. New Delhi Reaffirmed. **2004** (1983)
12. IS: 4031(Part 7), Determination of compressive strength of masonry cement. Bur. Indian Satand. (1988), [Online]. Available: https://archive.org/details/gov.in.is.4031.7.1988/page/n3
13. ASTM C642-13, Standard test method for density, absorption, and voids in hardened concrete. ASTM Int. (2013)
14. P. Concretes, Standard test methods for chemical resistance of mortars, grouts, and monolithic. Current **04**(February), 1–6 (1998). https://doi.org/10.1520/C0267-20.2
15. P. S. Deb, P. Nath, P. K. Sarker, Properties of fly ash and slag blended geopolymer concrete cured at ambient temperature. ISEC 2013 7th Int. Struct. Eng. Constr. Conf. New Dev. Struct. Eng. Constr., 571–576 (2013). https://doi.org/10.3850/978-981-07-5354-2-M-55-433
16. M.M.A. Elahi et al., Fly ash-based eco-friendly geopolymer concrete: a critical review of the long-term durability properties. Constr. Build. Mater. **30**(4), 189–193 (2020). https://doi.org/10.1016/j.jclepro.2019.119797
17. Z. Tian, Q. Yang, K. Guan, J. Meng, Z. Cao, *Microstructure and Mechanical Properties of a Peak-Aged*, vol. 731 (2018), pp. 704–713
18. S. Pangdaeng, T. Phoo-ngernkham, V. Sata, P. Chindaprasirt, Influence of curing conditions on properties of high calcium fly ash geopolymer containing Portland cement as additive. Mater. Des. **53**, 269–274 (2014). https://doi.org/10.1016/j.matdes.2013.07.018
19. A. Mehta, R. Siddique, Properties of low-calcium fly ash based geopolymer concrete incorporating OPC as partial replacement of fly ash. Constr. Build. Mater. **150**, 792–807 (2017). https://doi.org/10.1016/j.conbuildmat.2017.06.067
20. V. Sata, A. Sathonsaowaphak, P. Chindaprasirt, Resistance of lignite bottom ash geopolymer mortar to sulfate and sulfuric acid attack. Cem. Concr. Compos. **34**(5), 700–708 (2012). https://doi.org/10.1016/j.cemconcomp.2012.01.010

Sustainable Technique to Reduce Sea Pollution During Boring Operation

Hitendrabhai S. Dewangan and Aashish A. Mehta

1 Introduction

Rapid population growth requires creation of new infrastructure. Rapid growth of infrastructure projects in land and sea increases the pollution in all over the world. This pollution may be due to industry, thermal power plant, transportation, agriculture production, and marine offshore works. In offshore and marine piling work, drilling/boring supporting fluid is used to stabilize the borehole (excavation) prior to tremie concrete [1–6]. Mineral-based slurries (bentonite) or polymer support fluids are mainly used as supporting fluids. The effect of support fluids on the performance of deep foundation elements must be considered at the design stage. The type of support fluid can have a significant effect on both the geotechnical and the structural performance.

Bentonite have excellent suspensive waterproofing and lubricating characteristics. While using bentonite as supporting fluid, fines, and drill (drilling muds) cuttings are suspended in the form of fluid. During (boring operation) through granular soil, bentonite fluids form a filter cake to stabilize soil. Sodium activated bentonites, normally form thin and strong filter cakes. Pile shaft resistance decrease due to smear effect when bentonite fluid used for clayey type of soil. Usage of bentonites, is recommended as drilling fluid mixture for borehole stabilization.

The poly-fluid is a synthetic drilling granular polymer characterized by high molecular weight. It is mainly used for the preparation of stabilizing and lubrication mud in drilling of deep foundations.

H. S. Dewangan · A. A. Mehta (✉)
Shri Ramdeobaba College of Engineering and Management, Nagpur, India
e-mail: mehtaaa@rknec.edu

H. S. Dewangan
e-mail: dewanganhs@rknec.edu

A. K. Agnihotri et al. (eds.), *Proceedings of Indian Geotechnical and Geoenvironmental Engineering Conference (IGGEC) 2021, Vol. 2*, Lecture Notes in Civil Engineering 281,
https://doi.org/10.1007/978-981-19-4731-5_38

Disposal of bentonite/polymers after using it into the sea, pollutant the sea environment, which may be harmful for living organisms inside sea. Hence, it is essential to reused and disposed it ecofriendly. This paper highlights new method ology to reuse, recycled, and disposed it ecofriendly. Once the pile bore hole has been completed and concreting is initiated, the used slurry will be brought back to the tanks designated for storage. To reuse the stored slurry for further pile bore hole it must be regenerated. To regenerate, the reclaimed slurry will be transferred to the polymer mixing tank. Check and note the fluid characteristic of regenerated slurry in mixing tank. Based on the testing results (viscosity, density, and pH value), the amount of fresh materials/polymer to be added can be determined. Finally, initiate water flow and air agitation as required. Run the tests on the regenerated slurry before transferring to storage tank. Also, after storage, bentonite/polymers will be reused for next operation. Moreover, mud wastage coming from borehole will also be disposed at suitable dumping places.

2 Construction Details

A. Process of Boring Operation in Sea

Boring operation carried out with performing following stages (Fig. 1).

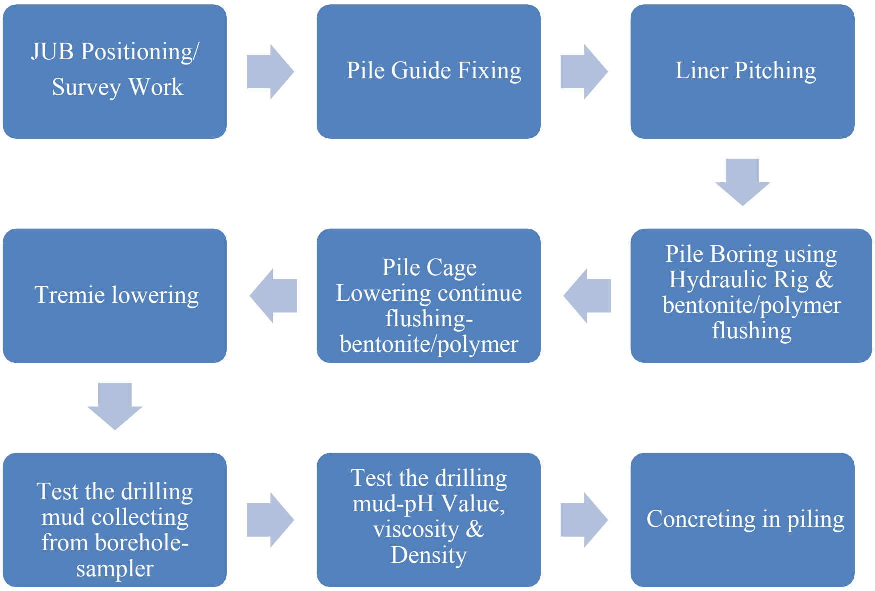


Fig. 1 Flowchart showing process of boring operation in sea

I. Pile Casing/Liner Pitching

- Pile guide arrangement will be made for the casing driving. Crane mounted on jack up will be used for lifting of liner and positioning inside the pile guide.
- After positioning Vibro/Monkey hammer will be attached at the top of the liner using crane and then casing will be driven up to its refusal.
- The position of the casing shall be within the tolerance of 75 mm vertically. The verticality of casing will be checked with plumb bob/spirit level tube.

II. Pile Boring

- Pile boring will be carried out using hydraulically operated rotary rig using direct or reverse circulation technique. Provision will be kept for percussion boring and chiseling within the borehole in case of any underground obstruction/hard strata.
- Diameter of boring tool will be little less, maximum 75 mm less than inner diameter of casing for free moment in the casing during operation of boring.
- Verticality of Kelly bar of piling rig will be ensured till the completion of bore hole.
- The pile boring will continue till the founding level.
- After completion of boring, proper clean-out buckets will be utilized to remove any sediment or remaining loose soil from the bottom of the pile.

III. Termination of Borehole

On completion of pile boring up to founding level, bore depth shall be checked by using sounding chain and bore shall be terminated.

IV. Tremie Lowering and Flushing

- After completion of reinforcement cage lowering into the pile, tremie pipes lowering will be commenced each tremie pipe unit must be measured and recorded jointly tremie lowered till the bottom of the tremie is between 300 mm from the bottom of the pile.
- Tremie pipes of 250 mm dia. will be used for concreting.
- Tremie head to be provided to the tremie pipe for the flushing activity. The bore will be cleaned by water/air flushing or by fresh mud circulation method.
- Flushing will be carried out to ensure that the borehole is free from all loose sediments which may have accumulated from the boring operations. Flushing operation shall be continued till the consistency of inflowing and out flowing slurry is similar (Fig. 2).

Fig. 2 Barge and Jack-up barge positioning and alignment of piles

3 Selection of Supporting Fluid

Bentonite

Bentonite is the most commonly used mineral additive for support fluid. Bentonite is a clay composed primarily of montmorillonite clay minerals which can absorb water to many times their own weight. When added to water, relatively small amounts of bentonite form a colloidal mixture with the effect of increasing the viscosity of the fluid over that of water, along with a small increase in unit weight. Besides the viscosity and unit weight, bentonite has the beneficial property of forming a filter cake on the face of the excavation which acts to restrict fluid loss into the surrounding soil and allow a positive hydrostatic head to be maintained within the excavation.

Polymers

The polymers are often synthetic long chain or high molecular weight (typically partially hydrolyzed polyacrylamides, or PHPAs) though as presented in this guide, other types of polymers can be used. Within the polymer types, different performance requirements can also be accepted (Table 1).

Table 1 Types of polymer

Poly-fluid™	Premium grade dry polymer	Soil stabilization for piling and special foundation
Poly-clear™	Cleaning agent thinner	Excavation cleaning and sedimentation
Poly-matrix™	Cross linking liquid polymer prevention	Increase solid suspension, mud loss

Table 2 Comparison analysis between polymer and bentonite

Item	Polymers	Bentonite
Mixing and hydration	Mixing time is less than 30 min	Minimum 24 h required for hydration of bentonite
De-sanding equipment	De-sanding not required for polymer	De-sanding equipment required to clean bentonite slurry before reuse
Flushing	Flushing is required for at least 30 min	Flushing required for at least 3–4 h to clean the pile toe before concreting
Site productivity	Increase the productivity by 10% as less flushing required	Site productivity is low due to flushing
Concrete over consumption	Soil stabilization is better with Eco DF products	–
Environment	Eco DF products are environment friendly	Bentonite is not environment safe
Slurry disposal after use	Very easy	Difficult
Storage and handling at site	80 times less	Difficult

4 Criteria to Select Supporting Fluid as Bentonite or Polymers

Both the bentonite and polymer we are selecting for any type of strata of soil. Generally, we are using the bentonite and polymer in sandy, clayey strata and silty soil, whereas in case of hard rock, soft rocks like sand stone. Normally, we are using water flushing type, water flushing type required in the hard and soft rock (Table 2).

5 Sustainable Technique to Reduce Sea Pollution During Boring Operation

In this approach, cutting in casing/liner in the form of window is used to collect the bentonite/polymers in tank. Also, after storage, bentonite/polymers will be reused for next operation (Fig. 3). Moreover, mud wastage coming from borehole will also be disposed at suitable dumping places. Details of methodology adopted with equipment are as follows.

1. **Slurry plant**

Set up for poly-fluid slurry plant to be done considering pile volume and desired production. For mixing of poly-fluid usage of positive displacement pumps and centrifugal pumps also used. The supply and retrieving lines of 4–6 inch pipes should

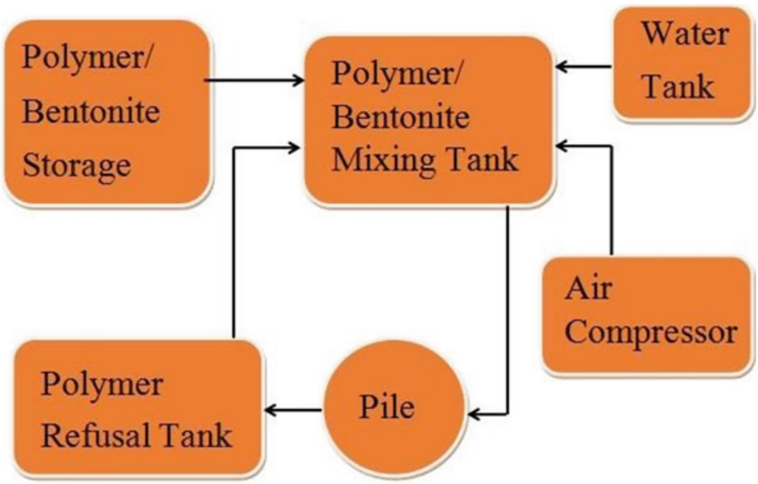


Fig. 3 Flowchart showing sustainable technique to reduce sea pollution during boring operation

be used. Proper slurry agitation can be provided by using a compressed air system or by proper circulation through pumps.

2. **Batching plant Schematic**

The installation of the slurry plant must allow all operations to be carried out at the same time. Mixing, sending, and receiving slurry without interfering with production rate. The sedimentation tanks are extremely important in the returning slurry's self-cleaning process by sedimentation and must be incorporated in a batching plant layout.

3. **Mixing**

Before mixing poly-fluid fresh water is to be treated with sodium hydroxide/soda ash at a dosage of 0.5 kg/m^3 to regulate the pH to 9–12 poly-fluid polymer is then slowly mixed directly in the flow of water at a dosage from 0.8 to 1.2 kg/m^3 of water. Viscosity of the slurry after adding recommended dosage of poly fluid will range from 55 to 70 s the poly fluid slurry can now be used for excavation.

4. **Excavation/Drilling**

Prepared poly-fluid slurry is to be pumped to the excavation to stabilize the bore. A minimum of 3 m of overhead pressure to be maintained during the excavation all the time. Compensation basin/slurry pool is recommended to maintain the slurry level drop while retraction of an excavation tool.

5. **Recycling**

Poly-fluid slurry recovered after concreting is stored back to the tanks. The slurry can be used again readjusting the parameters to the recommended values. The adjustment

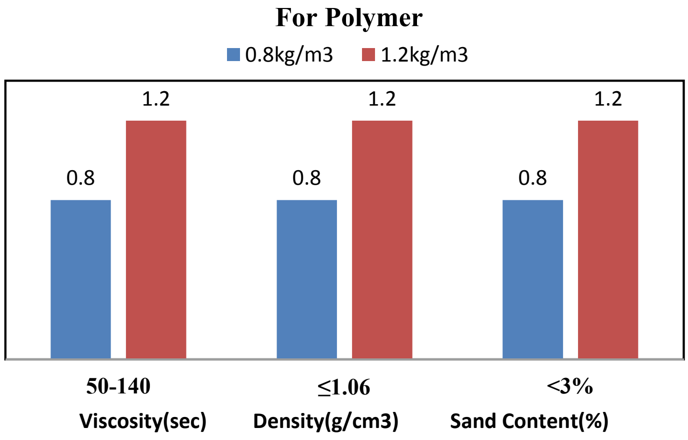


Fig. 4 Graph showing testing results of standard parameters for polymers

can be done by adding poly fluid polymer directly into the excavation or in the mixing tank.

6. **Disposal**

As per regulatory requirements, poly-fluid polymer slurry may be broken down using household bleach (5% sodium hypochlorite) at a ratio of 1:1 of bleach as the amount of polymer used in slurry. This is then mixed well with any recirculating pumps before disposal to landfill and land farming.

6 Testing of Supporting Fluid

Tests performed to identified measurable properties that characterize the nature and properties of a support fluid. Testing of supporting fluid were performed prior to concrete and before reused to satisficed various performances parameters as follows (Figs. 4 and 5; Tables 3 and 4).

7 Conclusion

To reduce the pollution in offshore/Onshore it is essentially to take the precautions during flushing proper recycled, re- used and Disposed at proper place. After performing field trials based on proposed methodology, pollution in sea environment, inside sea can be reduced to a larger extent.

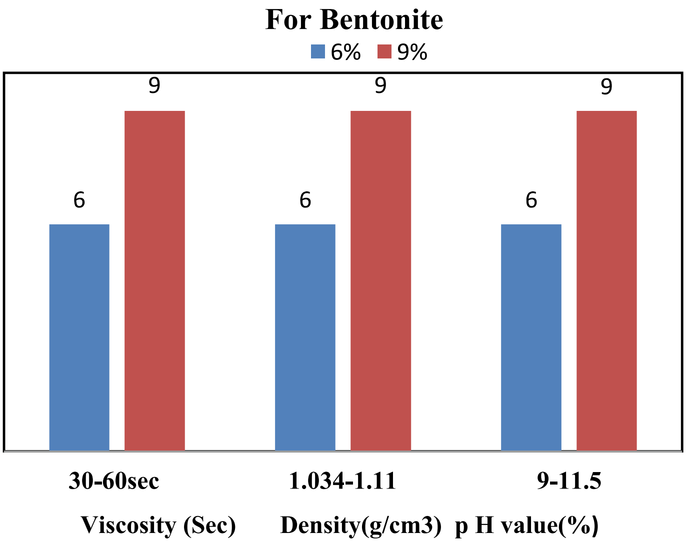


Fig. 5 Graph showing testing results of standard parameters for bentonite

Table 3 Test on polymer to evaluate standard parameters during different stages

Parameters	Fresh mix	Reused slurry	Prior to concrete	Minimum polymer (kg/m^3)
Viscosity (s)	65–140	55–140	50–140	0.80
Density (g/cm^3)	1.00–1.04	$\leq$1.05	$\leq$1.06	0.80
Sand content (%)	–	<2%	<3%	0.80

Table 4 Test on bentonite to evaluate standard parameters during different stages

Parameters	Fresh mix	Reused slurry	Prior to concrete	Minimum bentosund 120E (%)
Viscosity (s)	30–60 s	<60 s	30–60 s	6
Density (g/cm^3)	1.034–1.11	<1.2	1.034–1.11	6
pH	9–11.5	<12	9–11.5	6

References

1. A. A. Ata, M. W. O'Neill, in *Side-Wall Stability and Side-Shear Resistance in Bored Piles Constructed with High-Molecular-Weight Polymer Slurry*. Deep Foundations on Bored and Auger Piles (CRC Press, 2020), pp. 111–117
2. IS:2911 Part 1/sec2, *Design and Construction of Pile Foundation* (2010)
3. M. Kuiqian, L. Yanlai, W. Lilei, Z. Xiaolin, in *Practice of the Early Stage Polymer Flooding on LD Offshore Oilfield in Bohai Bay of China*. SPE Asia Pacific Enhanced Oil Recovery Conference (2015)
4. C. Lam, S. A. Jefferis, T. P. Suckling, V. M. Troughton. Effects of polymer and bentonite support fluids on the performance of bored piles. Soils Found. **55**(6), (2015)

5. C. Lam, S.A. Jefferis, *Polymer Support Fluids in Civil Engineering* (Ice Publishing, London, UK, 2018)
6. D. J. Lennon, D. Ritchie, G. O. Parry, T. P. Suckling. In *Piling Projects Constructed with Vinyl Polymer Support Fluid in Glasgow, Scotland*. Proceedings of the 10th International Conference on Piling and Deep Foundations (Deep Foundations Institute, Hawthorne, NJ, 2006), pp. 499–506