Proceedings of the 7th International Conference on Civil Structural and Transportation Engineering (ICCSTE'22)
Niagara Falls, Canada – June 05-07, 2022
Paper No. 233
DOI: 10.11159/iccste22.233

Influence of Coal Bottom Ash and Copper Slag on Permeation of Fly Ash Based Geopolymer Concrete

Navdeep Singh[1], Nitin Ankur[1], Md Marghoobul Haque[1], Akshit Gupta[1]
[1]Dr B R Ambedkar National Institute of Technology Jalandhar Punjab India
G.T. Road, Amritsar Bypass,
Jalandhar (Punjab), India – 144027
navdeeps@nitj.ac.in; nitina.ce.19@nitj.ac.in; mdmh.ce.20@nitj.ac.in; akshitg.ce.20@nitj.ac.in

Abstract **-** Geopolymer Concrete (GPC) concrete was formed by using Fly ash (FA) activated with the alkali activators such as Sodium Hydroxide (SH) and Sodium Silicate (SS). Coal Bottom Ash (CBA) another by-product of thermal power plants resembles the size of Natural Fine Aggregate (NFA) and was used as a replacement for the same in GPC. Similarly, Copper Slag (CS) obtained from the copper refining industry was used as NFA in GPC. The durability of concrete usually affects with inclusion of industrial by-products due to variation of chemical and physical properties that are varying from the conventional aggregates consequently leading to change in the microstructure. This pilot study investigates the permeation behaviour of FA-based GPC in which, CBA and CS were used as 10% and 30% replacement of NFA. Capillary Suction Absorption Test (CSAT) and Initial Surface Absorption Test (ISAT) were performed to assess the permeability of CBA and CS-based GPC. The compressive strength of the concrete mixes was also determined for reference. The investigation inferred that inclusion of CBA as NFA replacement in FA based GPC increases permeability as porous CBA leads to the development of additional pores in GPC. On the contrary, fine CS particles resulted in better pore size refinement and reduced the overall permeability of GPC. The findings indicate that an amount of 10% CBA and 30% CS can be considered as an optimum replacement for NFA in GPC.

Keywords**:** Capillary suction absorption, Coal bottom ash, Copper Slag, Fly Ash, Geopolymer, Initial surface absorption,

1. Introduction

Geopolymer Concrete (GPC) is regarded as the next generation concrete because it is ecologically benign, since it removes the need for Ordinary Portland Cement (OPC) in the manufacturing of concrete, hence lowering CO_2 emissions [1]–[4]. GPC is produced by using industrial by-products such as Fly Ash (FA), Metakaolin (MK), Ground Granulated Blast Furnace Slag (GGBFS) that act as alumina-silicates that are activated with the help of alkali activators like Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) [5]. FA is the most commonly used alumina-silicate that acts as a binder and the silica and alumina in FA are activated by the action of alkali to generate geopolymer [6], [7]. GPC composites provide several advantages, including a reduction in the amount of external heat required for early concrete strength, the removal of waste materials like FA from landfills, and a reduction in CO_2 emissions[8]. Coal Bottom Ash (CBA) is a coal combustion residual generated by thermal power plants, and it consists of heavy particles that settle at the bottom of the combustion chamber, accounting for 15–25% of total coal ash produced [9]. CBA is being landfilled over the years and causing land abuse. The problem of disposal of CBA is going to be a serious concern in developing countries that heavily relies on coal-fed thermal power plants for meeting their energy demands. In the lately concluded COP26, India has revised its target plans of being a carbon-neutral country by 2070. CBA resembles the size of NFA and can be a potent replacement for it in GPC [10], [11]. Various investigations have reported regarding introduction of CBA as a sustainable replacement option in the place of NFA in the manufacturing of concrete [9], [12], [13]. Copper Slag (CS) is another waste product of the copper refining process that has the potential to replace NFA in concrete. The world's annual output of CS is estimated to be over 25 million tonnes, and it is used as an abrasive, fine aggregate, and cementitious ingredient in concrete [14].

These by-products are being landfilled for their disposal and utilizing them in GPC as NFA replacement will not only provide an efficient way of waste disposal but will also reduce the dependency of the construction industry on natural resources. The durability of concrete is a key parameter in predicting the quality and expected service life of the concrete.

Durability performance is affected by the inclusion of industrial by-products as the chemical as well as physical properties differ from the conventional aggregates, further lead to change in the microstructure of concrete. The numbers, size, and interconnectivity of the pores are the key factors that govern the permeability characteristics of concrete. Larger and interconnected pores provide an easy and unhindered passage to the movement of water and foreign chemicals that results in the deterioration of concrete.

Limited investigation reports the durability aspects of FA-based GPC wherein, CBA and CS were used as NFA replacements [1], [15]. The present study investigates the effect of CBA and CS on the compressive strength as well as permeability characteristics of FA-based concrete to predict the long-term performance and practical implementation of these by-products in FA-based GPC.

2. Materials and Methods

2.1 Fly Ash

The present investigation uses Class-F Fly Ash (FA) as a binder and has been procured from Thermal Power Plant Ropar, Punjab India.

2.2 Coal Bottom Ash (CBA)

This study employed CBA collected from a coal-fired thermal power plant in Ropar, Punjab, India. CBA was tested for specific gravity and water absorption using BIS 2389-1963 (Part III). Before its usage in concrete, CBA was sieved through a 4.75mm screen to remove particles thicker than 4.75mm. CBA reported a specific gravity, fineness modulus, and water absorption of 1.39, 1.37, and 31.58 percent, respectively, and are tabulated in Table 1.

Table 1. Physical properties of CS, CBA, and NFA

Materials	Specific Gravity	Fineness Modulus	Water Absorption (%)
CBA	2.38	2.43	18.58
CS	3.92	1.97	0.8
NFA	2.6	2.23	1.52

2.3 Copper Slag (CS)

CS is an industrial derivative produced in the process of matte smelting and refining copper. The copper Slag used in this study was procured from Birla Copper, Dahej, Gujrat (India). It was delivered by Taj Abrasive, Rajasthan (India). The CS was originally in the granulated form and it was correspondent to that of coarse sand in terms of size (Fig.1). It can also be inferred from Fig. 1 that the particles of CS are finer than the NFA. Water absorption of CS was lower than the CBA and NFA whereas specific gravity was highest among all the fine aggregates (Table 1).

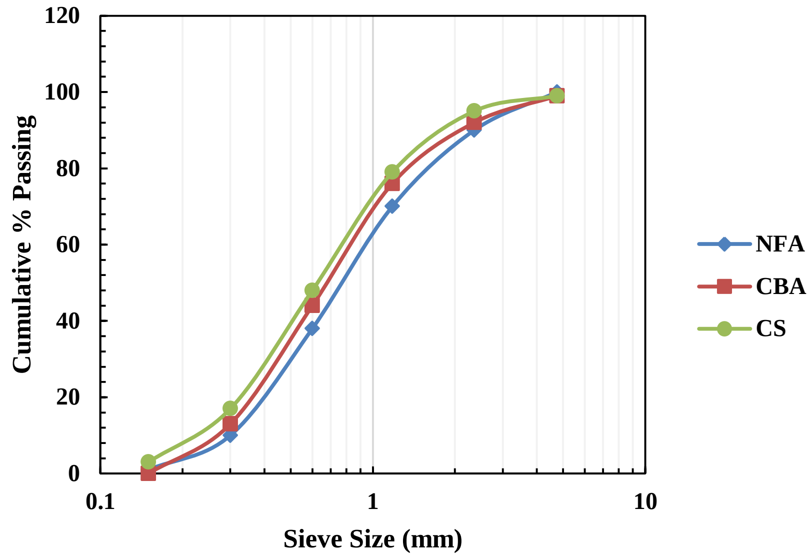


Fig.1. Particle size distribution of NFA, CS, and CBA

2.4 Natural Fine Aggregates

Natural Fine Aggregate (NFA) was obtained from a quarry in Pathankot, Punjab (India), and consisted of natural river-based quartz sand with a maximum particle size of nearly 4.75 mm. Sieve analysis of NFA was done as per BIS:2386- Part I, 1963[16]. Specific gravity and water absorption of aggregates were investigated using specifications of BIS 2386- Part III, 1963[17] and were 2.6 and 1.52 % respectively (Table 1).

2.4 Natural Coarse Aggregates

Natural Coarse Aggregate (NCA) was acquired from the Chapar-Kandi quarry in Punjab, India, near the Ravi River. Physical properties of NCA determined using BIS:2386- Part III. Aggregates passing through a 12.5 mm size sieve and retained on a 4.75mm sieve were utilized in this study and grading of NCA is done as per IS383,2016[18].

2.5 Alkali Activators

As an alkali liquid, a mixture of Sodium Hydroxide (NH) and Sodium Silicate (NS) solution opted in this study. Alkali activators were industrial grade, and these were supplied by M/s Garg Chemicals, Jalandhar, India. Industrial grade NS solutions with 19.5 % Na_2O, 29% SiO_2, and 51.6% water by weight along with 12M NaOH concentration have been used to activate the fly ash-based GPC.

2.6 Mix Proportions

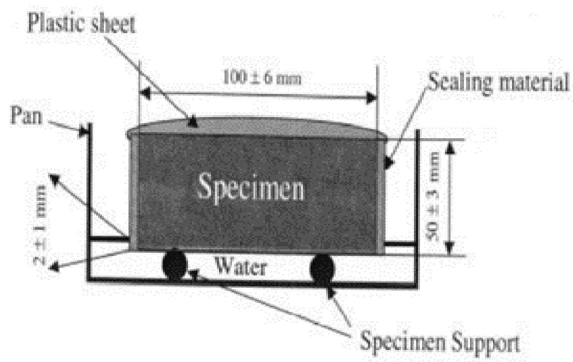
The mix proportions of GPC were carefully selected by trail mixes. FA content of 480 Kg per cubic meter was kept constant in each mix. The NFA and NCA were used under saturated surface dry (SSD) conditions. The present study comprises the five mixes the first mix is a control mix (CM) containing 100% NFA. The NS/NH ratio and alkali binder ratio was 0.45 and 2 for each mix. In a mix of CBA10 and CBA30, NFA was replaced with 10% and 30% CBA and superplasticizers were used at 1.5% of binder volume. The water absorption of CBA is high, and hence the amount of SP used was high in CBA-based mixes to achieve the desired workability of 50mm. In the mix, CS10 and CS30 NFA were replaced with 10% and 30% CS and a superplasticizer were used at 1% of binder volume. The amount of aggregate used and the description of the mix code in every concrete mix are shown in Table 2. For the replacement of aggregate, the volume method is used. Each mix satisfied the workability criteria of a 50mm slump. 24- hour oven curing at 65 degree Celsius has been adopted for improving the geoploymerization process.

Table 2. Mix proportion of GPC mixes

Mix Code	FA Kg/m^3	CS Kg/m^3	CBA Kg/m^3	NFA Kg/m^3	NCA Kg/m^3	Molarity of NaOH	$Na_2SiO_3/NaOH$	SP (%)	Alkali/Binder
CM	480	0	0	595.40	1054.19	12	2	1	0.45
CBA10	480	0	54.48	535.86	1054.19	12	2	1.5	0.45
CBA30	480	0	163.44	416.78	1054.19	12	2	1.5	0.45
CS10	480	89.91	0	535.86	1054.19	12	2	1	0.45
CS30	480	269.72	0	416.78	1054.19	12	2	1	0.45

2.7 Experimental Program

The present study consists of the determination of the compressive strength of all the mixes after 7 and 28 days of curing on a specimen of size 100x100x100mm as per Code requirements [19]. The Capillary Suction Absorption Test (CSAT) was performed on 50mm high and 100mm diameter disc after 28 days of curing in accordance with code ASTM C 1585–13[20] (Fig. 2a). The Initial Surface Absorption Test (ISAT) was performed in accordance with Code BS 1881-208 [21] on a 150x150x150mm cube after 28 days of curing (Fig. 2b).



a) Capillary Suction Test Setup

b) Initial Surface Absorption Test Apparatus

Fig.2 Experimental Setup and apparatus for a) CSAT b) ISAT

3. Results

3.1 Compressive Strength

The compressive strength results for different GPC mixes are presented in Table 3. It can be inferred that replacement of NFA with CBA results in decreases in the compressive strength development while CS as NFA replacement increased the compressive strength development in FA-based GPC. Mix (CBA10 and CBA 30) achieved 7.08% and 19.9% lower compressive strength at 28 days of testing respectively when compared with CM. CBA particles are coarser, porous, and weak in comparison with NFA, and hence attributes to the weaker and porous interfacial transition zone (ITZ) [9], [22]–[24]. However, results obtained in CBA 10 are slightly comparable but lower than the CM, and 10% of CBA can opt as a potent replacement of NFA in FA-based GPC.

On contrary, CS particles are finer and stronger in comparison with the NFA and hence contribute to increasing in compressive strength. Mix CS10 and CS30 reported higher compressive strength of 24.15MPa, and 25.01MPa with respect to CM. The fine and strong CS particles result in better pore size refinement, consequently, leading to the formation of dense microstructure, and therefore increasing the compressive strength.

Table 3. Compressive Strength Results

Mix	**Compressive Strength (MPa)**	
	7 Days	**28 Days**
CM	21.32	24.12
CBA-10	20.11	22.41
CBA-30	18.67	19.32
CS-10	21.82	24.15
CS-30	22.08	25.01

3.2 Capillary Suction Absorption Test (CSAT)

Capillary suction absorption in concrete is dependent on the number of porous, pore size, and interconnectivity of the pores. Fig. 2 represents the test setup for Capillary Suction Absorption. All the GPC mixes were tested for capillary absorption, and it has been reported that the inclusion of CBA as an NFA replacement in FA-based GPC resulted in higher absorption values. Coarse and porous CBA results in the generation of interconnected pores in the microstructure of concrete that provides easy and unhindered absorption of water, leading to a higher initial rate of absorption (IRA) and secondary rate of absorption (SRA). Mix CBA10 and CBA 30 reported higher IRA values of 0.0455 $mm/s^{1/2}$ and 0.0562$mm/s^{1/2}$ in comparison with 0.0426 $mm/s^{1/2}$ as reported in the CM. Similarly, SRA values reported in CBA 10 and CBA 30 were 33.33% and 58.33% higher than the CM (0.0012 $mm/s^{1/2}$). Fig. 3 shows the sorptivity trends of GPC mixes.

However, the inclusion of CS as an NFA replacement resulted in a decrease in the IRA and SRA values of the FA-based GPC. A reduction of 11.50% and 19.71% has been reported in IRA values on replacement of 10% and 30% NFA with CS in comparison with the mix prepared with 100% NFA (0.0426 $mm/s^{1/2}$). Similarly, lower SRA values of 0.001 $mm/s^{1/2}$ and 0.0011 $mm/s^{1/2}$ were reported in CS10 and CS30 with respect to CM which reported an SRA value of 0.0012 $mm/s^{1/2}$ reduction in capillary suction absorption in CS-based FA GPC can be accredited to the fine particle size of CS than NFA that results in the better pore filling and reduction in the tortuosity of the concrete, consequently, offering hindrance to the absorption of water through capillary suction.

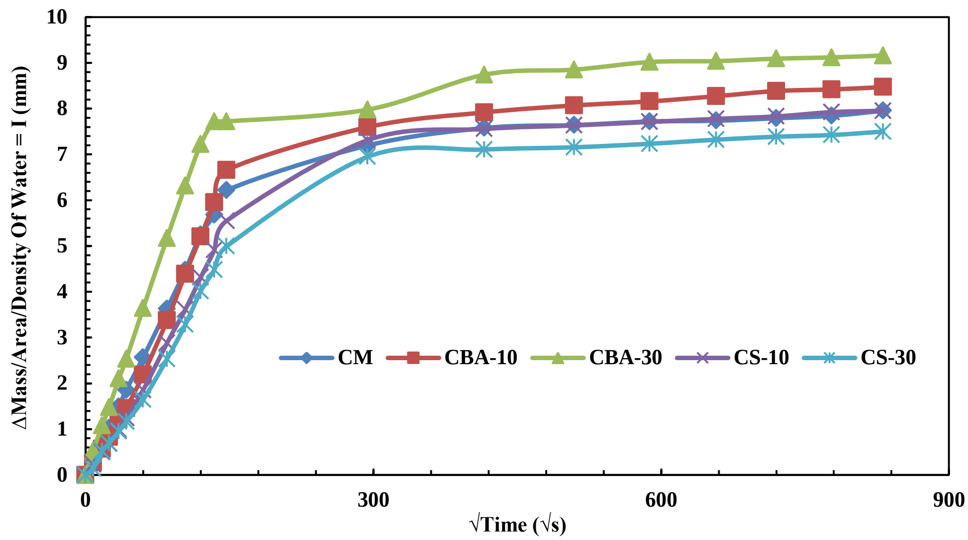


Fig. 3. Sorptivity values of GPC mixes

3.3 Initial Surface Absorption Test (ISAT)

The trends observed in ISAT were quite similar to CSAT as CBA-FA-based GPC reported higher ISA-10 values, whereas the ISA-10 values for CS-FA-based GPC were lower than the control mix. Fig. 4 depicts the test setup for the initial surface absorption. Porous CBA particles result in the porous microstructure resulting in higher absorption while on the other hand; fine CS particles make the concrete dense through pore filling and result in lower absorption values. An increment of 10.97% and 19.51% in ISA-10 has been reported with the replacement of 10% and 30% NFA with CBA respectively after 28 days of curing in comparison with the CM. Gen4eral trends of ISA values are depicted in Fig.5. On the other hand, inclusion of 10% and 30% CS as replacement of NFA resulted in 12.19% and 23.17% lower ISA-10 values with respect to CM (0.650794ml/m^2.sec). Similar trends have been observed in ISA-30 and ISA-60 values for all the GPC mixes. Fig. illustrates the trends of ISAT reported in all mixes studied in the present study.

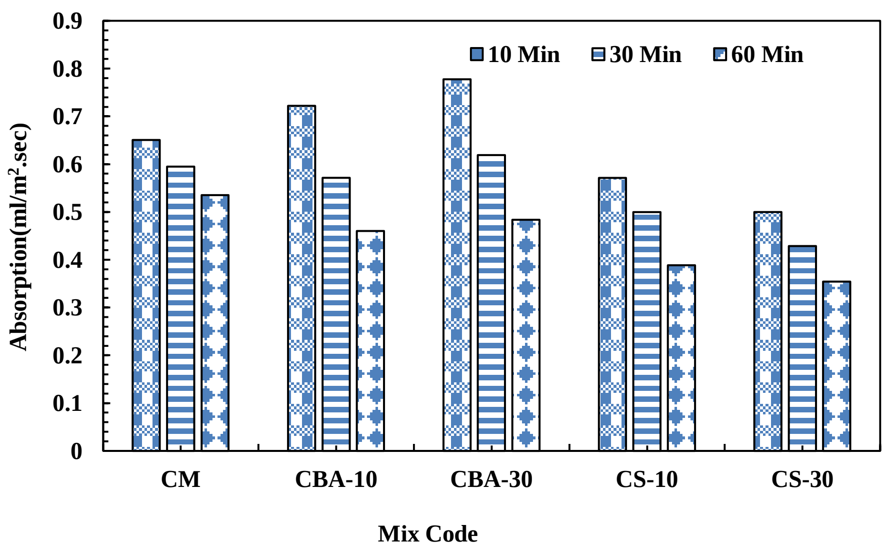


Fig. 4. ISA values of different GPC mixes

4. Conclusions

From the present study investigation the following conclusions are inferred:

i. CBA particles are porous, coarser, and weaker than the NFA and hence result in the formation of micro and macro pores in the microstructure of FA based GPC that further lead to decrement in compressive strength and water absorption resistance. On the other side, CS particles are finer and stronger than the NFA leading to better pore size refinement, hence, resulting in the superior performance of CS-FA based GPC.

ii. A reduction of 7.1% and 19.9% has been reported after 28 days of curing in the CBA 10 and CBA 30 mix respectively, whereas the CS 10 and CS 30 mix resulted in marginal (1% and 4% almost) increase in the compressive strength respectively with respect to the control mix.

iii. Higher porosity in CBA 10 and CBA 30 GPC mixes leads to higher IRA-SRA values of 0.0455-0.0016 $mm/s^{1/2}$ and 0.562-0.0019 $mm/s^{1/2}$ after 28 days of curing in comparison to the control mix (0.0426-0.0012 $mm/s^{1/2}$). On the contrary, fine CS particles result in the formation of a dense microstructure that further leads to lower IRA-SRA values of 0.0377-0.0011 $mm/s^{1/2}$and0.0342 -0.001 $mm/s^{1/2}$ respectively in CS10 and CS 30 as compared to CM.

iv. Alike trend was observed in ISAT, wherein, CBA 10 and CBA 30 reported 9.8% and 16.3% higher ISA-10 values than the control mix, and the addition of 10% and 30% CS as NFA replacement resulted in 12.19% and 23.17% lower ISA-10 values as compared to the CM.

v. The influence of CS was more dominant in the compressive as well as water permeation properties and 30% CS can be considered as an optimum replacement level of NFA in FA-based GPC. Despite the decrement in the properties of FA-based GPC with the inclusion of CBA as NFA replacement, the mix prepared with 10% CBA reported comparable but slightly inferior performance with respect to CM, and hence 10% replacement can be a possible replacement level of NFA with CBA.

References

[1] E. Ul Haq, S. Kunjalukkal Padmanabhan, and A. Licciulli, "Synthesis and characteristics of fly ash and bottom ash based geopolymers-A comparative study," *Ceram. Int.*, vol. 40, no. 2, pp. 2965–2971, 2014, doi: 10.1016/j.ceramint.2013.10.012.

[2] S. Gooi, A. A. Mousa, and D. Kong, "A critical review and gap analysis on the use of coal bottom ash as a substitute constituent in concrete," *J. Clean. Prod.*, vol. 268, p. 121752, 2020, doi: 10.1016/j.jclepro.2020.121752.

[3] R. Firdous, D. Stephan, and J. N. Y. Djobo, "Natural pozzolan based geopolymers: A review on mechanical, microstructural and durability characteristics," *Constr. Build. Mater.*, vol. 190, pp. 1251–1263, 2018, doi: 10.1016/j.conbuildmat.2018.09.191.

[4] O. F. Nnaemeka and N. B. Singh, "Durability properties of geopolymer concrete made from fly ash in presence of Kaolin," *Mater. Today Proc.*, vol. 29, pp. 781–784, 2019, doi: 10.1016/j.matpr.2020.04.696.

[5] M. Amran, S. Debbarma, and T. Ozbakkaloglu, "Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties," *Constr. Build. Mater.*, vol. 270, p. 121857, 2021, doi: 10.1016/j.conbuildmat.2020.121857.

[6] S. K. Das, J. Mishra, and S. M. Mustakim, "An Overview of Current Research Trends in Geopolymer Concrete," *Int. Res. J. Eng. Technol.*, vol. 05, no. 11, pp. 376–381, 2018.

[7] V. K, "A Review Paper on Geopolymer Concrete Using Hollow Core Slab," *Int. J. Emerg. Trends Sci. Technol.*, vol. 5, no. 3, pp. 6573–6576, 2018, doi: 10.18535/ijetst/v5i3.06.

[8] X. Y. Zhuang, L. Chen, S. Komarneni, C. H. Zhou, D. S. Tong, H. M. Yang, W. H. Yu, and H.Wang, "Fly ash-based geopolymer: Clean production, properties and applications," *J. Clean. Prod.*, vol. 125, pp. 253–267, 2016, doi: 10.1016/j.jclepro.2016.03.019.

[9] N. Ankur and N. Singh, "Performance of cement mortars and concretes containing coal bottom ash: A comprehensive review," *Renew. Sustain. Energy Rev.*, vol. 149, no. May, p. 111361, 2021, doi: 10.1016/j.rser.2021.111361.

[10] A. Wongsa, Y. Zaetang, V. Sata, and P. Chindaprasirt, "Properties of lightweight fly ash geopolymer concrete

containing bottom ash as aggregates," *Constr. Build. Mater.*, vol. 111, pp. 637–643, 2016, doi: 10.1016/j.conbuildmat.2016.02.135.
[11] A. Sathonsaowaphak, P. Chindaprasirt, and K. Pimraksa, "Workability and strength of lignite bottom ash geopolymer mortar," *J. Hazard. Mater.*, vol. 168, no. 1, pp. 44–50, 2009, doi: 10.1016/j.jhazmat.2009.01.120.
[12] M. Singh and R. Siddique, "Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate," *Constr. Build. Mater.*, vol. 50, pp. 246–256, 2014, doi: 10.1016/j.conbuildmat.2013.09.026.
[13] M. Singh and R. Siddique, "Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete," *J. Clean. Prod.*, vol. 112, pp. 620–630, 2016.
[14] J. Singh and S. P. Singh, "Synthesis of alkali-activated binder at ambient temperature using copper slag as precursor," *Mater. Lett.*, vol. 262, p. 127169, 2020, doi: 10.1016/j.matlet.2019.127169.
[15] G. Lavanya and J. Jegan, "Durability Study on High Calcium Fly Ash Based Geopolymer Concrete," *Adv. Mater. Sci. Eng.*, vol. 2015, 2015, doi: 10.1155/2015/731056.
[16] BIS:2386- Part I, "Method of test for aggregate for concrete. Part I - Particle size and shape.," *Indian Stand.*, p. (Reaffirmed 2002), 1963.
[17] IS 2386- Part III, "Method of Test for aggregate for concrete. Part III- Specific gravity, density, voids, absorption and bulking," *Bur. Indian Stand. New Delhi*, p. (Reaffirmed 2002), 1963.
[18] IS 383, "Coarse and Fine Aggregate for Concrete □ Specification IS383," 2016.
[19] IS 516:2014, "Method of Tests for Strength of Concrete," *IS 516 - 1959 (Reaffirmed 2004)*, p. New Delhi,India, 2004.
[20] ASTM C1585-13, "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes," *ASTM Int.*, vol. 41, no. 147, pp. 1–6, 2013.
[21] BS 1881-208:1996, "British Standard Testing concrete — Part 208: Recommendations for the determination of the initial surface absorption of concrete," 2010.
[22] D. Hardjito and S. S. Fung, "Fly Ash-Based Geopolymer Mortar Incorporating Bottom Ash," *Mod. Appl. Sci.*, vol. 4, no. 1, 2009, doi: 10.5539/mas.v4n1p44.
[23] M. Magesh, S. Jawahar, E. Dhanesh, and V. Vasugi, "Influence of bottom ash as fine aggregate in ggbfs geopolymer concrete," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 6, pp. 919–924, 2019.
[24] N. Singh, M. Mithulraj, and S. Arya, "Influence of coal bottom ash as fine aggregates replacement on various properties of concretes: A review," *Resour. Conserv. Recycl.*, vol. 138, no. March, pp. 257–271, 2018, doi: 10.1016/j.resconrec.2018.07.025.