

DURABILITY STUDY ON GEOPOLYMER CONCRETE MADE WITH GROUND GRANULATED BLAST FURNACE SLAG AND BLACK RICE HUSK ASH

KALADI DURGA PRASAD¹, G.TEJA²

¹ Student, ²Assistant Professor
Civil Engineering Department, HITE

Abstract:

Concrete remains the most widely utilized construction material globally. However, the primary binding agent in concrete—Ordinary Portland Cement (OPC)—has been associated with numerous environmental drawbacks. Concurrently, vast amounts of industrial and agricultural by-products with inherent cementitious characteristics are routinely generated and often discarded in landfills. Utilizing these waste materials as cement alternatives offers substantial environmental, economic, and sustainability advantages, including effective waste management. A notable alternative that eliminates the use of OPC entirely is Geopolymer Concrete (GPC)

The concept of "geopolymers" was introduced by Davidovits in 1978 to define a class of mineral-based binders created through a polymerization process involving an alkaline activator and a silica- and alumina-rich source material. These source materials can be naturally occurring, such as metakaolin, or industrial/agro-industrial by-products like fly ash, ground granulated blast furnace slag (GGBS), silica fume, and rice husk ash. The alkaline solution typically comprises sodium or potassium hydroxide and their corresponding silicates. GPC has demonstrated enhanced mechanical strength and improved durability over traditional concrete

Among agro-industrial residues, Black Rice Husk Ash (BRHA) is produced by incinerating rice husks and contains a high silica content (approximately 90%) but also retains significant unburnt carbon, which limits its conventional use in construction. Despite this, some studies suggest that incorporating BRHA into concrete can improve its durability. However, to date, no research has thoroughly explored BRHA's application within geopolymer concrete systems.

This study aimed to develop GPC mixtures utilizing both GGBS (an industrial waste) and BRHA (an agro-industrial by-product) as primary materials. GGBS was used as the main binder for the reference mix, while BRHA was introduced as a partial replacement for GGBS in proportions of 10%, 20%, and 30% to assess its impact. A series of experimental tests were conducted to evaluate the mechanical and durability characteristics of the resulting GPC.

Keywords: GEOPOLYMER, BLAST FURNACE.

I. INTRODUCTION

Cement production is witnessing an annual growth rate of approximately 3% (McCaffrey, 2002). The manufacture of just one tonne of Ordinary Portland Cement (OPC) releases nearly an equivalent amount of carbon dioxide (CO₂) into the atmosphere. This emission primarily stems from the thermal decomposition of limestone in kilns and the significant consumption of fossil fuels during production (Roy, 1999).

Globally, cement manufacturing contributes to around 7% of total CO₂ emissions, with current annual output surpassing 1.6 billion tonnes. The process not only ranks among the most energy-intensive in the construction industry but also has a substantial ecological footprint. For every tonne of OPC produced, nearly 4 gigajoules (GJ) of energy are consumed (Mehta, 2001).

India holds the position as the world's second-largest cement producer after China, operating 137 major and 365 mini cement plants. Forecasts indicate that the country's cement output will continue to expand, with expectations of reaching 303 million metric tonnes by 2013–14, growing at an approximate Compound Annual Growth Rate (CAGR) of 12% between 2011 and 2014. The Cement Manufacturing Association (CMA) projected a national production capacity of 550 million tonnes by 2020 (Vora, 2011).

II. LITERATURE

Concrete and Its Environmental Impact

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Chemical Composition of GGBS

According to the Indian Standard IS 12089:1987, slag is defined as a non-metallic by-product primarily composed of glassy silicates and aluminates of calcium and other base elements. In blast furnaces or electric pig iron furnaces, slag forms simultaneously with molten iron. Granulated slag is produced by rapidly cooling this molten material using water, steam, or air, resulting in a granular, glass-like substance suitable for further grinding.

IS 12089 also specifies permissible limits for certain compounds in slag, including a maximum of 5.5% manganese oxide (MnO), 17% magnesium oxide (MgO), and 2% sulphide sulphur (S). The principal chemical constituents of GGBS typically include calcium oxide (CaO: 30–48%), magnesium oxide (MgO: 28–45%), aluminium oxide (Al₂O₃: 5–18%), and silicon dioxide (SiO₂: 1–18%), closely mirroring the oxide composition of OPC (Wang & Reed, 1995). Additionally, trace elements such as iron oxide (Fe₂O₃), manganese oxide (MnO), titanium dioxide (TiO₂), and sulphur trioxide (SO₃) are also present. These compositional values remain relatively stable provided the raw materials—iron ore, flux, and coke—are consistently sourced (Bye, 1999).

III. METHODOLOGY;

MATERIAL PROPERTIES:

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) conforming to the specifications of IS 12089:1987 was used as the primary binder in the production of Geopolymer Concrete (GPC). In this study, Black Rice Husk Ash (BRHA) was incorporated as a partial replacement for GGBS at varying proportions ranging from 0% to 30% by weight. The GGBS used was procured from JSW Cements Limited, Bellary, India. Its chemical composition and physical properties were evaluated in accordance with ASTM D3682-01 at SGS Laboratories, Chennai. The detailed properties of GGBS are presented in Table 3.1.

Table 3.1 — Chemical and Physical Properties of GGBS

S. No.	Property	Value
1	Silicon Dioxide (SiO ₂)	31.25 %
2	Aluminium Oxide (Al ₂ O ₃)	14.06 %
3	Ferric Oxide (Fe ₂ O ₃)	2.80 %
4	Calcium Oxide (CaO)	33.75 %
5	Magnesium Oxide (MgO)	7.03 %
6	Loss on Ignition (LOI)	1.52 %
7	Specific Gravity	2.61
8	Blaine Fineness	4550 cm ² /g

Black Rice Husk Ash (BRHA)

Black Rice Husk Ash (BRHA) was sourced from a rice mill located near Karaikudi, India. Prior to its utilization in Geopolymer Concrete (GPC) production, the ash was ground using a ball mill for 30 minutes and sieved through a 75 µm mesh, as recommended by Rashid et al. (2010). The chemical composition and physical properties of BRHA were determined in accordance with ASTM D3682-01 at SGS Laboratories, Chennai. The results are presented in Table 3.2.

Table 3.2 — Chemical and Physical Properties of BRHA

S. No.	Property	Value
1	Silicon Dioxide (SiO ₂)	93.96 %
2	Aluminium Oxide (Al ₂ O ₃)	0.56 %
3	Ferric Oxide (Fe ₂ O ₃)	0.43 %
4	Calcium Oxide (CaO)	0.55 %
5	Magnesium Oxide (MgO)	0.40 %
6	Loss on Ignition (LOI)	9.79 %
7	Specific Gravity	2.14
8	Blaine Fineness	5673 cm ² /g

The SEM images of GGBS, unground BRHA and ground BRHA are shown in Figures 3.1, 3.2 and 3.3 respectively.

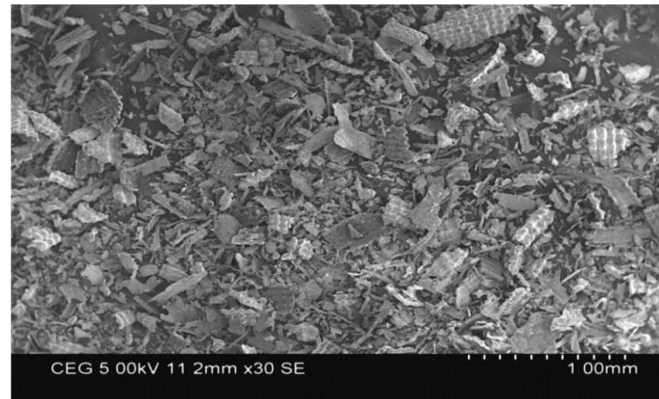


Figure 3.1 SEM image of GGBS

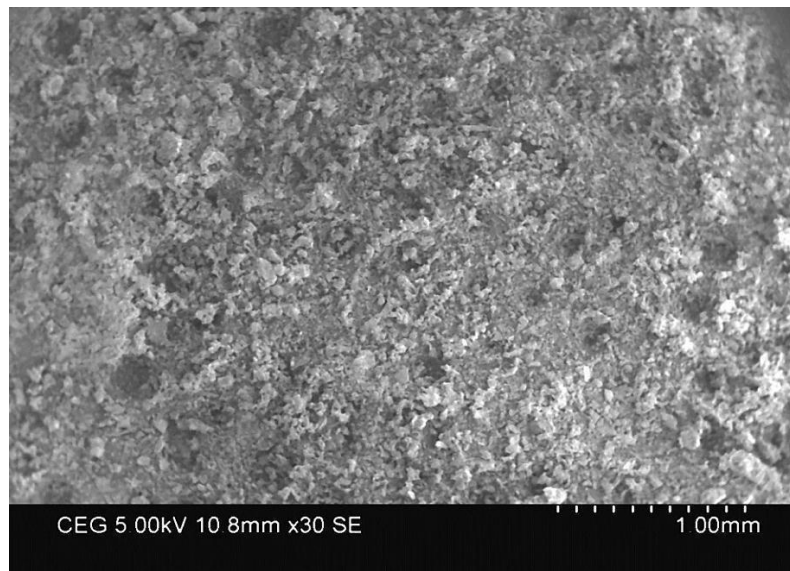


Figure 3.2 SEM image of unground BRHA

Aggregates

Natural river sand conforming to Zone II as per IS 383:1987 was used as the fine aggregate. It had a fineness modulus of 3.54 and a specific gravity of 2.61. The coarse aggregate used was crushed granite, also conforming to IS 383:1987, with a maximum nominal size of 20 mm, specific gravity of 2.72, and fineness modulus of 6.29. All aggregates were tested in accordance with IS 2386 (Part I–VIII):1963.

Alkaline Solution

The alkaline solution used for geopolymer concrete (GPC) production was a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3):

Sodium hydroxide pellets had a purity of 97–100%. Sodium silicate solution had 14.7% Na_2O , 29.4% SiO_2 (total solids: 45.4%), and 55.6% water by mass.

The alkaline liquid-to-binder ratio was fixed at 0.40, and the $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio was taken as 2.5 based on preliminary trials for optimal workability and strength. The NaOH concentration was fixed at 8 M for all tests except for the specific investigation on its influence. To enhance workability: A naphthalene-based high-range water-reducing superplasticizer was added at 2% by binder weight. Additionally, extra water at 15% of binder weight was introduced to further improve the mix fluidity.

Tests Conducted

Compressive Strength Test

The compressive strength of geopolymer concrete was evaluated in accordance with IS 516:1959. The permissible error in the results was limited to $\pm 2\%$ of the maximum load.

Several studies have addressed the influence of different parameters on GPC compressive strength. Hardjito and Rangan (2005) identified twelve key factors, among which curing temperature and sodium hydroxide concentration play critical roles. Palomo et al. (1999) concluded that curing temperature acts as a reaction accelerator in geopolymer systems, while Nazari et al. (2011) emphasized the effect of alkaline concentration on strength development.



Figure 3.4 Test setup of compressive strength

Split Tensile Strength Test

The splitting tensile strength of geopolymer concrete was evaluated in accordance with the procedures outlined in IS 5816:1999. The precision requirements of the testing apparatus were consistent with those specified in IS 516:1959.

Prismatic beam specimens of dimensions 700 mm $\times$ 150 mm $\times$ 150 mm were cast for the test. These specimens were evaluated for their flexural strength at curing ages of 3, 7, and 28 days. The testing was conducted using a calibrated Universal Testing Machine (UTM), under a two-point loading arrangement until failure. The ultimate load was recorded and used for computing the flexural strength of each specimen



Figure 3.5 Test setup of split tensile strength

Flexural Strength Test

The flexural strength of the geopolymer concrete (GPC) specimens was determined in accordance with IS 516:1959. The permissible deviation in applied load was restricted to within $\pm 0.5\%$ of the measured value, as stipulated by the standard.



Figure 3.6 Test setup of flexural strength

IV. RESULTS AND DISCUSSION

Table 4.1 Compressive strength of GPC at different NaOH concentrations

S. No	NaOH concentration	Mix	Average compressive strength (MPa)			
			3 days	7 days	28 days	90 days
1.	5 M	GP	56.2	60.5	62.7	65.5
		GPR1	58.9	61.4	62.9	66.1
		GPR2	39.9	41.4	43.3	45.4
		GPR3	17.8	18.6	19.1	21.0

2.	8 M	GP	60.9	66.5	69.3	72.5
		GPR1	62.3	67.6	70.7	73.2
		GPR2	44.7	46.3	51.5	54.1
		GPR3	19.2	20.5	22.5	24.1
3.	11 M	GP	67.1	72.1	74.3	77.4
		GPR1	69.1	75.1	76.8	80.0
		GPR2	49.5	54.5	56.6	59.5
		GPR3	21.4	22.8	23.4	25.7

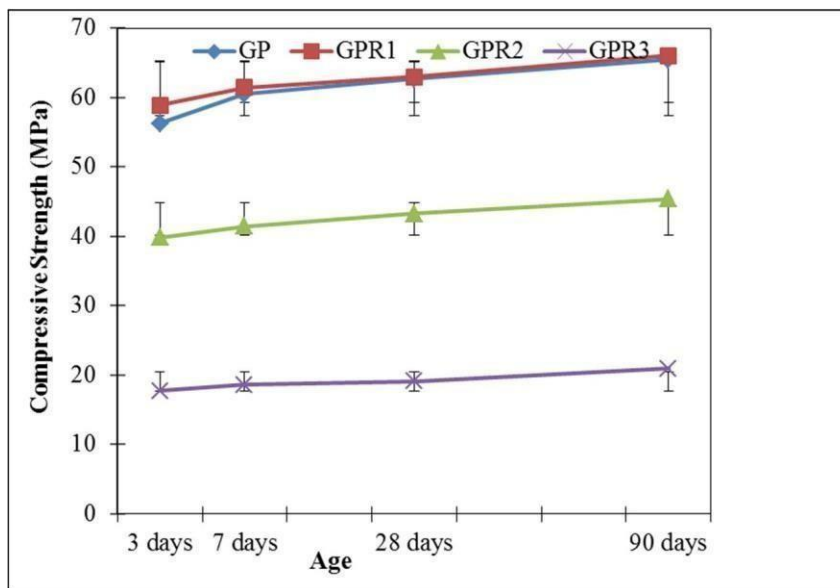


Figure 4.1 Compressive strength of GPC at 5 M NaOH concentration

Table 4.2 (Continued)

S. No	Curing temperature	Mix	Average compressive strength (MPa)			
			3 days	7 days	28 days	90 days
2.	60°C	GP	60.9	66.5	69.3	72.9
		GPR1	62.3	67.6	70.7	74.0
		GPR2	44.7	46.3	51.5	53.2
		GPR3	19.2	20.5	24.5	25.8
3.	90°C	GP	63.0	66.2	71.6	73.7
		GPR1	64.5	67.4	72.3	75.1
		GPR2	42.7	47.2	52.7	53.9
		GPR3	10.4	12.9	16.1	16.5

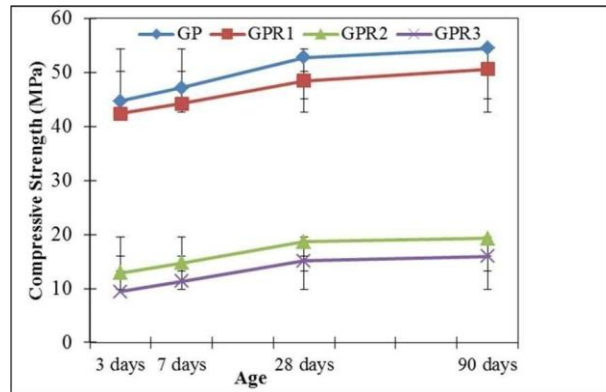


Figure 4.4 Compressive strength of GPC cured at ambient temperature

Compressive strength of GPC cured at 90°C

An increasing trend in compressive strength was clearly observed with the rise in curing temperature. For the control mix (GP), specimens cured at 60°C demonstrated a strength improvement of approximately 36%, while those cured at 90°C exhibited a 41% enhancement compared to samples cured at ambient temperature. Similarly, for the 10% BRHA replacement mix (GPR1), the strength gain was 45% at 60°C and 54% at 90°C over ambient conditions. For the 20% BRHA mix (GPR2), oven curing at both 60°C and 90°C resulted in nearly triple the strength compared to ambient-cured counterpart

V.CONCLUSIONS:

1. The study confirms that geopolymer concrete (GPC) incorporating ground granulated blast furnace slag (GGBS) and bagasse rice husk ash (BRHA) can achieve considerable strength and durability characteristics.
2. Increasing the sodium hydroxide (NaOH) molarity led to a noticeable improvement in compressive strength, with enhancements ranging from 10% to 18% as the molarity increased from 5 M to 11 M.
3. Oven curing proved more effective than ambient curing, significantly improving strength performance. Under ambient conditions, compressive strengths reached up to 53 MPa for GGBS-only mixes and around 40 MPa for mixes with 10% BRHA replacement.
4. When comparing ambient curing to curing at 60°C, a strength enhancement of 45% was observed for the 10% BRHA mix (GPR1), while the 20% BRHA mix (GPR2) showed almost a threefold increase.
5. Raising the curing temperature to 90°C yielded only modest additional strength, indicating that 60°C oven curing is preferable for GPC mixes containing BRHA.
6. Strength declined when BRHA content exceeded 10%. However, with up to 20% replacement, the compressive strength still surpassed the target value of 30 MPa, reaching as high as 51 MPa at 28 days.

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