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Enhancing Geopolymer Concrete Properties Through Processed Fly Ash and Alccofine Integration

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Abstract

Geopolymer concrete (GPC) is gaining attention as a sustainable alternative to ordinary Portland cement (OPC) due to its potential to reduce the environmental impact of cement production, which accounts for roughly 7% of global CO_2 emissions. This study investigates the use of processed fly ash and alccofine as key ingredients in GPC to improve its workability and compressive strength. Experimental tests were conducted to evaluate the effects of different proportions of fly ash, alccofine content, and curing methods on the concrete's performance. The results demonstrate that processed fly ash significantly enhances both the slump values, and the early-age compressive strength of GPC compared to unprocessed fly ash. Furthermore, the inclusion of alccofine boosts workability by up to 200%, while also improving compressive strength. Under heat curing conditions, compressive strength values reached as high as 73 MPa, while ambient curing achieved up to 32 MPa by the 28-day mark. This indicates that GPC can meet the compressive strength requirements of M25 grade concrete, even under ambient curing conditions. The research highlights the potential of GPC as a sustainable construction material, offering significant environmental benefits by repurposing industrial by-products like fly ash and alccofine. Additionally, GPC's ability to achieve high compressive strength under ambient conditions makes it a viable option for a range of construction applications. This study contributes to the growing body of knowledge on green construction materials, presenting GPC as an effective solution for reducing the carbon footprint of the construction industry and advancing sustainable building practices.

Keywords: Geopolymer concrete, fly ash, alccofine, compressive strength, workability, sustainable construction, ambient curing, heat curing

INTRODUCTION

Concrete, after water, is the most widely used building material globally. The production of its key component, ordinary Portland cement (OPC), is environmentally unsustainable due to its energy-intensive process and the significant emissions of carbon dioxide (CO_2). The need for cement and concrete as strong and durable construction materials will persist until an equally effective and economical alternative is found. Therefore, it is crucial to address the severe environmental impact of conventional concrete production. According to "Sustainable Development and Concrete Technology," the contribution of OPC to global greenhouse gas emissions is estimated to be around 1.35 billion tons annually, which accounts for approximately 7% of the total greenhouse gas emissions worldwide [1–3].

Alternative Materials

Given the discussions, future construction materials should be easy to produce, durable,

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strong, and most importantly, environmentally friendly. To mitigate the environmental impact, the construction industry can increase the use of industrial by-products, such as fly ash, granulated blast furnace slag, silica fume, and rice-husk ash. These by-products pose environmental threats if not properly disposed of, as their deposition can negatively affect water and soil due to their granulometric and mineral composition, as well as morphology and filtration properties [4, 5]. Recent studies have demonstrated the potential to use 100% waste materials as binders in concrete by activating them with alkali components, such as caustic alkalis, silicate salts, and non-silicate salts of weak acids [6].

Geopolymer Concrete

Geopolymer concrete (GPC) is an innovative class of construction material that utilizes a geopolymer (GP) as the primary binder to bond the system's other components, such as fine and coarse aggregates. There are two key ingredients required for the development of GP binders [7].

1. *Geopolymeric source materials (GSMs):* These materials are rich in silica and alumina and can be derived from natural minerals (such as kaolinite, clays, etc.) or industrial by-products (such as fly ash, silica fume, slag, rice-husk ash, etc.).
2. *Alkaline activator solution (AAS):* This solution is typically based on alkali metals, most commonly sodium or potassium. The most used AAS is a combination of alkali hydroxide (NaOH, KOH) and alkali silicate (sodium or potassium silicate) [8].

Motivation

The motivation for this study stems from the urgent need to address the environmental challenges posed by traditional construction materials, particularly OPC. The production of OPC is energy-intensive and contributes significantly to global CO_2 emissions, accounting for approximately 5% of the world's total emissions. This environmental impact is exacerbated by the release of Cement Kiln Dust, which poses health risks. The construction industry must find sustainable alternatives to mitigate these effects and reduce the carbon footprint associated with cement production [9].

Objectives

The primary objective of this study is to evaluate the potential of using processed fly ash and alccofine as key components in GPC. It aims to analyze the impact of different types and varying contents of fly ash on the workability and compressive strength of GPC. The study also investigates the role of alccofine in enhancing early-age strength and workability of the mixes. Additionally, it compares the effects of ambient and heat curing methods on compressive strength, aiming to identify the optimal mix proportions for achieving M25 grade concrete while utilizing sustainable materials [10–12].

Material

Fly Ash

This study utilized two distinct types of fly ash: processed and unprocessed. For preliminary laboratory experiments, GPC was developed using both types. The processed fly ash, a low-calcium (calcareous) variety with a specific gravity of 1.95 and complies with IS: 3812 – 2013. Fly ash serves as the primary source of alumina-silicate in GPC.

Rice Husk Ash (RHA)

Rice husk ash (RHA) is a sustainable, carbon-neutral byproduct and an effective super pozzolan for creating specialized concrete mixes. Its increasing use is attributed to its fine amorphous silica content, which is essential for manufacturing high-performance and high-strength concrete with minimal permeability. The RHA used in this study was sourced from a local supplier in Mandi deep, M. P. [13].

Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a vitreous, granular substance produced as a by-product from the blast furnace process. Its chemical composition can vary significantly based on the raw materials used in iron production.

GGBS is a non-metallic material comprising calcium silicates and alumino-silicates, formed in a molten state alongside iron in a blast furnace [14].

Fine Aggregates

For this study, locally sourced river sand was utilized, blended with coarse sand in a 50:50 ratio to achieve Zone II grading as per IS 383:1970. The sand was thoroughly cleaned to remove all inorganic impurities and used if it passed through a 2.36 mm sieve and was retained on a 150-micron sieve. The fine aggregates had a fineness modulus of 2.83, a specific gravity of 2.60, and a water absorption rate of 1.5% [15, 16].

Coarse Aggregates

The coarse aggregates employed in this study consisted of 14 mm, 10 mm, and 7 mm sizes, all in a saturated surface-dry (SSD) condition. These aggregates complied with IS 383-1970, while the fine aggregate was crushed sand, graded according to IS: 2386 (Part I)-1963 [17].

Water

The water used in mixing and curing the concrete specimens was clean, fresh, and potable, meeting the requirements of IS 456 [18].

Alccofine 1203

Alccofine 1203 (AF) is a finely refined low calcium silicate material derived from GGBS. Alccofine enhances both the fresh and hardened properties of high-performance concrete [19].

Sodium Silicate

For this study, sodium silicate in the form of a heavy syrup was utilized as an alkaline activator, crucial for the geopolymerization process. The sodium silicate solution (Na_2SiO_3) had a SiO_2-Na_2O ratio ranging from 1.90 to 2.01. According to the supplier, its composition was: Na_2O: 14.7%, SiO_2: 29.4%, and Water: 55.9% [20]

Sodium Hydroxide (NaOH)

NaOH pellets with 98% purity were obtained commercially for this study. The solution was prepared by dissolving these pellets in water at the required molar concentration for use in the concrete mix [21].

Superplasticizer

To enhance the workability of the fresh GPC, a naphthalene sulphonate-based superplasticizer was used. This water-reducing agent, compliant with IS 9103:1999, was necessary due to the higher viscosity and stickiness of sodium silicate and NaOH solutions compared to water, which can make the GPC more cohesive [22].

Mixing and Casting Procedure

The mixing process is crucial for producing GPC with the desired properties in both its fresh and hardened states. To ensure consistency, the mixing procedure recommended by M. T. Junaid was followed in this study. First, cube, cylinder, and beam molds were thoroughly oiled to prepare them for concrete pouring. Waste oil was used as a mold release agent for GPC, as typical greases used for cement-based concretes were less effective [23].

The NaOH and Na_2SiO_3 solutions were mixed 24 hours before creating the GPC. The mixing process itself was like that of traditional concrete. Initially, all dry aggregates, alumino-silicate materials (such as fly ash, RHA, or GGBS), and alccofine were placed in the pan mixer and mixed for five minutes to ensure thorough blending. Following this, the alkaline solution, along with any additional water and superplasticizer, was gradually added and mixed for another five minutes or until a uniform mixture was achieved [24, 25].

The mixed concrete was then poured into the molds on a vibrating table in three layers to ensure proper compaction, with each layer being filled as the vibration helped eliminate air voids. After pouring, the molds were removed from the table and stored at room temperature in the laboratory. The cubes were allowed to rest for 24 hours to ensure proper hardening of the concrete, making it possible to demold the specimens without causing damage [26–28].

RESULTS AND DISCUSSION

Workability

Workability of GPC Mixes

The workability of the GPC mixes was evaluated using the slump cone test, as shown in Figure 1. The fresh GPC mixes exhibited considerable harshness, especially those incorporating unprocessed fly ash, which resulted in very low slump values. The addition of 2% Naphthalene Sulphonate-based superplasticizer significantly enhanced the workability of the fresh GP mix, aligning with observations from previous studies. Notably, mixes that did not include alccofine demonstrated very poor workability [29].

Impact of Fly Ash Type and Content

The use of unprocessed fly ash in GP mixtures resulted in a slump value of zero, indicating a complete lack of workability. As illustrated in Figure 1, GPC mixes made with processed fly ash exhibited a measurable slump, which improved markedly with higher fly ash content. Specifically, the slump value increased from 20 mm to 120 mm as the fly ash content was raised from 355 kg/m³ to 405 kg/m³.

The absence of slump in the unprocessed fly ash mixture was attributed to the presence of unburned carbon particles, which make the fly ash hygroscopic. In contrast, the increased slump observed with processed fly ash is likely due to the higher proportion of fine, spherical particles and the overall increased fly ash content.

Impact of Alccofine Content

Incorporating alccofine into the GPC mix significantly enhanced workability. As depicted in Figure 1, workability improved notably with increasing alccofine content. Specifically, a slump collapse was observed at 10% alccofine due to its highly refined structure, with a fineness exceeding 12,000 cm²/g.

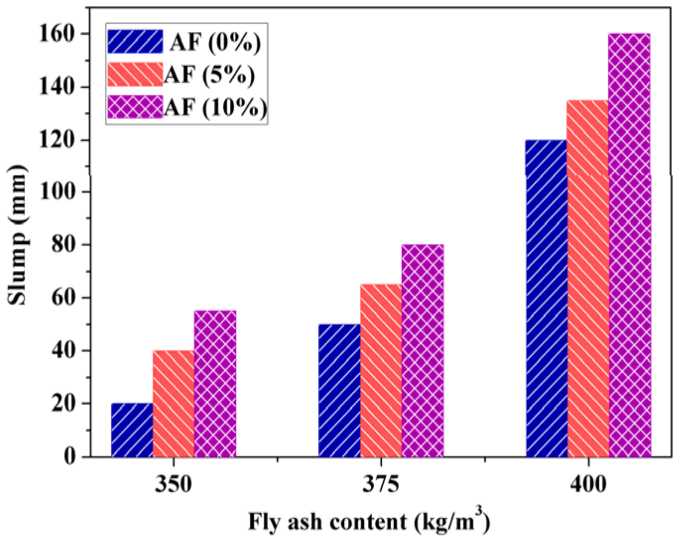

Figure 1. Workability (slump) of fly ash-based geopolymer concrete with varying alccofine contents ranging from 0% to 10%. (FA – Fly Ash, AF – Alccofine).

The slump increased by approximately 200% when comparing mixes with 10% alccofine and minimum fly ash content to those with maximum fly ash content but without alccofine. Additionally, slump values rose by 29–30% and 33-34% when alccofine content was increased from 0% to 5% and from 5% to 10%, respectively, with constant fly ash content. The enhanced workability of the GPC was attributed to alccofine's high fineness and spherical particle size, which contributed to a ball bearing effect, improving the mix's flow characteristics.

Compressive Strength

The compressive strength of GPC incorporating different types of fly ash and varying alccofine contents, as well as different curing methods, is discussed below.

Impact of Fly Ash Type and Curing Method

The effect of fly ash type on the compressive strength of GPC is depicted in Figures 2 and 3. The results indicate that GPC using processed fly ash demonstrated improved compressive strength under both ambient and heat curing conditions. Specifically, the compressive strength of GPC (Mix M1A0UP) with unprocessed fly ash increased from 3 MPa to 7 MPa and from 5 MPa to 13 MPa as the curing age progressed from 3 days to 28 days, respectively, for ambient and heat curing conditions. In contrast, the compressive strength of GPC (Mix M1A0P) made with processed fly ash without alccofine rose from 6 MPa to 13 MPa and from 11 MPa to 21 MPa over the same time periods and curing conditions.

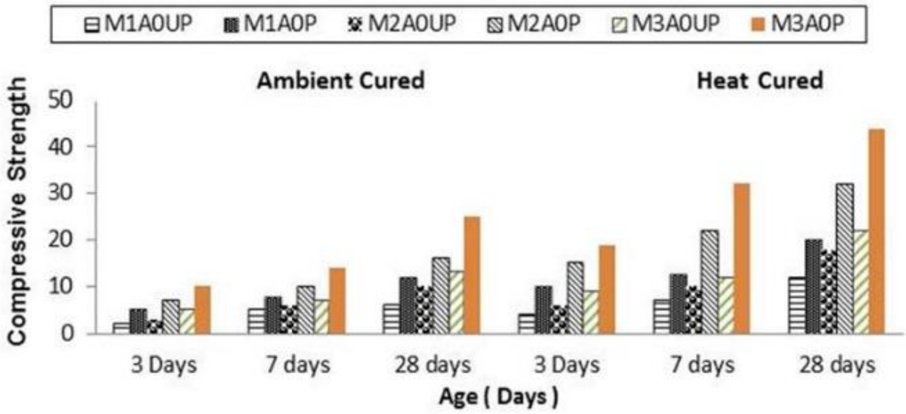

Figure 2. Comparison of compressive strength between geopolymer concrete (GPC) using processed and unprocessed fly ash.

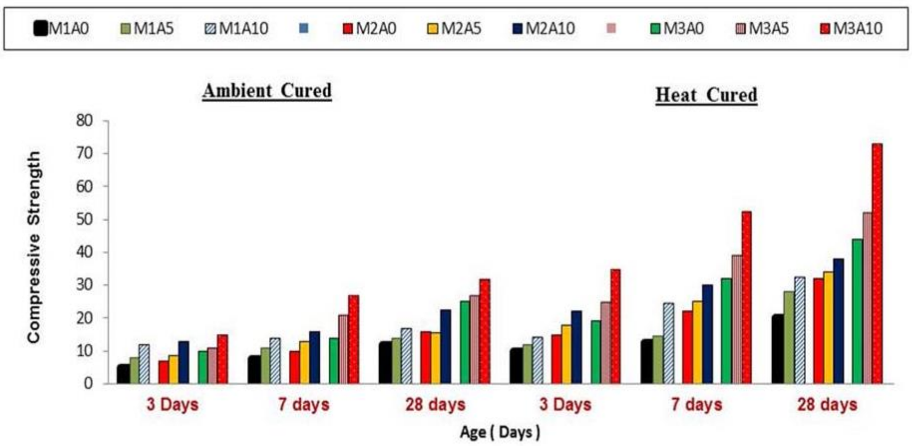

Figure 3. Impact of varying fly ash content, alccofine levels, curing methods, and casting age on the compressive strength of fly ash-based GPC.

The graph clearly indicates that GPC made with 405 kg of processed fly ash and cured at an ambient temperature can achieve up to 21 MPa compressive strength. For sample M3A0P (with 400 kg of fly ash), the compressive strength further improved when the curing temperature was elevated to 90°C. The results reveal a notable increase in early compressive strength – ranging from 300% to 130% – when comparing heat-cured specimens to those cured at ambient temperatures over 3 and 7 days. This enhancement in compressive strength at higher temperatures is attributed to the beneficial properties of processed fly ash in the concrete mix.

Influence of Fly Ash Content

Figure 3 illustrates how varying fly ash content affects the compressive strength of GPC made with processed fly ash. The results show that at early ages (3 and 7 days), the compressive strength of GPC increased from 6 MPa to 8 MPa and 11 MPa, from 7.5 MPa to 10 MPa, and up to 16 MPa. At 28 days, the compressive strength rose from 13 MPa to 16 MPa and 25 MPa with ambient curing as the fly ash content increased from 355 kg to 375 kg and then to 405 kg per cubic meter.

This demonstrates that GPC using processed fly ash can meet the minimum compressive strength requirements for general construction. In contrast, the highest compressive strength achieved with 405 kg/m³ of unprocessed fly ash at ambient temperature was 13 MPa, which falls short of the 20 MPa required for M20 grade concrete (according to BIS 456).

The increase in fly ash content enhances the binder material quantity and contributes to a denser concrete mix, thereby improving compressive strength. GPC with processed fly ash performs better than that with unprocessed fly ash, owing to its superior fineness and controlled chemical composition.

Impact of Alccofine Content

Figure 3 illustrates the effect of varying alccofine content on the compressive strength of different GPC mixes. It was observed that the compressive strength of GPC made with processed fly ash (M1A5 and M1A10) increased by 20% to 45% at early ages (3 and 7 days) and up to 62% at 28 days when heat curing was employed. This trend was consistent across mixes with higher fly ash content, indicating that the inclusion of alccofine enhances both early and ultimate compressive strength.

Specifically, GPC with 10% alccofine demonstrated compressive strengths of 35 MPa and 15 MPa at 3 days for heat and ambient curing, respectively. These values increased to 73 MPa and 32 MPa by 28 days. However, the relative increase in compressive strength was less pronounced for higher fly ash content compared to mixes with lower fly ash content.

The results suggest that GPC with alccofine can meet the target compressive strength for M25 grade, even with ambient curing. Nonetheless, literature emphasizes that heat curing is crucial for achieving the minimum required compressive strength. Heat curing significantly enhances the effectiveness of alccofine, especially with higher fly ash content, enabling the specimens to reach up to 73 MPa. This demonstrates that GPC containing alccofine is highly effective for general construction and precast applications.

Comparing the properties of fly ash and alccofine reveals that alccofine, with its finer particle size and higher alumina content, facilitates more effective hydration and polymerization. The ultra-fine particles of alccofine help fill micro-pores, thereby improving the compressive strength of GPC.

CONCLUSIONS

This study demonstrates that GPC utilizing processed fly ash and alccofine presents a viable and sustainable alternative to traditional cement-based concrete. Processed fly ash significantly enhances the workability and compressive strength of GPC, addressing the limitations associated with unprocessed fly ash, such as poor slump values. The inclusion of alccofine further improves workability, with a notable increase in slump values, and enhances compressive strength, especially when heat curing is applied. GPC containing 10% alccofine and 405 kg/m³ of processed fly ash achieved compressive strengths up to 73 MPa under heat curing and met the requirements for M25 grade concrete under ambient conditions. These results suggest that GPC with processed fly ash and alccofine can be an effective solution for general construction and precast applications, aligning with the goals of sustainable development. By utilizing industrial by-products, the proposed approach not only reduces the environmental footprint of concrete production but also offers a pathway for the construction industry to adopt greener practices.

REFERENCES

1. Malhotra V. Introduction: Sustainable development and concrete technology. ACI Concrete International. 2002;24(7).
2. Worrell E, Price L, Martin N, Hendriks C, Meida LO. Carbon dioxide emissions from the global cement industry 1. Annu Rev Energy Env. 2001;26(1):303–329. doi: 10.1146/annurev.energy.26.1.303.
3. Huntzinger DN, Eatmon TD. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. J Clean Prod. 2009;17(7):668–675. doi: 10.1016/j.jclepro.2008.04.007.
4. Lokeshappa B, Dikshit AK. Disposal and management of flyash, 2001 International Conference on life sciences and Technology IPCEBEE, 2011.
5. Partha SD, Pradip N, Prabir KS. Strength and permeation properties of slag blended fly ash based geopolymer concrete. Adv Mater Res. 2013;651:168–173. doi: 10.4028/www.scientific.net/AMR.651.168.
6. Alonso S, Palomo A, Bakharev T, Sanjayan J, Cheng Y, Brooke N, et al. A conceptual model of geopolymerisation, PhD Thesis of Chemical & Biomolecular Engineering Department. Melbourne: The University of Melbourne; 2006.
7. Davidovits J. High-alkali cements for 21st century concretes. Mater Sci Eng. 1994;144:383–398. doi: 10.14359/4523.
8. Xu H, Van Deventer JS. Geopolymerisation of multiple minerals. Miner Eng. 2002;15(12):1131–1139. doi: 10.1016/S0892-6875(02)00255-8.
9. Rajamane N, Nataraja M, Lakshmanan N, Ambily P. Literature survey on geopolymer concretes and a research plan in Indian context. The Masterbuilder. 2012;148–160.
10. Junaid MT, Kayali O, Khennane A, Black J. A mix design procedure for low calcium alkali activated fly ash-based concretes. Constr Build Mater. 2015;79:301–310. doi: 10.1016/j.conbuildmat.2015.01.048.
11. Parthasarathy P, Reddy MS, Dinakar P, Rao BH, Satpathy B, MohantyA. A mix design procedure for geopolymer concrete with fly ash. J Clean Prod. 2016;133:117–125. doi: 10.1016/j.jclepro.2016.05.041.
12. Hardjito D, Wallah SE, Sumajouw DM, Rangan BV. On the development of fly ash- based geopolymer concrete. ACI Materials Journal-American Concrete Institute 2004;101(6):467–472. doi: 10.14359/13485
13. Noushini A, Aslani F, Castel A, Gilbert RI, Uy B, Foster S. Compressive stress- strain model for low-calcium fly ash-based geopolymer and heat-cured Portland cement concrete. Cem Concr Compos. 2016;73:136–146. doi: 10.1016/j.cemconcomp.2016.07.004.
14. Jana D. The great pyramid debate: Evidence from detailed petrographic examinations of casing stones from the Great Pyramid of Khufu, a natural limestone from Tura, and a man- made (geopolymeric) limestone, Proceedings of the 29th Conference on Cement Microscopy. International Cement Microscopy Association, Quebec City, QC, 2007, pp. 207–266.
15. Roy DM. Alkali-activated cements opportunities and challenges. Cem Concr Res. 1999;29(2):249–254. doi: 10.1016/S0008-8846(98)00093-3.
16. Fernandez-Jimenez AM, Palomo A, Lopez-Hombrados C. Engineering properties of alkali-activated fly ash concrete. ACI Mater J. 2006;103(2):106–112.

17. Weng L, Sagoe-Crentsil K. Dissolution processes, hydrolysis and condensation reactions during geopolymer synthesis: Part I—Low Si/Al ratio systems. J Mater Sci. 2007;42(9):2997–3006. doi: 10.1007/s10853-006-0820-2.
18. Bakharev T. Geopolymeric materials prepared using Class F fly ash and elevated temperature curing. Cement and Concrete Research 2005;35(6):1224–1232. doi: 10.1016/j.cemconres.2004.06.031.
19. Bakharev T. Durability of geopolymer materials in sodium and magnesium sulfate solutions. Cem Concr Res. 2005;35(6):1233–1246. doi: 10.1016/j.cemconres.2004.09.002.
20. Perera D, Uchida O, Vance E, Finnie K. Influence of curing schedule on the integrity of geopolymers. J Mater Sci. 2007;42(9):3099–3106. doi: 10.1007/s10853-006-0533-6.
21. BIS, IS 3812 (Part 1) Indian Standard Pulverized Fuel Ash - Specification, Bureau of Indian Standards, New Delhi, India, 2003.
22. BIS : 2386 (Part I) Indian Standard Methods of Test For aggregates Concrete - Part I Particle Size and Shape, Bureau of Indian Standards, New Delhi, India, 1963.
23. BIS, IS : 383 Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete Bureau of Indian Standards, New Delhi, India, 1970.
24. BIS, IS : 2386 (Part I) Indian Standard Methods of Test For aggregates Concrete - Part I Particle Size and Shape, Bureau of Indian Standards, New Delhi, India, 1963.
25. BIS, IS 456 Indian Standard Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standards, New Delhi, India, 2000.
26. Parmar A, Patel DM, Chaudhari D, Raol H. Effect of alccofine and fly ash addition on the durability of high performance concrete. International Journal of Engineering Research and Technology, ESRSA Publications, 2014.
27. Jindal BB, Yadav A, Anand A, Badal A. Development of high strength fly ash based geopolymer concrete with alccofine. IOSR-JMCE. 2016; 55–58. doi: 10.9790/1684-15010010155-58.
28. Deb PS, Nath P, Sarker PK. The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature. Mater Des. 2014;62:32–39. doi: 10.1016/j.matdes.2014.05.001.
29. IS 9103 Indian Standard Concrete Admixtures- Specification, Bureau of Indian Standards, New Delhi, India, 1999.

