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Structural Performance of Fly Ash-GGBS Based Geopolymer Concrete Beams and Columns Under Loading

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Abstract:

By drastically lowering carbon emissions, geopolymer concrete which uses industrial waste materials offers a sustainable substitute for traditional Ordinary Portland Cement (OPC) concrete. The mechanical and structural characteristics of geopolymer concrete made of fly ash and ground granulated blast furnace slag (GGBS) under ambient curing are evaluated in this work. Sodium hydroxide solutions at concentrations of 8M, 10M, and 12M were used to activate different ratios of fly ash and GGBS. Compressive strength, split tensile strength, flexural strength, modulus of elasticity, stress-strain behavior, and structural performance of reinforced concrete beams and columns were all evaluated experimentally. Compressive strength increased by 84%, from 28.5 MPa for a 100% fly ash mix (GPC-1) to 52.6 MPa for the optimized combination (GPC-4), according to the results. Split tensile strength increased from 2.6 MPa to 4.4 MPa (≈69% increase), whereas flexural strength increased from 4.1 MPa to 6.8 MPa (≈66% increase). Beam testing revealed an improvement of about 54% in stiffness, with deflection at 90 kN decreasing from 11.5 mm (GPC-1) to 5.3 mm (GPC-5). In a similar vein, stress-strain measurements showed that a larger GGBS content caused a peak stress increase of almost 71%, from 30.5 MPa to 52.3 MPa. Increasing GGBS percentages improved axial load-carrying capacity, according to column testing. 25% fly ash and 75% GGBS made up the composition that achieved the optimal balance between strength and structural performance. This work supports the viability and sustainability of ambient-cured fly ash-GGBS geopolymer concrete for structural applications, lowering CO_2 emissions and encouraging environmentally friendly building techniques.

Keywords: Geopolymer Concrete, Fly Ash, GGBS, Ambient Curing, Structural Behavior, Sustainable Construction.

1. Introduction

Geopolymers are a novel building material with significant environmental benefits that is mostly derived from agricultural and industrial waste. By reducing the amount of OPC in concrete by up to 70%, these materials such as fly ash and rice husk ash (RHA) significantly cut energy use and CO_2 emissions. One ton of CO_2 is produced for every ton of OPC produced, accounting for 5-7% of the world's greenhouse gas emissions. Alternatives like geopolymer concrete are becoming more popular because of their ability to reduce emissions, especially in light of the projected increase in OPC production to over five billion metric tons [1-2].

Geopolymers are inorganic, aluminosilicate-based binders that are created when silica and alumina-rich source materials react chemically with an alkaline activator (sodium hydroxide and sodium silicate). In contrast to conventional cement hydration, this process known as geopolymerization creates a three-dimensional polymeric network that offers remarkable strength, low permeability, and longevity [3-4]. Three steps make up the geopolymerization process: dissolution, which breaks down alumino-silicate minerals; polymerization, which creates chains and networks; and hardening, which forms the gel into a dense matrix [5-6].

Based on interactions between alkaline activators and alumino-silicate ingredients, geopolymer concrete is a sustainable substitute for OPC concrete. Fly ash and GGBS, which supply essential components for the geopolymeric binder, are the main constituents. Because of its exceptional mechanical qualities, the environmental advantages such as lower carbon emissions and efficient waste utilization have sparked a lot of interest, especially for structural applications [7-9].

The type and composition of the source materials have a significant impact on the efficacy of geopolymer concrete. While GGBS improves early strength, fly ash is essential for long-term strength. Performance is enhanced by a well-balanced combination of the two. The molarity of the alkaline solution, the FA-GGBS ratio, the curing conditions, and the temperature during mixing and curing are important elements that affect the geopolymerization process. Desired mechanical qualities, such as durability and compressive strength, result from the ideal circumstances [10-12].

Applications for geopolymer concrete are numerous and include infrastructural components like pavements and precast goods, as well as structural elements in buildings. Because of these qualities, it can be used in fire-resistant applications, waste encapsulation, marine buildings, and harsh environments [13-14]. The study does point out that, although the majority of geopolymer systems in use today rely on heat curing, more research into ambient curing is necessary to enable more extensive applications in the building industry [15-16].

The paper offers a thorough analysis of the use of industrial waste materials, specifically FA and GGBS, as binding agents in geopolymer concrete, emphasizing their potential as environmentally friendly substitutes for traditional concrete manufacturing. It lists some industrial residues that have demonstrated effectiveness in improving the qualities of concrete, including copper slag, rice husk, and silica fume. The study highlights the environmental advantages of using these materials to lower carbon emissions linked to the use of traditional cement, which are noticeably increasing as a result of the increased demand for concrete.

The review part highlights past research and the development of conclusions about fly ash-based geopolymer concrete, starting with Hardjito and Rangan's (2005) work showing that heat curing might improve early-age strength while ambient curing presented challenges [17]. The sluggish geopolymerization processes that take place in the absence of a significant calcium concentration are framed by Davidovits's (1991) investigation of the solubility of silica and alumina compounds in fly ash [3].

Additional research has shown that adding GGBS causes issues like greater shrinkage when used in high percentages, but it also speeds up early strength and improves workability at ambient settings. For best results, a balance between FA and GGBS is advised [28].

The research outlines the requirements for successful geopolymer synthesis, such as the choice of suitable alkaline activators, curing conditions, and the chemical characteristics of the raw ingredients.

The SiO_2/Al_2O_3 ratio (2.0–3.5) and the liquid-to-material ratio affected the strength and workability of fly ash-based geopolymer concrete activated by a high-alkaline solution, according to Hardjito et al. (2004). Viscosity and performance were also significantly impacted by the concentration of sodium hydroxide (NaOH) (8–16 M) and the ratio of Na_2SiO_3 to NaOH. Strength was enhanced by curing at high temperatures (30–90°C for 6–96 hours), especially with diminishing returns after 48 hours. With a binder making about 20–25% of the overall mass, the water concentration was controlled to guarantee workability without compromising durability, showcasing GPC's promise as a low-carbon material [13].

Rangan (2008) used NaOH (8–16 M) and Na_2SiO_3 activator solutions to study low-calcium fly ash with high silicon and aluminum content (around 80% mass) [18]. Tests showed that although too much water decreased compressive strength, higher NaOH concentrations and ideal Na_2SiO_3-to-NaOH ratios increased it. Joseph and Mathew (2012) evaluated the impact of aggregate composition on GPC, concentrating on NaOH-Na_2SiO_3 activators and low-calcium fly ash. With a maximum strength of 56 MPa at a 70% aggregate content, their blends demonstrated that ideal aggregate proportions (60% to 75% by volume) increased compressive strength [24].

Using 100% fly ash and several alkali activator concentrations were emphasized by Ryu et al. (2013) [25]. With SEM and XRD analyses describing hardening mechanisms, their findings showed that increased NaOH molarity enhances early strength. Aliabdo et al. (2016) investigated the effects of water, plasticizer, NaOH content, and ratio on workability and strength as well as other parameters influencing GPC. The findings demonstrated that while more water enhanced workability, it had a negative impact on strength, with 30 kg/m3 being the optimal water content [26]. Assi et al. (2016) investigated fly ash sources and activating solutions and found that certain fly ash had significant structural benefits, whereas silica fume increased compressive strength more than Na2SiO3 [27]. To find the best GPC formulations, Chithambaram et al. (2018) experimented with several materials and curing conditions. According to their testing, the highest compressive strength (42.5 MPa at 28 days) was obtained using a 76% aggregate blend and 12 M NaOH at 90°C [27].

Ge et al. (2023) monitored the long-term evolution of fly ash GPC's compressive strength over a four-year period, noting strength growth from 47.29 MPa at 28 days to 65.54 MPa, which they attributed to ongoing geopolymerization [29]. Deb et al. (2014) evaluated the effects of GGBS content on GPC strength and found that, like OPC, increases in GGBS resulted in greater strength values [20]. In their attempt to create GPC for ambient curing, Nath and Sarker (2014) discovered that ambient-cured fly ash GPC with GGBS minimized environmental impact while achieving strengths comparable to OPC [21].

In the evaluation of alkali-activated fly ash-slag concrete, Fang et al. (2018) found that while development decreased after 28 days, strength increased with increasing slag concentration [22]. According to Lee et al. (2019), GPC produced under various curing conditions attained high compressive strengths, with particular ratios producing the best outcomes [25]. By combining different ratios of GGBS with fly ash, Bhikshma and Kumar (2014) were able to achieve compressive strengths that showed mechanical characteristics similar to those of conventional concrete with additional sustainability advantages [31].

The authors highlight the greater durability and resilience to external chemical attacks of geopolymer concrete, as well as the reduced CO_2 emissions generated during its production when compared to OPC [30].

The uneven quality of waste-derived materials, long setting periods, and a lack of standards for ideal mix proportions are the main obstacles to the practical application of geopolymer technology, despite its advantages [19,23]. The introduction of GGBS-based geopolymer concrete in structural applications is urged by recent studies that demonstrate its resilience in harsh weather conditions.

Furthermore, a number of cited experimental studies demonstrate steady progress in comprehending the impact of mix design and curing techniques on the mechanical characteristics of geopolymer concrete, demonstrating that deliberate optimization of binder compositions, alkaline activator concentrations, and curing conditions results in notable performance gains.

Most people agree that fly ash and GGBS can be used as sustainable binders in concrete, however current research emphasizes that precise formulation is required to fully utilize their potential in structural engineering.

The main goals of the study are to determine the best blend for balanced performance, evaluate the impacts of alkaline activator concentration on strength, and evaluate the structural performance of ambient-cured geopolymer concrete by altering fly ash and GGBS compositions. Standard specimens and reinforced structural components are tested as part of the experimental investigations to shed light on the mechanical behaviours essential for real-world applications. In the end, this study highlights geopolymer concrete's potential as a sustainable substitute for conventional cement-based materials, opening the door for its further use in environmentally friendly building techniques.

2. Materials used

For geopolymer concrete beams and columns, the chapter describes the components, mix design procedure, specimen preparation, reinforcing, casting, curing, and testing techniques. By subjecting reinforced geopolymer concrete components to flexural and axial loads, it seeks to replicate actual structural conditions. Using experimental software, the performance is contrasted with conventional OPC concrete. In order to ensure that the results are dependable and applicable to real-world construction circumstances, the chapter focuses on the characteristics of the materials and the alkaline activator solution production method.

2.1 Flyash

In accordance with IS 3812 (Part 1) guidelines, the investigation used Class F fly ash from a coal-fired thermal power plant as the main source of aluminosilicate in the geopolymer binder system. It was excellent for geopolymerization due to its low calcium content and high silica and alumina levels, but early strength development was hampered by the slow reactivity under ambient curing conditions.

Figure 1 Flyash

Table 1 Physical and Chemical Properties of Fly Ash

Property	Value
Specific gravity	2.2
Fineness (μm)	< 45
SiO_2 (%)	59
Al_2O_3 (%)	26
CaO (%)	5
Loss on ignition (%)	< 2

2.2 GGBS

When GGBS was added as a binder, the mechanical performance of geopolymer concrete cured at room temperature improved. Through the production of calcium-aluminosilicate-hydrate (C-A-S-H) gel in addition to sodium-aluminosilicate-hydrate (N-A-S-H) gel, GGBS, an off-white powder high in calcium obtained from a steel factory, improves early-age strength. This facilitates an efficient curing process without the need for external heat by encouraging a synergistic geopolymerization process with fly ash.

Figure 2 GGBS

Table 2 Physical and Chemical Properties of GGBS

Property	Value
Specific gravity	2.85
Blaine fineness (m^2/kg)	400
CaO (%)	38
SiO_2 (%)	36
Al_2O_3 (%)	15

2.3 Fine and coarse aggregates

Natural river sand was used as fine aggregate in geopolymer concrete mixes that complied with IS 383 requirements. The sand's cleanliness, lack of impurities, and Zone II grading improved its workability and packing density. Because of its angular shape, crushed granite stone aggregate, with a maximum size of 20 mm, provided good mechanical strength when used as coarse material. Additionally, it passed structural concrete compatibility tests and complied with IS 383, which improved the geopolymer concrete's stiffness and load transfer.

Table 3 Physical Properties of Fine and Coarse Aggregates

S. No	Property	Fine Aggregate (Sand)	Coarse Aggregate	Unit
1	Specific Gravity	2.60	2.67	-
2	Bulk Density	1650	1700	kg/m^3
3	Fineness Modulus	2.6	6.0	-
4	Water Absorption	1.0	0.7	%
5	Maximum Size	4.75	20	mm

2.4 Alkaline activator solution

The alkaline activator solution, which in this study included sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), is a crucial part of the geopolymerization process. 98% pure NaOH pellets were dissolved in distilled water to create solutions with molarities of 8 M, 10 M, and 12 M. A minimum preparation time of 24 hours was required for stability. To guarantee consistent geopolymerization behaviour, the mass ratio of sodium silicate to sodium hydroxide was consistently kept at 2.5 in all mixes. The sodium silicate utilized was commercial grade and had a silica modulus of roughly 2.5.

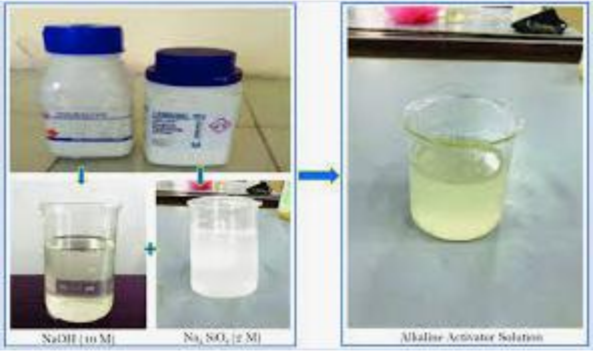

Figure 3 Alkaline Activator

2.5 Steel Reinforcement

In order to provide ductility and tensile strength, Fe500 grade reinforcing steel is used in beams and columns, enabling the study of structural behavior under loading. The steel reinforcement in this study is High Yield Strength Deformed (HYSD) bars, grade Fe 415, which are well known for their outstanding concrete bonding and high strength. With a yield strength of 415 MPa and a modulus of elasticity of 200 GPa, these bars ensure structural rigidity. The ribbed surface enhances load transfer by decreasing slippage and fortifying the steel-concrete bond. Because of its great ductility, steel can undergo considerable deformation before failing, which is crucial for safety. It reduces thermal stresses since it has a density of roughly 7850 kg/m³ and a coefficient of thermal expansion comparable to concrete. For beams to survive tensile pressures and to increase the load capacity of columns, steel reinforcing is consequently crucial.

Table 4 Mechanical Properties of Steel Reinforcement

S.No	Property	Value	Unit
1	Yield Strength	415	MPa
2	Ultimate Tensile Strength	540	MPa
3	Modulus of Elasticity	200×10^3	MPa
4	Poisson’s Ratio	0.3	-
5	Density	7850	kg/m³

2.6 Superplasticizers

To make geopolymer concrete more workable, a naphthalene-based superplasticizer that complies with IS 9103 was applied in modest amounts. Superplasticizer was especially crucial for mixtures with a higher GGBS content because these mixes typically show lower flow and quick setting. In order to achieve sufficient workability without negatively impacting the geopolymerization process, the dosage was modified.

3. Test Program

In this study, aggregate proportions, binder content, and alkaline activator concentration rather than a water-to-cement ratio—are the main elements influencing geopolymer concrete's performance, which differs from that of OPC concrete. Every geopolymer mixture kept the alkaline activator-to-binder ratio constant at 0.45 and the overall binder concentration at 400 kg/m³. Different combinations were made while keeping other factors constant in order to investigate the impact of different fly ash (FA) and ground granulated blast-furnace slag (GGBS) ratios on mechanical performance.

The following were the main factors influencing the mix proportions:
400 kg/m³ is the total binder content.
Ratio of alkaline activator to binder: 0.45The ratio of fine aggregate to total aggregate is 0.35.
The ratio of Na_2SiO_3 to NaOH is 2.5.

Sodium hydroxide (NaOH) pellets were dissolved in distilled water to create the alkaline activator solution. To avoid early reactions, the solution was allowed to cool before being combined with sodium silicate. Using a pan mixer, the aggregates were first mixed dry for two minutes. FA and GGBS were then added, then superplasticizer and the alkaline activator solution were gradually added to create a uniform mixture. A slump test was used to assess the fresh geopolymer concrete's workability.

Layers were compressed using a table vibrator after specimens for different mechanical tests were cast in oiled molds. Casting contained columns (150 mm × 150 mm × 1200 mm) reinforced with longitudinal bars and ties, and beams (100 mm × 150 mm × 1500 mm) reinforced with tension and compression bars.

In order to evaluate the practical use of geopolymer concrete in construction, specimens were covered with plastic sheets to prevent moisture loss, demolded after 24 hours, and kept at ambient laboratory conditions (27 ± 2°C) without water or external heat curing.

Figure 4 Casting and curing of specimens

Table 5 Sample details

Mix ID	FA (%)	GGBS (%)	NaOH Molarity
GPC-1	100	0	8 M
GPC-2	75	25	10 M
GPC-3	50	50	10 M
GPC-4	25	75	12 M
GPC-5	0	100	12 M

This research covered the materials, mix design, specimen preparation, and testing techniques used to evaluate the structural performance of geopolymer concrete beams and columns. The approach ensures precise comparison with conventional concrete while facilitating the practical implementation of geopolymer technology.

4. Results and discussion

Experimental results on the mechanical performance of ambient-cured geopolymer concrete composed of fly ash and ground granulated blast furnace slag are presented in this chapter. It evaluates characteristics including modulus of elasticity, flexural strength, split tensile strength, and compressive strength in relation to alkaline activator molarity and FA-GGBS ratios. With an emphasis on ultimate load, load-deflection behavior, stiffness, ductility, stress-strain response, and failure mechanisms, the performance of reinforced geopolymer concrete beams and columns under axial and flexural loading is compared to that of conventional OPC concrete. Performance changes are shown by analyzing percentage variation.

4.1 Compressive strength

The results of the compressive strength test show that, in ambient curing circumstances, the addition of GGBS greatly increases the strength of geopolymer concrete. Because geopolymerization was delayed at room temperature, the control mix with 100% fly ash (GPC-1) had the lowest strength. Strength increased by 29.1% when 25% GGBS was substituted for fly ash (GPC-2), demonstrating the advantageous calcium concentration of GGBS. In comparison to the fly ash-only mix, strength grew progressively when GGBS was substituted, reaching a peak of 84.6% in GPC-4 (25% FA + 75% GGBS). But when compared to GPC-4, the 100% GGBS mix (GPC-5) showed a 6.3% drop, suggesting that some fly ash enhances matrix densification and geopolymer gel formation, demonstrating the synergistic effect of FA and GGBS in ambient-cured systems.

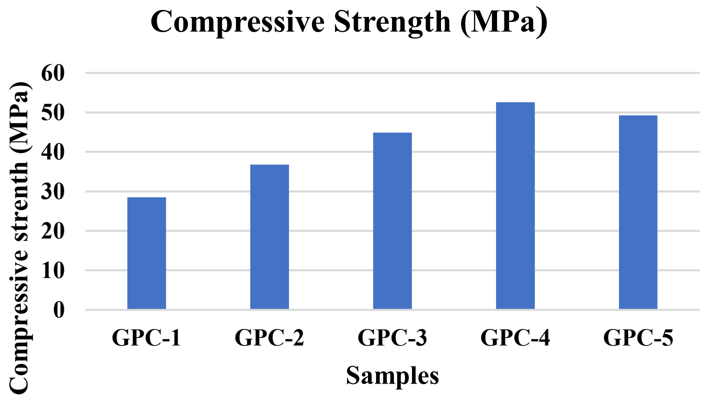

Figure 5 Compressive strength outcomes

4.2 Split tensile strength

It was exposed that the split tensile strength and compressive strength of GPC were comparable. Because of a tighter link between aggregates and the geopolymer paste, the tensile resistance increased as the GGBS percentage increased. GPC-4 showed a 69.2% increase in tensile strength over GPC-1, suggesting higher fracture resistance. When properly cured under ambient conditions, geopolymer concrete can achieve balanced tensile behavior, as seen by the split tensile to compressive strength ratio ranging from 8 to 9%.

Table 6 Split Tensile Strength Results (28 days)

Mix ID	Split Tensile Strength (MPa)	% Increase w.r.t GPC-1
GPC-1	2.6	-
GPC-2	3.2	23.1
GPC-3	3.8	46.2
GPC-4	**4.4**	**69.2**
GPC-5	4.1	57.7

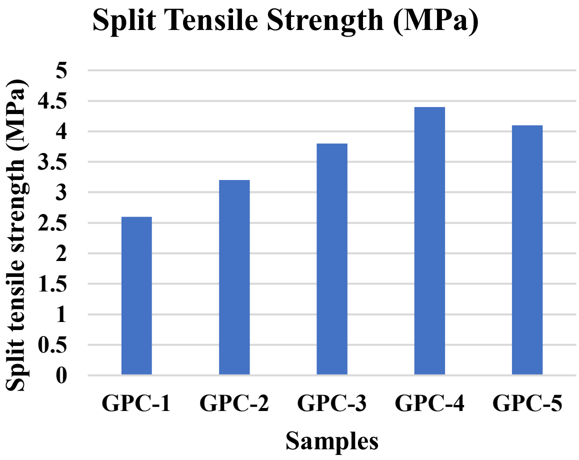

Figure 6 Split tensile strength outcomes

4.3 Flexural strength

Flexural strength was greatly enhanced by improved interfacial transition zone (ITZ) characteristics brought about by the addition of GGBS; GPC-4 demonstrated a 65.9% improvement over the fly ash control mix. The development of blended C-A-S-H and N-A-S-H gels, which improve crack-bridging ability under bending, is responsible for this advance. The 100% GGBS mixture, however, showed decreased flexural strength, indicating more brittleness.

Table 7 Flexural test results

Mix ID	Flexural Strength (MPa)	% Increase w.r.t GPC-1
GPC-1	4.1	-
GPC-2	5	22
GPC-3	5.9	43.9
GPC-4	**6.8**	**65.9**
GPC-5	6.3	53.7

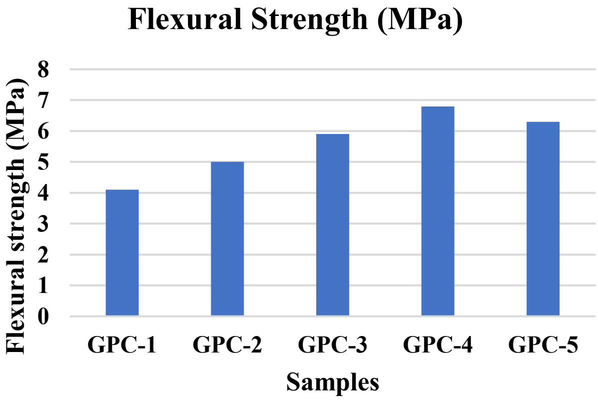

Figure 7 Flexural strength outcomes

4.4 Flexural performance of RC beams

The flexural performance of geopolymer concrete beams greatly enhanced when GGBS content reached 75% replacement. Due to slower geopolymerization, the control mix GPC-1 (100% fly ash) had the lowest flexural strength and load capacity. GPC-2, which benefited from calcium's involvement in early strength, demonstrated a 12.9% rise in ultimate load with partial GGBS replacement. With a greater GGBS content, GPC-3 showed increased matrix densification as seen by a 32.3% increase in ultimate load. With a 50% improvement in flexural strength and a 53.2% increase in ultimate load, GPC-4 (25% FA + 75% GGBS) produced the best flexural performance. GPC-5 (100%

GGBS), on the other hand, showed a 5.3% decrease in load, suggesting possible brittleness from too much calcium. These findings were reflected in deflection behavior, where GPC-4's maximum deflection was 22.7% less than GPC-1's. GPC-4 had finer, more uniformly spaced cracks than GPC-1, which had larger cracks and failed quicker. Overall, the results highlight the benefits of a well-balanced FA-GGBS combination for improving flexural behavior.

Table 8 Flexural strength of RC beams

Mix ID	First Crack Load (kN)	Ultimate Load (kN)	Max Deflection (mm)	Flexural Strength (MPa)
GPC-1	18	62	13.2	6.2
GPC-2	22	70	12.4	7.0
GPC-3	26	82	11.5	8.1
GPC-4	30	95	10.2	9.3
GPC-5	28	90	10.8	8.8

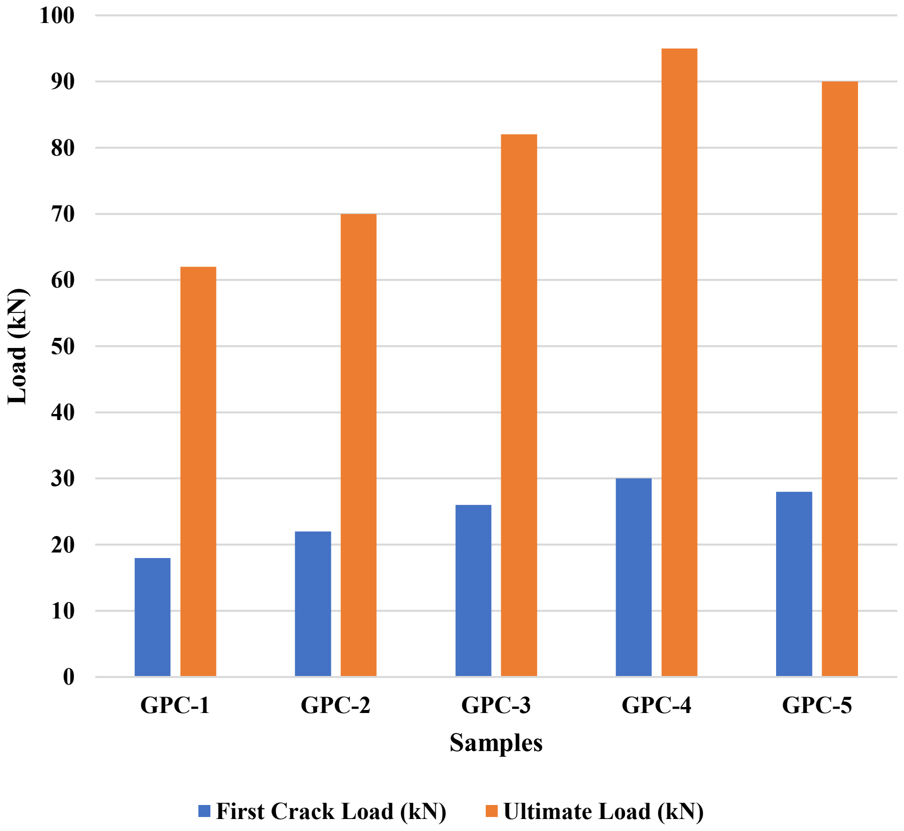

Figure 8 Graph plotted for first and ultimate loads

4.5 Load-Deflection Behavior

Geopolymer concrete beams have nonlinear load-deflection behavior; at first, they respond elastically and almost linearly, but as the stress increases, cracking results in nonlinearity. At 90 kN, the beam mix GPC-1 has the greatest deflection of 11.5 mm, showing decreased stiffness, whereas GPC-5 exhibits around 54% less deflection, at roughly 5.3 mm. With deflection reductions of 44% and 32%, respectively, GPC-4 and GPC-3 outperform GPC-1, while GPC-2 improves by 18%. Because of improved bonding and a denser microstructure from calcium-rich GGBS, increased GGBS concentration is correlated with decreased deflection, resulting in increased stiffness and load-carrying capability. These findings suggest that a larger GGBS content enhances flexural performance, which makes these beams more appropriate for structural applications.

Table 9 Load vs Deflection

Load (kN)	GPC-1 (mm)	GPC-2 (mm)	GPC-3 (mm)	GPC-4 (mm)	GPC-5 (mm)
0	0.00	0.00	0.00	0.00	0.00
10	0.45	0.38	0.32	0.28	0.25
20	0.95	0.80	0.68	0.60	0.55
30	1.60	1.35	1.15	1.00	0.90
40	2.45	2.05	1.75	1.50	1.30
50	3.60	3.00	2.55	2.20	1.90
60	5.10	4.20	3.50	3.00	2.60
70	6.80	5.60	4.60	3.90	3.30
80	8.90	7.30	6.00	5.00	4.20
90	11.50	9.40	7.80	6.40	5.30

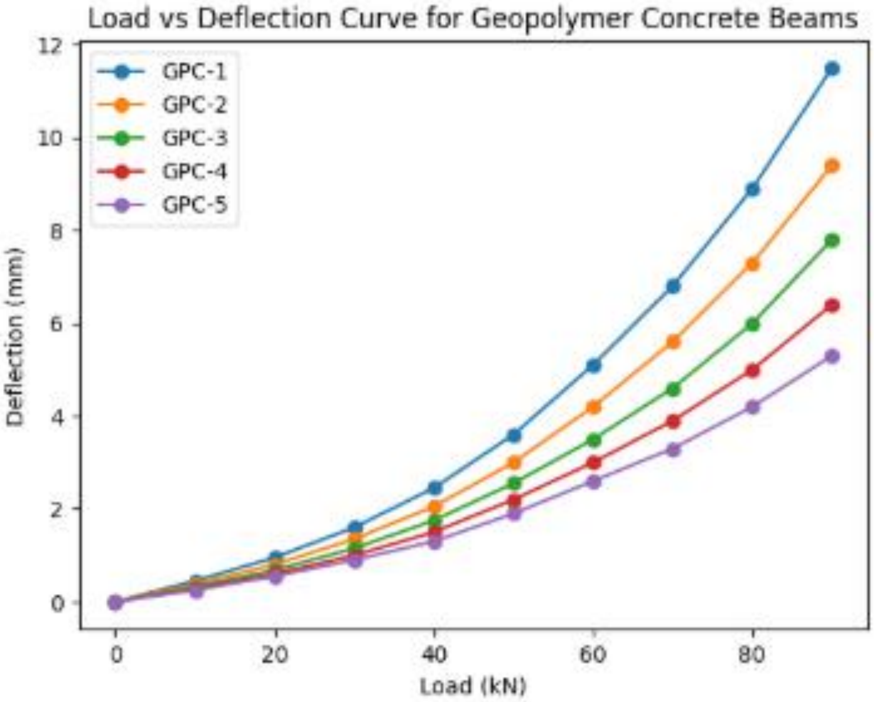

Figure 9 Load vs Deflection curve

4.6 Axial Load Behavior of Columns

The axial load-carrying capability of geopolymer concrete columns increased in proportion to compressive strength as the GGBS concentration rose to 75%. The lowest load capacity was found in the control mix GPC-1. Ultimate load increased by 20.5% in mix GPC-3 and 10.3% in mix GPC-2. GPC-4 outperformed GPC-1 by 38.5%. GPC-5, however, saw a little decline of 5.6%, suggesting possible brittleness at elevated GGBS levels. Furthermore, deformation decreased from 4.8 mm (GPC-1) to 3.8 mm (GPC-4), demonstrating the substantial impact of binder content on the axial performance of geopolymer concrete, with GPC-4 signifying the optimal ratio of stability to strength.

Table 10 Axial Performance of GPC Columns

Mix ID	Ultimate Load (kN)	Deformation (mm)	Compressive Strength (MPa)
GPC-1	780	4.8	28.5
GPC-2	860	4.5	36.8
GPC-3	940	4.2	44.9
GPC-4	1080	3.8	52.6
GPC-5	1020	4.0	49.3

4.7 Stress-Strain Behavior Discussion

An initial linear elastic zone is followed by a nonlinear plastic region in geopolymer concrete's nonlinear stress-strain relationship, which ultimately results in failure. Because of its increased calcium content, which promotes geopolymerization and C-A-S-H gel formation, GPC-5, with 100% GGBS and 12M molarity, obtains the maximum peak stress of 52.3 MPa, above GPC-1's 30.5 MPa. Significant improvements in peak stress are also seen in GPC-4 and GPC-3, suggesting that while higher molarity facilitates alumino-silicate dissolution for increased strength, increased GGBS contributes to improved stiffness and load-bearing capacity. GPC-4 and GPC-5 are shown to be the best options for structural applications requiring exceptional strength and stiffness, despite the post-peak stress behavior suggesting some brittleness.

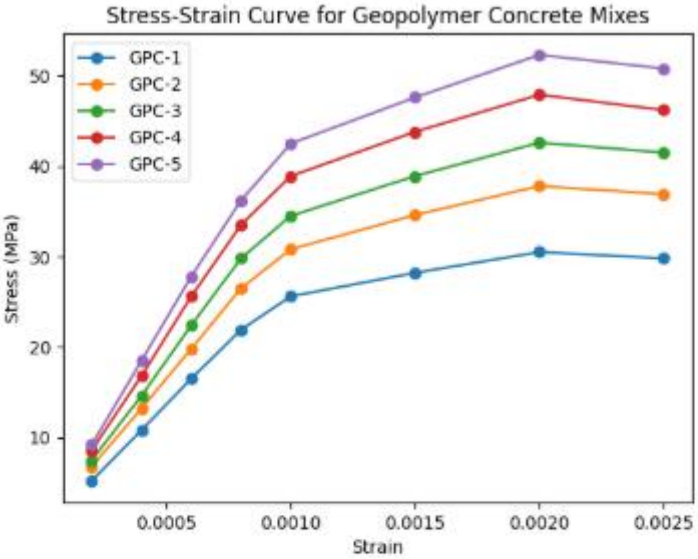

Figure 10 Stress-Strain graph

5. Conclusions

As a sustainable substitute for OPC concrete, ambient-cured FA-GGBS geopolymer concrete, which is derived from industrial waste, exhibits outstanding mechanical performance. In addition to producing notable increases in split tensile and flexural strengths, the ideal combination of 25% fly ash and 75% GGBS increases compressive strength by 84–85%. This mix is appropriate for reinforced structural components because it provides improved stiffness, deformation properties, and load-carrying capacity. Although utilizing 100% GGBS may result in decreased performance due to brittleness, higher GGBS levels increase early-age strength and stiffness. Fly ash and GGBS work together to produce a thick microstructure that lowers CO_2 emissions and promotes environmental sustainability. All things considered; this study highlights the practicality of ambient-cured geopolymer concrete in building.

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