

Physical and Mechanical Properties of GGBS Based Geopolymer Concrete with the Inclusion of Metakaolin

Kajol Priya¹, Vipin Mahadevan^{2*}, Vishal Kumar³, Rajat Yadav⁴

Abstract

The use of ecologically friendly materials in the production of concrete is a significant and pertinent development in the global movement for sustainable construction. Geopolymer concrete (GPC) has gained popularity as an alternative to conventional Portland cement (OPC)-based concrete due to its utilisation of ground granulated blast furnace slag (GGBS), fly ash, and metakaolin, among other industrial by-products. The production of geopolymer concrete addresses serious environmental problems and contributes to the fight against global warming because it emits significantly fewer greenhouse gases than OPC. Using bio-additives, GGBS, metakaolin, and a reduced dose of alkaline activator, the project aims to produce an ambient-cured geopolymer concrete. The goal was to create a sustainable concrete mix with good mechanical performance that doesn't require curing at high temperatures. Specifically, the mechanical characteristics of GGBS-based geopolymer concrete that was combined with metakaolin were assessed. After 28 days of curing at room temperature, the GPC sample containing 100% GGBS demonstrated favourable mechanical properties, obtaining a compressive strength of 37.31 MPa, a split tensile strength of 5.18 MPa, and a flexural strength of 5.18 MPa. These results confirm that GPC can be a high-performing and sustainable alternative to OPC concrete, particularly when made with industrial waste materials and allowed to cure in the open air. The effective use of these materials contributes to the larger objective of lessening the impact on the environment while maintaining the structural integrity of concrete.

Keywords: Compressive strength, metakaolin, GGBS, split tensile strength, flexural strength

INTRODUCTION

In addition to its use in making concrete, Ordinary Portland Cement (OPC) is an essential material in the building trade. There were large amounts of carbon dioxide released into the atmosphere during the production of OPC, and the process left the environment highly polluted [1]-[3]. A recent study confirmed that the production of one tonne of OPC generates one tonne of carbon dioxide. The International Energy Agency estimates that 5-7 percent of worldwide greenhouse gas emissions came

from OPC production, setting the stage for global warming's impact [4]-[6]. The Geological Survey (2012) estimates that annual global OPC production is currently at 3.6 billion metric tonnes, and predicts that this figure will rise to well over 5 billion metric tonnes during the next few years [7]-[10]. Since geopolymer concrete has the potential to replace regular Portland cement, it can significantly reduce carbon dioxide emissions [11]. Due to these environmental concerns, initiatives have been done to reduce the amount of Portland cement used in building projects. Cement has been the standard binder for a long time, but Geopolymer[12]-[14] can be made from Silicon (Si) and Aluminum (Al)-rich source materials mixed with an alkaline liquid

*Author for Correspondence

Vipin Mahadevan

¹Assistant Professor, Department of civil engineering, Harcourt Butler Technical University, Kanpur, Uttar Pradesh, India

^{2,3}Assistant Professor, Department of civil engineering, Rajkiya engineering college, Azamgarh, Uttar Pradesh, India

⁴Assistant Professor, Department of Mechanical Engineering, GLA University, Mathura, Uttar Pradesh, India

Received Date: November 12, 2024

Accepted Date: January 24, 2025

Published Date: April 24, 2025

Citation: Kajol Priya, Vipin Mahadevan, Vishal Kumar, Rajat Yadav. Physical and Mechanical Properties of GGBS Based Geopolymer Concrete with The Inclusion of Metakaolin. Journal of Polymer & Composites. 2025; 13(Special Issue 3): S261-S266p.

or byproduct materials like metakaolin and rice husk ash through a polymerization chemical reaction. This temperature, which is greater than the surrounding environment, is essential for the growth of strength since it is the site of the initial reaction. Curing it at or above its working temperature can get it to that point [15].

There was a marked improvement in durability when the material was cured at temperatures between 50 and 80 degrees Celsius rather than at room temperature. When GPC's curing temperature is increased past a particular degree, the setting time decreases. A 70 percent strength gain is possible after only 3 to 4 hours of curing time when the curing temperature is raised to about 65 degrees Celsius. Maximum early strength was achieved during curing at 65°C, and there was no further rise in strength beyond 28 days[16]. High-strength, well-workable Geopolymer was developed using aggregate that was not treated to the saturated-surface-dry state. The flexural properties of GPC beams were studied. It was found that within reasonable limits, conventional reinforced concrete theory may be applied to the study of GPC beams in flexure, allowing for the calculation of moment capacity, deflection, and crack width.

MATERIALS

This research set out to determine that different curing durations at ambient temperature affected the mechanical properties of geopolymer concrete that contained metakolin and GGBS. Both metakaolin and GGBS were selected as binders, although for different reasons. For a comparison of metakaolin and GGBS in terms of their chemical and physical properties, see Table 1. Metakaolin from Gujarat's Navdeep Tradex and ground granulated blast furnace slag from Andhra Pradesh's Vizag Steel Plant were utilised to create GPC. Figure 1(a and b) shows the metakaolin and ggbs in powder form. The alkaline liquid was made by mixing sodium silicate solution and sodium hydroxide solution. The sodium silicate solution consisted of 54.9 percent water and a Na₂O supply from a nearby provider (SiO₂ accounted for 29.4 percent, Na₂O for 13.8 percent, and water for 54.9 percent by mass). A local supplier provided flake sodium hydroxide with a purity of 96%-98%. In order to get the job done, a 12 M sodium hydroxide (NaOH) solution had to be made. One day before using, a mixture of the Na₂SiO₃ solution and the NaOH solution was prepared. The fine aggregate was comprised of river sand, while the coarse aggregate was made up of crushed granite stones that ranged in size from 20mm to 10mm. The water absorption and specific gravity of coarse aggregates (10 mm) 0.29% and 2.60 and correspondingly under oven-dry conditions. When dried in an oven at room temperature, 20 mm of sand had water absorption of 1% and a bulk specific gravity of 2.58.

Methodology

After 7 and 28 days, cube samples were taken from each mixture and compressed to assess their compressive strength in accordance with IS 516. There were three specimens of each age and mix formed into cubes of 100 mm³ and analysed. All of the combination samples were tested for splitting tensile strength after 7 and 28 days of curing, as specified by IS 5816. Three 100 mm x 200 mm cylinders were cast and tested for each age and mixture. All of the mixes had their flexural strength tested after 7 and 28 days of curing using IS 516-compliant testing procedures. For each age and mix, three examples of concrete beams (100mmx100mmx500mm) were constructed and tested. All of the test samples were kept at ambient temperature during the curing process to ensure uniformity. Table 2 indicate the sample id of concrete mix.

Table 1. Chemical Composition of metakaolin and GGBS.

S N	Oxide compound	GGBS (%)	Metakaolin (%)
1	Silicon dioxide	32.18	46.18
2	Calcium oxide	34.54	0.81
3	Magnesium oxide	6.58	0.0
4	Aluminum oxide	15.31	39.12
5	Ferric oxide	2.75	1.20
6	Sodium oxide	-	0.9
7	Titanium oxide	-	2.45



Figure 1. (a) Metakaolin (b) GGBS.

Table 2. Sample ID

Sample ID	GGBS (%)	Metakaolin (%)
G100M0	100	0
G80M20	80	20
G60M40	60	40
G40M60	40	60
G20M80	20	80

RESULT AND DISCUSSION

Compressive Strength

Manufactured geopolymer concrete specimens were subjected to compression testing to establish their potential strength. In this case, specimens measuring 150 mm x 150 mm x 150 mm are subjected to a force applied at a right angle to their long axis on both sides. Fig. 2 displays the results of a compressive test performed on samples with varying percentages of ground granulated blast furnace slag concrete (GGBS) and metakaolin.

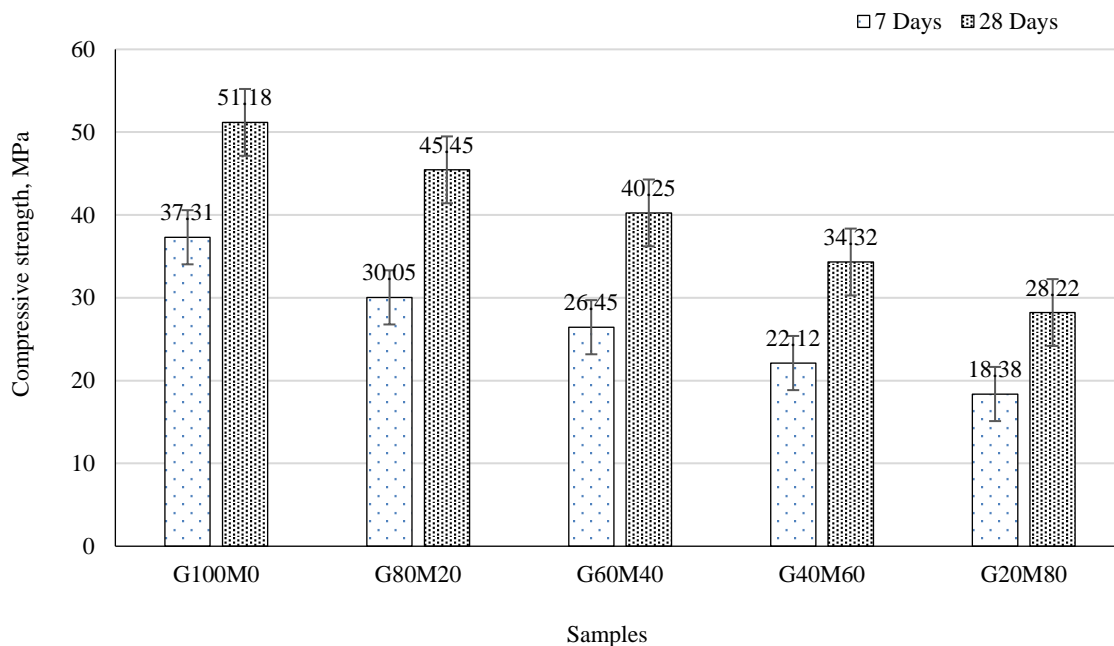


Figure 2. Compressive strength of concrete mix.

Compression strength was significantly enhanced by increasing the GGBS content from 20% to 100% throughout all curing durations, as shown in Figure 2. A higher percentage of GGBS as a substitute in geopolymer results in a more robust material. The GPC with 100% GGBS specimen showed values of compressive strength of 37.31 MPa after 7 days of curing at room temperature, and 51.18 MPa after 28 days of curing. Possible explanations for the increased strength include the GGBS filling in voids and the growth of the CSH gel in association with the geo-polymeric gel. All of this contributes to slag-based geopolymer concrete's superior early age strength compared to that of regular concrete.

Split Tensile Strength

The specimen was bent in a tensile test to establish the easily geopolymer concrete would rupture under stress. Samples were cylinders with a diameter of 150mm and a height of 300mm, and they were subjected to a radial stress. Results from a split tensile test are depicted in Figure 3.

As can be seen in Figure 3, the splitting tensile strength significantly increased across the board as the percentage of GGBS increased from 20% to 100% over the course of a year. Increasing the amount of GGBS replacement in GPC improves the material's microstructure, which in turn increases the tensile strength of the material when it splits. The GPC with 100% GGBS sample had splitting tensile strengths of 4.19 MPa after 7 days of curing at room temperature and 5.18 MPa after 28 days of curing at room temperature.

Flexural Strength

The flexural strength of the samples was tested after 1 and 4 weeks of cure using universal testing equipment. The three-point load method specified in IS: 516-1959 was used to carry out the test. The flexure test outcomes are depicted in Figure 4.

Figure 4 shows that flexural strength was significantly increased across the board for all curing durations as the GGBS percentage was raised from 20% to 100%. The flexural strength of GPC can be improved by increasing the degree to which GGBS is substituted for its natural polymer, polyglycerol. The GPC with 100% GGBS sample had splitting tensile strengths of 5.81 MPa after 7 days of curing at room temperature, and 6.82 MPa after 28 days of curing.

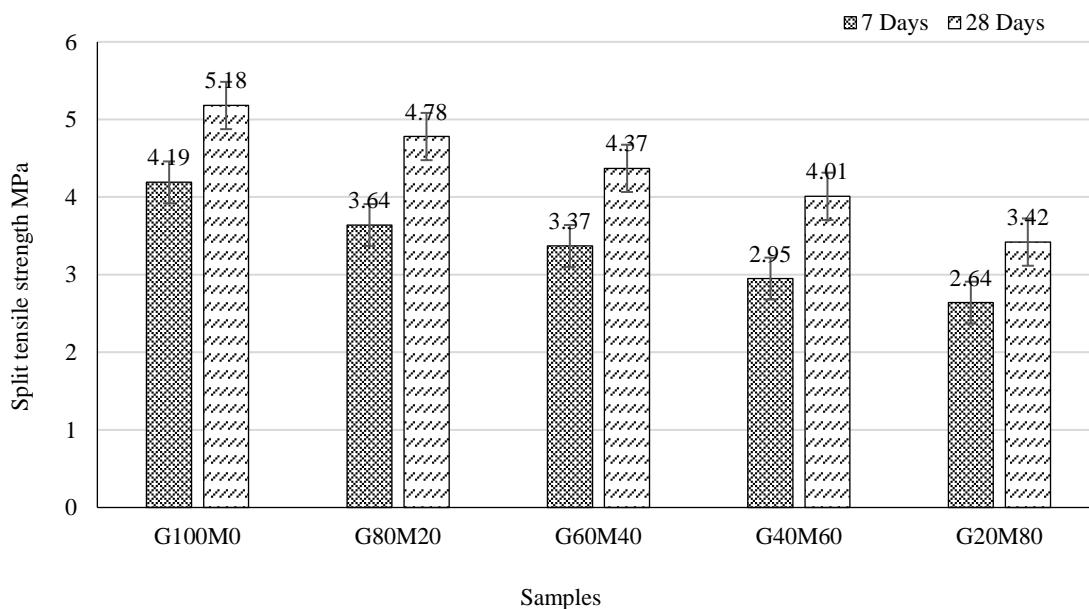


Figure 3. Split tensile strength of concrete mix.

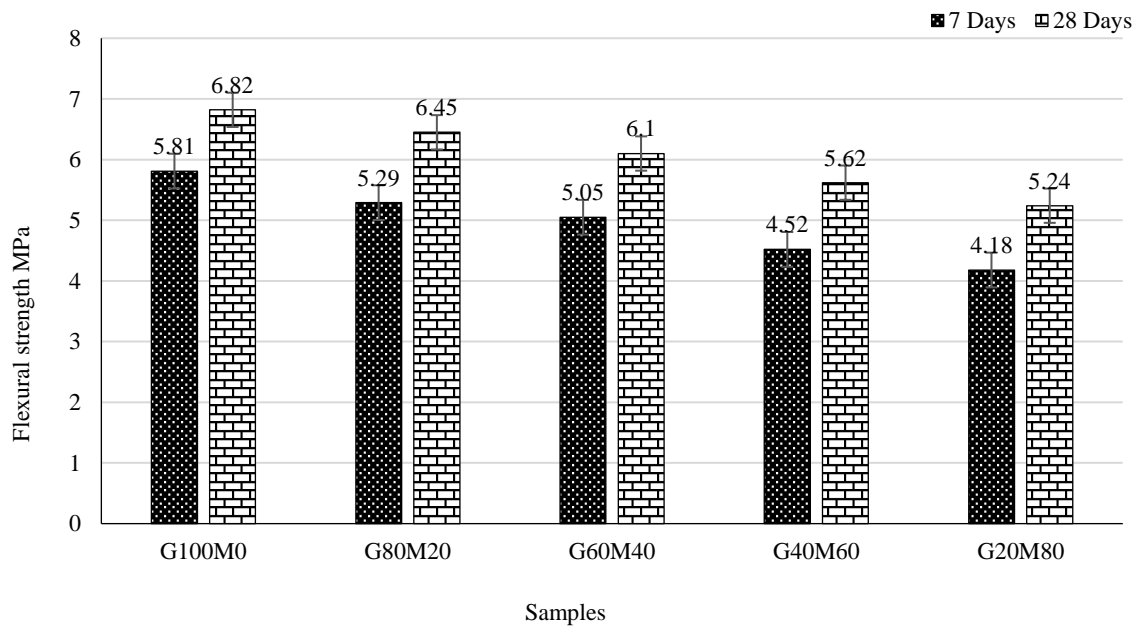


Figure 4. Flexural strength of GGBS based concrete.

CONCLUSION

- Increases in the GGBS substitution proportion improve the microstructure of GPC, leading to greater compressive strength. The GPC with 100% GGBS sample had compressive strength of 37.31 MPa after 7 days of curing at room temperature and 51.18 MPa after 28 days of curing at room temperature.
- It can be deduced that improving the microstructure of GPC by increasing the amount of GGBS substitution improves the GPC splitting tensile strength. The GPC with 100% GGBS sample had splitting tensile strengths of 4.19 MPa after 7 days of curing at room temperature and 5.18 MPa after 28 days of curing at room temperature.
- Stronger GPC can be made by increasing the amount of GGBS replacement, since this process "fills the voids" in the material's structure. The GPC with 100% GGBS specimen had flexural strengths of 5.81 MPa after 7 days of curing at room temperature and 6.82 MPa after 28 days of curing.

REFERENCES

1. Gupta, A., Gupta, N., & Saxena, K. K. (2021). Mechanical and Durability Characteristics Assessment of Geopolymer Composite (GPC) at Varying Silica Fume Content. *Journal of Composites Science*, 5(9), 237.
2. Bahoria, B. V., Ranjith, A., Laxmaiah, G., Raj, S. S., Padhi, M. R., & Palanisamy, S. (2024). Verification of the mechanical behavior of concrete with partial replacement of the fiber resulting from tire retreading. *Materials Today: Proceedings*.
3. Parashar, A. K., & Gupta, A. (2022). Assessment of the Impact of Bacillus Cereus Bacteria on Strength and Water Absorption Capacity of Sustainable Concrete. In *Proceedings of International Conference on Innovative Technologies for Clean and Sustainable Development (ICITCSD-2021)* (pp. 379-388). Springer, Cham
4. Sharma, N., Sharma, P., & Parashar, A. K. (2022). Use of waste glass and demolished brick as coarse aggregate in production of sustainable concrete. *Materials Today: Proceedings*.
5. Parashar, A. K., Gupta, A., Gupta, N., & Verma, P. (2022). Regression Analysis for Assessing the Impact of Megaterium Bacterial Solution on Bagasse Ash Concrete.

6. Parashar, A. K., Gupta, N., Kishore, K., & Nagar, P. A. (2021). An experimental investigation on mechanical properties of calcined clay concrete embedded with bacillus subtilis. *Materials Today: Proceedings*, 44, 129-134.
7. Verma, M., Sharma, N., Sharma, P., & Singh, P. (2020). Evaluate the Effect in Terms of Setting Time and Compressive Strength of Oleic Acid as an Admixture in Cement. *Test Eng. Manag.*, 12422, 12422-12427.
8. Palaniappan, M., Palanisamy, S., Khan, R., H. Alrasheedi, N., Tadepalli, S., Murugesan, T. M., & Santulli, C. (2024). Synthesis and suitability characterization of microcrystalline cellulose from Citrus x sinensis sweet orange peel fruit waste-based biomass for polymer composite applications. *Journal of Polymer Research*, 31(4), 105.
9. Sharma, N., & Sharma, P. (2021, April). Effect of hydrophobic agent in cement and concrete: A Review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1116, No. 1, p. 012175). IOP Publishing.
10. Parashar, A. K., & Gupta, N. (2023). An investigation of micro-silica inclusion in slag-based geopolymer concrete with regression and cluster analysis. *Asian Journal of Civil Engineering*, 24(8), 3759-3765.
11. Govindarajan, P. R., Antony, J. A., Palanisamy, S., Ayrilmis, N., Khan, T., Junaedi, H., & Sebaey, T. A. (2024). Advances in Manufacturing of Carbon-based Molecular Nanomaterials Based on Rice Husk/hull Waste. *BioResources*, 19(4).
12. Gupta, A., Gupta, N., & Saxena, K. K. (2021). Experimental study of the mechanical and durability properties of Slag and Calcined Clay based geopolymer composite. *Advances in Materials and Processing Technologies*, 1-15.
13. Parashar, A. K., Kumar, A., Goud, K. A., Gupta, N., Saxena, K. K., Iqbal, A., Djavanroodi, F., & Saadaoui, S. (2024). An approach for environment protection by regression and cluster analysis of GGBS-based geopolymer composite at different proportion of brick dust. *Mechanics of Advanced Materials and Structures*, 31(27), 9223-9231.
14. Parashar, A. K., Kumar, A., Gupta, N., Saxena, K. K., Alla, N., Chandrashekar, R., Vinayak, M & Abduvalieva, D. (2024). Regression and Cluster Analysis of GGBS based geopolymer composite at different proportion of Ceramic Dust.
15. Gandhi, S., Roji, S. S. S., Motta, M., Nalawade, R. R. D., Khan, M. A., & Palanisamy, S. (2024). Analysis of potential incorporation of waste into asphalt pavements. *Materials Today: Proceedings*.
16. Sharma, N., Sharma, P., & kr Verma, S. (2021, April). Influence of Diatomite on the properties of mortar and concrete: A Review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1116, No. 1, p. 012174). IOP Publishing.