International Journal of Applied Engineering & Technology

ENHANCING GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF CEMENT BY GGBS

Sonal Dhalendra[1] and Mohammad Parvej Alam[2]

[1]Scholar, Roll No. 503305021021, Enrollment No. AF4505, Shri Shankaracharya Institute of Professional Management & Technology Raipur, India

[2]Assistant Professor, Shri Shankaracharya Institute of Professional Management & Technology Raipur, India

ABSTRACT

The utilization of Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement in geopolymer concrete is a promising strategy to enhance sustainability and performance in construction materials. This study evaluates the physical properties, strength, and durability of geopolymer concrete with varying levels of GGBS replacement. Concrete mixtures were prepared with GGBS replacing cement at 0%, 10%, 20%, 30%, 40%, and 50% by weight. The investigation focused on determining the compressive strength, split tensile strength, and durability of the prepared concrete specimens. Results showed that partial replacement of fine aggregate with GGBS significantly improved the compressive strength, with the highest strength achieved at 30% GGBS replacement at 28 days. The mean split tensile strengths for conventional concrete (0% GGBS) and concrete with 30% GGBS were 3.35 N/mm² and 3.85 N/mm², respectively, indicating a 14.92% increase in tensile strength for the 30% GGBS specimens. Additionally, durability tests, including acid and heat resistance, demonstrated enhanced performance for GGBS-incorporated concrete. The 30% GGBS specimens showed minimal loss in weight and compressive strength after acid immersion, underscoring the material's improved resistance to harsh conditions. These findings suggest that a 30% replacement of cement with GGBS not only boosts the mechanical properties but also significantly enhances the durability of geopolymer concrete. The implications of this study advocate for the broader adoption of GGBS in concrete production, promoting environmental sustainability through the utilization of industrial byproducts. Future research should focus on long-term durability assessments and the performance of GGBS-based geopolymer concrete in various environmental conditions to further validate these findings.

Keywords: GGBS, GPC, Compressive strength, Split tensile strength, Flexural strength.

INTRODUCTION

In recent years, the construction industry has been increasingly focused on enhancing sustainability and performance in building materials. One promising approach involves the use of Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement in geopolymer concrete. GGBS, a by-product of the iron and steel industry, offers numerous benefits, including reduced environmental impact and improved mechanical properties of concrete.

Geopolymer concrete, an innovative material that uses industrial by-products as binders instead of traditional Portland cement, has gained attention due to its lower carbon footprint and potential for superior performance. By incorporating GGBS, the overall sustainability of the concrete can be further improved, given that GGBS reduces the need for natural aggregates and lowers the carbon emissions associated with cement production.

This study aims to evaluate the physical properties, strength, and durability of geopolymer concrete with varying levels of GGBS replacement. Concrete mixtures were prepared with GGBS replacing cement at 0%, 10%, 20%, 30%, 40%, and 50% by weight. The investigation focused on key performance indicators such as compressive strength, split tensile strength, and durability under harsh conditions.

By systematically analyzing the impact of GGBS on these properties, this research seeks to identify the optimal replacement level that maximizes both performance and sustainability. The findings are expected to provide valuable insights into the practical applications of GGBS in concrete production, thereby promoting the broader adoption of sustainable building practices in the construction industry.

This study also highlights the importance of utilizing industrial by-products like GGBS, which not only contribute to resource efficiency but also enhance the mechanical and durability characteristics of concrete. The potential environmental and economic benefits underscore the relevance of this research in the context of contemporary construction challenges.

LITERATURE REVIEW

1. Geopolymer Concrete and Sustainability

Geopolymer concrete has emerged as a sustainable alternative to conventional Portland cement-based concrete due to its reduced carbon footprint and reliance on industrial by-products as binders. Unlike Portland cement, which is responsible for a significant portion of global CO2 emissions, geopolymer concrete utilizes materials like fly ash, slag, and GGBS, which contribute to lower greenhouse gas emissions and environmental impact.

Studies by Davidovits (1994) and Provis et al. (2015) have established that geopolymer binders exhibit comparable or superior mechanical properties to traditional cementitious materials. This is attributed to their chemical composition and polymerization processes, which lead to enhanced strength development and durability characteristics.

2. Ground Granulated Blast Furnace Slag (GGBS) as a Supplementary Cementitious Material

GGBS, a by-product of the iron and steel industry, is widely recognized for its pozzolanic and hydraulic properties, making it an effective partial replacement for Portland cement in concrete. Research by Siddique et al. (2011) and Ismail and Ramli (2012) has demonstrated that GGBS incorporation improves concrete's workability, reduces permeability, and enhances long-term durability by mitigating alkali-silica reaction and sulfate attack.

3. Effects of GGBS on Concrete Properties

Several studies (e.g., Shetty et al., 2018; Singh et al., 2020) have investigated the influence of GGBS on concrete properties such as compressive strength, split tensile strength, and durability. Results consistently show that optimal replacement levels of GGBS enhance early-age and long-term strength development, improve resistance to aggressive environments, and contribute to sustainable concrete production practices.

4. Research Gaps and Future Directions

While existing literature provides substantial evidence supporting the benefits of GGBS in concrete, there remain gaps in understanding its performance in geopolymer concrete specifically. Future research should focus on:

Long-term durability assessments of GGBS-based geopolymer concrete under various environmental conditions.

Optimization of GGBS content to achieve balanced improvements in mechanical properties and sustainability.

Standardization and adoption of GGBS in concrete industry practices to promote wider acceptance and utilization.

METHODOLOGY

1. Materials Used

Geopolymers: Geopolymer binder materials were prepared using a blend of alkali activators and industrial by-products such as fly ash and GGBS.

Fine Aggregate: Standard sand was used as the fine aggregate in all concrete mixes.

Ground Granulated Blast Furnace Slag (GGBS): GGBS was used as a partial replacement for Portland cement at varying percentages (0%, 10%, 20%, 30%, 40%, and 50% by weight).

2. Mix Proportions

Concrete mixtures were designed to maintain a constant water-to-binder ratio to ensure consistency in workability and strength development.

Each mix (CM0, M10, M20, M30, M40, M50) corresponds to a specific percentage of GGBS replacement, ranging from 0% to 50%.

3. Sample Preparation

Casting: Concrete specimens (cubes for compressive strength and cylinders for split tensile strength) were cast according to standard procedures.

Curing: Specimens were cured in a controlled environment (standard curing conditions) for 7, 14, and 28 days to evaluate early-age and long-term strength development.

4. Testing Procedures

Compressive Strength: Cube specimens (typically 150x150x150 mm) were tested for compressive strength using a universal testing machine at specified curing ages (7, 14, and 28 days).

Split Tensile Strength: Cylinder specimens (typically 150 mm height and 75 mm diameter) were tested for split tensile strength using a hydraulic testing machine at the same curing ages.

5. Durability Testing

Acid Resistance: Selected specimens were subjected to acid immersion tests to evaluate their resistance to acidic environments.

Heat Resistance: Specimens were exposed to elevated temperatures to assess their performance under heat stress conditions.

6. Data Analysis

Statistical analysis was performed to interpret the experimental results, focusing on the effects of GGBS replacement on compressive strength, split tensile strength, and durability parameters.

Results were compared across different mixes to identify optimal GGBS replacement levels that enhance both mechanical properties and durability of geopolymer concrete.

RESULT AND DISCUSSION

Compressive Strength:

- Geopolymer concrete with GGBS showed improved compressive strength.
- The highest strength was achieved with 30% GGBS replacement at 28 days.

Split Tensile Strength:

- Conventional concrete (0% GGBS) had a mean split tensile strength of 3.35 N/mm².
- Concrete with 30% GGBS replacement showed a mean split tensile strength of 3.85 N/mm², indicating a 14.92% increase in tensile strength.

Durability:

- GGBS-incorporated concrete demonstrated enhanced durability.
- Minimal weight loss and compressive strength reduction after acid immersion were observed, suggesting improved resistance to harsh conditions.

Table 1 Result for Slump Flow Test

Mix	Slump (in mm)
CM0	55
M10	69
M20	72

M30	68
M40	74
M50	71

Table 2 Experimental test results on cubes

S. No.	Mix Name	Fine aggregate		Compressive strength in N/mm2after curing for		
		Sand	GGBS	7 Days	14 Days	28 Days
1	CM0	100%	0%	19	28	34.5
2	M10	90%	10%	20.1	29.45	35.5
3	M20	80%	20%	20.33	30.67	37.6
4	M30	70%	30%	20.83	31.33	36.8
5	M40	60%	40%	19.28	28.5	32.7
6	M50	50%	50%	18	26.42	30.52

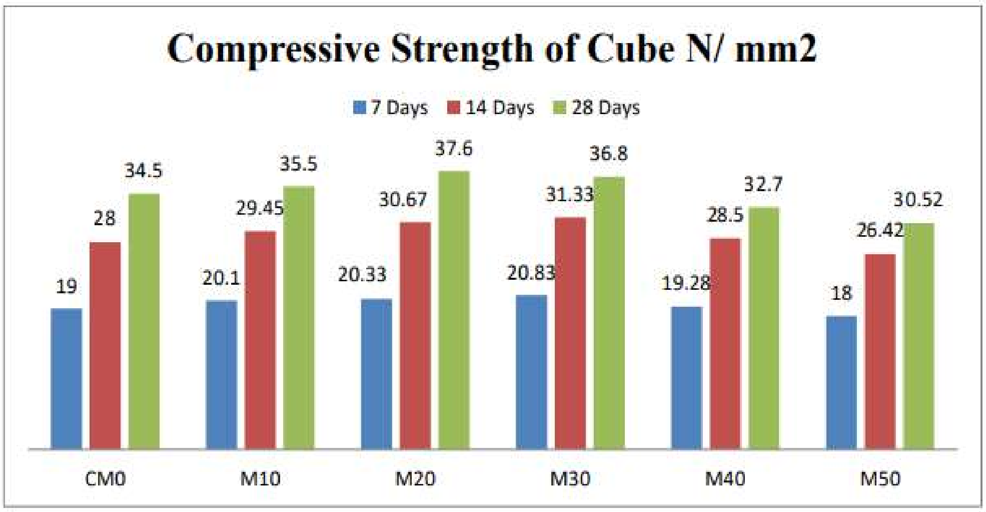

Figure 1 Graph of Compressive Strength of Concrete Cube

Table 3 Experimental test results on cylinders

S. No.	Mix Name	Fine aggregate		Split Tensile strength in N/mm2after curing for		
		Sand	GGBS	7 Days	14 Days	28 Days
1	CM0	100%	0%	2.5	3.1	3.95
2	M10	90%	10%	2.1	2.97	3.42
3	M20	80%	20%	2.53	3.43	4.12
4	M30	70%	30%	2.22	3.4	3.85
5	M40	60%	40%	2.1	3.15	3.45
6	M50	50%	50%	1.96	2.8	3.15

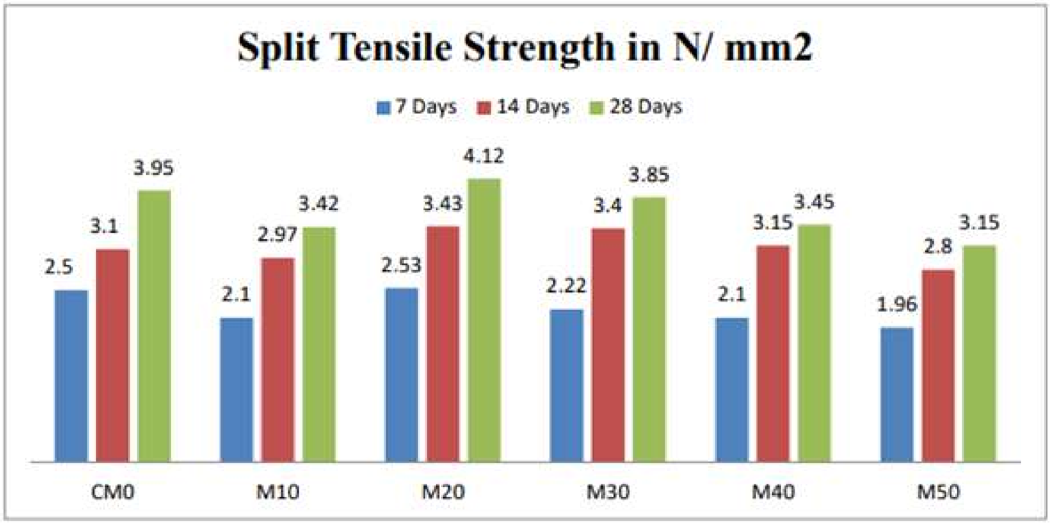

Figure 2 Graph of Split Tensile Strength of Concrete Cube

Table 4 Experimental test results on prisms

S. No.	Mix Name	Fine aggregate		Flexural strength in N/mm2 after curing for		
		Sand	GGBS	7 Days	14 Days	28 Days
1	CM0	100%	0%	3.2	4.5	5.
2	M10	90%	10%	3.2	4.8	5.
3	M20	80%	20%	3.3	4.9	5.
4	M30	70%	30%	3.4	5.1	5.
5	M40	60%	40%	3.1	4.7	5.
6	M50	50%	50%	2.9	4.1	4.

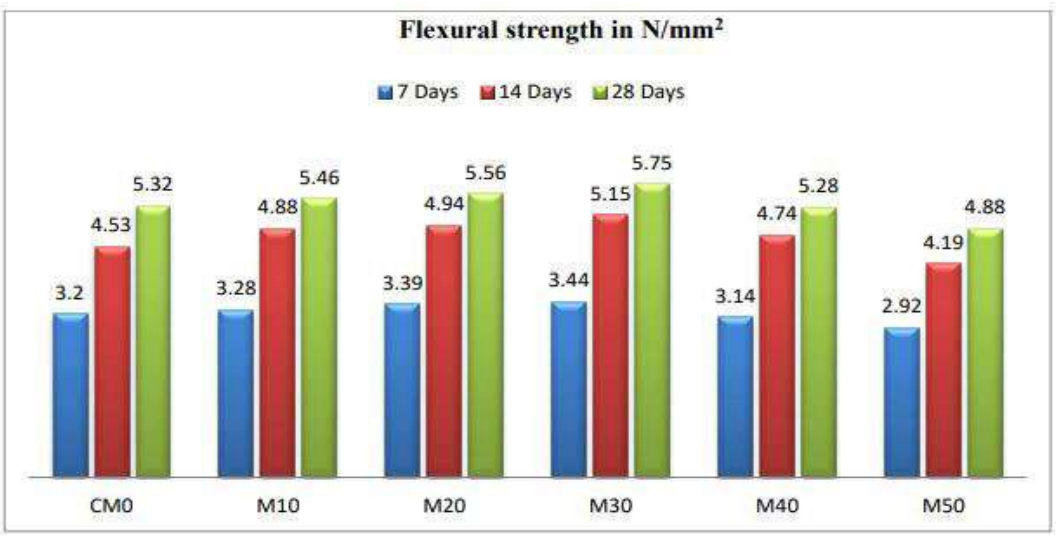

Figure 4.8 Graph of Flexural Strength of Concrete Cube

CONCLUSION

General In this experimental study, the GGBS industrial waste was utilised to replace the river sand partially in concrete. 30% GGBS imparted concrete specimens showed higher characteristic strengths than conventional specimens. In addition to that, the GGBS used cube specimens possess more resistance against acid attack and heat than conventional cube specimens. Also the GGBS used beam elements performed well in ultimate load bearing strength and elastic behaviors than the conventional concrete elements. 5.2 Specimen Testing The mean compressive, split tensile and flexural strengths of GGBS used specimens were attained higher value than the conventional specimens after 7 days, 14 days and 28 days water curing. The results of 30% GGBS incorporated specimen revealed higher strength than the others. 5.2.1 Compressive Strength The mean compressive strength values after 7 days, 14 days and 28 days curing of 0%, 10%, 20%, 30%, 40% and 50% GGBS used specimens. The compressive strength values after 7 days curing for various proportions were 19.00 N/mm2, 20.10 N/mm2, 20.33 N/mm2, 20.83 N/mm2,19.28 N/mm2and 18.00 N/mm2; after 14 days curing were 28.00 N/mm2, 29.45 N/mm2, 30.67 N/mm2, 31.33 N/mm2, 28.50 N/mm2and 26.42 N/mm2and after 28 days curing were 34.50 N/mm2, 35.50 N/mm2, 37.60 N/mm2, 36.80 N/mm2, 32.70 N/mm2and 30.52 N/mm2. It shows that the compressive strength increased up to 30% and for further increment in replacement, the strength decreased. The mean compressive strengths of conventional (0% GGBS) and 30% GGBS used specimens were 31.50N/mm2and 37.50 N/mm2. 30% GGBS used cube specimen possesses 19.05% more compressive strength than the conventional specimen. It achieved maximum compressive strength when there is partial replacement of fine aggregate with GGBS (10%, 20%, and 30%). But the 28 days strength of partial replaced concrete is maximum for 30%. 5.2.2 Split Tensile Strength The mean split tensile strength values of cylinder specimens after 7 days, 14 days and 28 days curing of 0%, 10%, 20%, 30%, 40% and 50% GGBS used specimens were tabulated in Table 4.3 and plotted in graph as shown in Figure 4.6. The split tensile strength values after 7 days curing were 2.50 N/mm2, 2.10 N/mm2, 2.53 N/mm2, 2.22 N/mm2, 2.10 N/mm2 and 1.96 N/mm2; after 14 days curing were 3.10 N/mm2, 2.97 N/mm2, 3.43 N/mm2, 3.40 N/mm2, 3.15 N/mm2 and 2.80 N/mm2 and after 28 days 39 curing were 3.95 N/mm2, 3.42 N/mm2, 4.12 N/mm2, 3.85 N/mm2, 3.45 N/mm2 and 3.15 N/mm2. It shows that there was an increase in the split tensile strength up to 30% and further replacement caused the decrement in strength. The mean split tensile strengths of conventional (0% GGBS) and 30% GGBS used specimens were 3.35 N/mm2 and 3.85 N/mm2. 30% GGBS used cylinder specimen possess 14.92% higher split tensile strength than the conventional one. 5.2.2 Flexural Strength The mean flexural strength values of prisms after 7 days, 14 days and 28 days curing of 0%, 10%, 20%, 30%, 40% and 50% GGBS used specimens were tabulated in Table 4.3 and plotted in graph as shown in Figure 4.8. The flexural strength values after 7 days curing were 3.20 N/mm2, 3.28 N/mm2, 3.39 N/mm2, 3.44 N/mm2, 3.14 N/mm2 and 2.92 N/mm2; after 14 days curing were 4.53 N/mm2, 4.88 N/mm2, 4.94 N/mm2, 5.15 N/mm2, 4.72 N/mm2and 4.19 N/mm2and after 28 days curing were 5.32N/mm2, 5.46N/mm2, 5.66 N/mm2,5.74 N/mm2, 5.28 N/mm2and 4.88 N/mm2. It shows that the flexural strength increased up to 30% replacement and on further increment in replacement, the strength decreased. The mean split tensile strengths of conventional (0% GGBS) and 30% GGBS used specimens were 5.32 N/mm2and 5.74 N/mm2. 30% GGBS used prism possess 7.89% higher characteristic strength than the conventional. The maximum flexural strength afetr 28 days of curing for partial replacement of fine aggregate with GGBS be achieved by 10%, 20% and 30% is found to be greater than the conventional concrete. The results of this experimental study prove that the inclusion of 30% GGBS waste from washing process unit helps in increasing the characteristic strength of concrete specimens. The inclusion of GGBS controls the deformation and enhances its flexural behaviours. The GGBS used specimens like cube, cylinder and prism showed more strength than the conventional specimens. The elastic properties of GGBS used specimens are more effective than the conventional specimens. The economy of concrete is effective when GGBS is used in place of river sand and reclamation of landfills. From these experimental results, it is concluded that 30% GGBS used specimens possess more characteristic strengths. The loss of weight and compressive strength of cube specimens after immersion in acid is very less when compared to conventional specimens. The study of acid resistance and heat resistance tests prove that the inclusion of GGBS in concrete increases the durability of concrete. 40 Hence it is concluded that GGBS

Industrial waste from washing process unit can be used in place of river sand in concrete. So optimum Percentage of Replacement is 30%

REFERENCE

1. Abhilash P, S. C. (2017 Jul;4(7)). Evaluation of Performance of Geopolymer Concrete in Acid Environment. International Research of Engineering and Technology (IJRET).
2. Albidah A, A. M.-S. (2021 Jan 1). Characteristics of metakaolin-based geopolymer concrete for different mix design parameters. Journal of Materials Research and Technology, 10:84-98.
3. Azad, N. M. (2021). Utilization of industrial by-products/waste to manufacture geopolymer cement/concrete. Sustainability. 13(2), 873.
4. Favier, A, Habert, G, D'Espinose, JB, De Lacailerie & Roussel, N. 2013, 'Mechanical properties and compositional heterogeneities of fresh geopolymer pastes' Cement and Concrete Research, vol. 48, pp. 9-16.
5. Geetha, S & Ramamurthy, K 2013, 'Properties of geopolymerised lowcalcium bottom ash aggregate cured at ambient temperature', Cement and Concrete Composites, vol. 43, pp. 20-30.
6. Ghafoor, M. T. (2021). Influence of alkaline activators on the mechanical properties of fly ash based geopolymer concrete cured at ambient temperature. Construction and Building Materials 273, 121752.
7. Kenne Diffo, B, Elimbi, A, Cyr, M, Dika Manga, J, Tchakoute & Kouamo, H 2015, 'Effect of the rate of calcination of kaolin on the properties of metakaolin-based geopolymers', Journal of Asian Ceramic Societies, vol. 3, no. 1, pp. 130-138.
8. Khalil MG, E. F.-F.-S. (2020 May). Performance of geopolymer mortar cured under ambient temperature. Construction and Building Materials. , 10;242:118090.
9. Khanna, P. K. (2017, November). Study on the compressive strength of fly ash based geo polymer concrete. IOP Conference Series: Materials Science and Engineering). IOP Publishing., Vol. 263, No. 3, p. 032032.
10. Kumar P, P. C. (2018 Jan). Study of mechanical and microstructural properties of geopolymer concrete with GGBS and Metakaolin. Materials Today: Proceedings, 1;5(14):28127-35.
11. Kumar P, P. C. (2018 Jan). Study of mechanical and microstructural properties of geopolymer concrete with GGBS and Metakaolin. Materials Today: Proceedings, 1;5(14):28127-35.
12. Lavanya, B. P. (2020). "Properties of geopolymer bricks made with flyash and GGBS. In IOP Conference Series: Materials Science and Engineering, vol. 872, no. 1,IOP Publishing, p. 012141
13. Lloyd, N. A. (2010). Geopolymer concrete: A review of development and opportunities. 35th conference on Our World In Concrete & Structures, Singapor.
14. Nath, P. &. (2015). Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition. Construction and Building materials, 66, 163-171.
15. Patankar, S. V. (2015). "Mix design of fly ash based geopolymer concrete. In Advances in Structural Engineering: Materials Springer India,, Volume Three, pp. 1619-1634. 43
16. Poloju KK, A. S. (2023 Mar). Analysis of Rheological Characteristic Studies of FlyAsh-Based Geopolymer Concrete. Buildings. 20;13(3):811.
17. Poloju, K. R. (2020). A study on effect of alkaline activator on strength properties of geopolymer concrete. International Journal of Engineering Research and Management (IJERM) ISSN, , pp.2349-2058.
18. Shahmansouri, A. A. (2020). Compressive strength prediction of eco-efficient GGBSbased geopolymer concrete using GEP method. Journal of Building Engineering 31, 101326.

19. Venkatesan, R. P. (2016). Strength and durability properties of geopolymer concrete made with ground granulated blast furnace slag and black rice husk ash. KSCE Journal of Civil Engineering 20, 2384-2391.

20. Vignesh, P. a. (2015). An experimental investigation on strength parameters of flyash based geopolymer concrete with GGBS. International Research Journal of Engineering and Technology 2, no. 2, 135-142.