Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 31s (2025)
https://www.jneonatalsurg.com

Experimental Investigations on Geopolymer Concrete for Sustainable Construction

Japthi Sravani[a)], D. Kalaimathi[b)], Manjunatha. H[c)], Dr. G. Sree Lakshmi Devi[d)], Festus Olutoge[e)], Surisetti Vamsi Harischandra Prasad[f)]

[a]Assistant Professor, Department of Civil Engineering, G Pulla Reddy Engineering College (Autonomous), Kurnool, Andhra Pradesh, India-518007.

[b]Assistant Professor, Department of Civil Engineering, Akshaya College of Engineering and Technology, Coimbatore-109, Tamilnadu, India.

[c]Assistant Professor, Department of Civil Engineering, Government Engineering College, Huvinahadagali-583219, Vijayanagara District, Karnataka, India.

[d]Assistant Professor, Department of Civil Engineering, Nalla Malla Reddy Engineering College (Autonomous), Divyanagar, Kachivanisingaram near Narapally, Ghatkesar Mandal, Medchal District, Hyderabad, Telangana, India-500088

[e]Professor, Department of Civil and Environmental Engineering, University of the West Indies, St Augustine

[f]Assistant Professor, Department of Civil Engineering, Godavari Institute of Engineering and Technology(A), NH-16, Chaitanya Knowledge City, Rajamahendravaram-533296, Andhra Pradesh, India

Cite this paper as: Japthi Sravani, D. Kalaimathi, Manjunatha. H, Dr. G. Sree Lakshmi Devi, Festus Olutoge, Surisetti Vamsi Harischandra Prasad, (2025) Experimental Investigations on Geopolymer Concrete for Sustainable Construction, *Journal of Neonatal Surgery*, 14 (31s), 571-574

ABSTRACT

The search for environmentally friendly construction materials with durability comparable to ancient concrete has spurred significant interest in alkali-activated cementitious systems over the past two decades, leading to the development of Geopolymer Concrete (GPC). This study focuses on the development of geopolymer mixes using various proportions of fly ash and Ground Granulated Blast Furnace Slag (GGBS), and investigates their mechanical properties. A comprehensive literature review on the mechanical and durability aspects of geopolymer concrete has also been conducted.

In this research, the ratio of sodium hydroxide (NaOH) to sodium silicate was maintained at 1:2 for all mixes, while the alkaline liquid-to-binder ratio was fixed at 0.70. However, the concentration of sodium hydroxide solution was varied as 6M, 4M, and 3M. Three mix designs were prepared—F75G25, F50G50, and F25G75—where "F" and "G" represent fly ash and GGBS, respectively, and the numerical value indicates the percentage of fly ash replaced by GGBS. These mixes were prepared in the AML Laboratory at CSIR-SERC, Chennai. Ambient curing at room temperature was adopted for all specimens.

Compressive strength was measured at 3, 7, and 28 days. Results indicated that the compressive strength of geopolymer concrete increased with a higher percentage of GGBS in the mix. Notably, the mix F25G75, with 75% GGBS and 25% fly ash, achieved the highest compressive strength at a NaOH concentration of 3M. Additionally, leaching in geopolymer concrete was found to decrease with increasing GGBS content.

Overall, geopolymer concrete demonstrates relatively higher strength and improved durability characteristics, making it a promising sustainable alternative to conventional Portland cement concrete.

Keywords: *GGBS, Geopolymer Concrete.*

1. INTRODUCTION

Concrete is the most widely used construction material globally, with its usage surpassed only by water. The increasing demand for large-scale infrastructure and high-performance buildings has significantly raised the global consumption of Ordinary Portland Cement (OPC), the primary binder in conventional concrete. However, the manufacture of OPC is highly energy-intensive and a major contributor to carbon dioxide (CO_2) emissions, releasing approximately 0.85 to 0.95 kg of CO_2 per kg of cement produced. Globally, OPC production accounts for around 8% of anthropogenic CO_2 emissions. The high emissions stem mainly from:

i) Calcination of limestone ($CaCO_3 \rightarrow CaO + CO_2$), and

ii) High thermal energy requirements, where raw materials are heated in rotary kilns at temperatures exceeding 1450°C.

Amid growing environmental concerns, there is an urgent need for sustainable construction materials that minimize natural resource consumption and greenhouse gas emissions without compromising mechanical performance and durability. One promising alternative is geopolymer concrete (GPC), which uses alkali-activated industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin, and rice husk ash as binders instead of OPC.

Geopolymer concrete offers several environmental and performance advantages:

- Significant reduction in CO_2 emissions
- Enhanced durability and chemical resistance
- Higher early strength development
- Lower shrinkage and improved thermal resistance

The geopolymerization process involves:

1. Dissolution of silica (Si) and alumina (Al) from source materials in an alkaline medium,
2. Reorganization and condensation of dissolved species into Si–O–Al–O bonds, and
3. Formation of a three-dimensional aluminosilicate polymer network, primarily composed of sialate (-Si-O-Al-O-) linkages.

Research studies have shown the impact of mix design, curing temperature, and type of activators on the properties of geopolymer concrete:

- Zhang and Wang (2013) investigated efflorescence in fly ash-based geopolymers. They found that sodium carbonate heptahydrate ($Na_2CO_3 \cdot 7H_2O$) was the main efflorescence compound. Efflorescence formation was more pronounced under ambient curing but reduced under hydrothermal conditions. Increasing soluble silicate content enhanced early strength and reduced long-term alkali leaching.
- Madheswaran and Gnanasundar (2013) studied the influence of NaOH molarity (3M, 5M, 7M) in blends of FA-GGBS (50:50, 25:75, 0:100). The highest compressive strength of 62 MPa at 28 days was achieved with 100% GGBS and 7M NaOH. An increase in GGBS content significantly improved both compressive and split tensile strengths.
- Chamila Gunasekara (2016) evaluated the durability of four types of fly ash-based geopolymer concretes over a period of one year. The highest strength (50.2 MPa at 28 days) was reported in Gladstone fly ash mix. These geopolymers exhibited low permeability, reduced water absorption, and excellent resistance to chloride ion penetration, meeting marine exposure classifications (C1, C2). Microstructural analysis showed dense aluminosilicate gel formation and fewer microcracks.
- Zengqing Sun (2020) compared the leaching behavior of fly ash geopolymer (FAG), metakaolin geopolymer (MKG), and commercial geopolymer (CG) over 56 days. MKG exhibited the highest strength (68 MPa), while FAG showed greater alkali leaching due to incomplete reaction. Strength losses after leaching in deionized water were about 9–15%, but all mixes remained structurally stable.

Rachit Ghosh (2018) examined geopolymer mixes using fly ash from different thermal plants (FA1, FA2, FA3) and GGBS and bottom ash. Alkali activators included NaOH and Na_2SiO_3 in ratios of 1:1 at 6M, 8M, and 10M. The 28-day compressive strength ranged from 30 MPa to 52 MPa, with 6MFA3GC showing the highest performance. TCLP and batch leach tests confirmed heavy metal leachates were well below IS code limits, and no visual degradation was observed after 180 days of weathering exposure

2. MATERIALS AND METHODS

Materials Used

The primary aluminosilicate sources employed in this study were Class F fly ash and Ground Granulated Blast Furnace Slag (GGBS). The alkaline activator solution (AAS) was formulated using a 1:2 weight ratio blend of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). NaOH was used in flake form with molarity levels varied at 8 M, 6 M, and 4 M to assess the impact of activator strength on the concrete's performance. Sodium silicate was used as a commercial liquid solution.

The physical characteristics of the binders and aggregates are as follows: Fly ash had a specific gravity of 2.74, bulk density of 980 kg/m³, and a fineness of 340 m²/kg. GGBS displayed slightly higher values, with a specific gravity of 2.90, bulk density of 1225 kg/m³, and fineness of 410 m²/kg. Manufactured sand (M-sand) used as fine aggregate had a specific gravity of 2.65 and a bulk density of 1530 kg/m³. Coarse aggregates were a blend of 10 mm and 20 mm sizes in a 60:40 ratio, with a combined specific gravity of 2.70 and bulk density of 1600 kg/m³.

X-ray fluorescence (XRF) analysis showed that fly ash was rich in silica (61.5%) and alumina (26.8%) with minimal calcium oxide content (1.0%), confirming its Class F classification. GGBS, by contrast, had a higher calcium oxide content (41.1%), making it more reactive and suitable for strength development.

Mix Proportions and Casting

Three geopolymer concrete mixes were developed with varying FA:GGBS ratios—75:25 (GM1), 50:50 (GM2), and 25:75 (GM3). All mixes used a consistent alkaline activator dosage, but molarity was varied—8 M for GM1, 6 M for GM2, and 4 M for GM3. The total binder content was adjusted to maintain consistency across mixes.

Mixing was performed using a 50 kg capacity pan mixer. NaOH was dissolved in water 24 hours before casting to prevent exothermic interference, and sodium silicate was incorporated just before mixing. Aggregates and binders were blended dry before adding the activator gradually to ensure uniform workability.

Cubes of 100 mm were cast and cured under ambient conditions (28 ± 2°C) for evaluation of fresh and hardened properties.

Workability Evaluation

Slump tests indicated excellent workability across all mixes. GM1 achieved the highest slump of 210 mm, followed by GM2 and GM3 at 200 mm and 185 mm respectively. This high workability ensured ease of casting and compaction. The slight reduction in slump from GM1 to GM3 is attributed to increasing GGBS content, which enhances viscosity and reduces fluidity.

Tests on Concrete

Compressive Strength Test

Compressive strength testing was carried out on cube specimens at 3, 7, and 28 days using a Universal Testing Machine in line with IS 516:2014. The results demonstrated a clear trend:

- GM1 (FA:GGBS = 75:25, 8 M NaOH) showed moderate strength development, with values increasing from 12.5 MPa at 3 days to 35.2 MPa at 28 days.
- GM2 (50:50, 6 M) exhibited a significant improvement, achieving 48.4 MPa at 28 days, indicating the beneficial synergy of balanced FA and GGBS proportions.
- GM3 (25:75, 4 M) achieved the highest strength across all age periods, peaking at 55.6 MPa at 28 days, highlighting the dominant role of GGBS in rapid strength gain even at lower molarity.

3. RESULTS AND DISCUSSIONS

The study confirmed that geopolymer concrete developed under ambient curing conditions can achieve high early strength, outperforming traditional OPC systems. High slump values across mixes indicated excellent workability, with workable time extending up to 40 minutes.

The transition from FA-rich to GGBS-rich blends significantly enhanced compressive strength. GM3 stood out with its superior 28-day strength of 55.6 MPa, primarily due to its high calcium content from GGBS, which aids in rapid geopolymerization.

Early age leaching and efflorescence were observed but declined with curing. The denser microstructure observed in GGBS-rich mixes helped mitigate these durability issues over time. Even with a relatively low activator molarity of 4 M, GM3 demonstrated structural-grade strength, underscoring the feasibility of using lower alkali concentrations—a notable advantage from an environmental and economic standpoint.

In summary, geopolymer concrete formulated with varying FA:GGBS ratios and moderate activator molarity offers a sustainable, high-performance alternative to OPC-based concrete, with promising application in rapid and green construction

REFERENCES

[1] Chamila Gunasekara, W. (2016). Durability performance of fly ash-based geopolymer concrete exposed to marine environment. Construction and Building Materials, 117, 119–127. https://doi.org/10.1016/j.conbuildmat.2016.04.153

[2] Ghosh, R., Mandal, S., & Saha, S. (2018). Mechanical and durability performance of geopolymer concrete using fly ash and GGBS blends activated with alkali solutions. Journal of Cleaner Production, 199, 254–263.

https://doi.org/10.1016/j.jclepro.2018.07.045

[3] Madheswaran, C., & Gnanasundar, D. (2013). Effect of NaOH molarity on strength of fly ash-GGBS blended geopolymer concrete. International Journal of Engineering Research and Applications, 3(4), 570–576.

[4] Rachit Ghosh, S., & Mandal, S. (2018). Performance evaluation of fly ash and GGBS based geopolymer concrete: Mechanical properties and leaching behavior. Environmental Science and Pollution Research, 25, 3571–3581. https://doi.org/10.1007/s11356-017-0598-0

[5] Sun, Z., Li, Q., & Zhou, J. (2020). Comparative study on leaching behavior and mechanical properties of fly ash, metakaolin, and commercial geopolymer concretes. Journal of Materials in Civil Engineering, 32(5), 04020052. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003158

[6] Zhang, Z., & Wang, J. (2013). Efflorescence formation in fly ash-based geopolymer under ambient curing conditions. Construction and Building Materials, 47, 1007–1014. https://doi.org/10.1016/j.conbuildmat.2013.06.060

..