An Experimental Investigation of Fiber Reinforced Geopolymer Concrete Beams

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Abstract- *Geopolymer concrete (GPC), synthesized from industrial by-products like fly ash and GGBS activated with alkaline solutions (NaOH and Na₂SiO₃), offers a sustainable alternative to conventional Portland cement concrete (CC). This study investigates the flexural behaviour of M25 grade reinforced concrete beams, comparing conventional and geopolymer matrices with and without hybrid fibers under static loading. Eight full- absorption. This improved performance is attributed to the synergistic action of glass and steel fibers within the GPC matrix, enhancing strength, crack resistance, and deformability. Beam specimens of size(150 × 250 mm cross-section, 1500 mm span) were tested: (B1) CC M25, (B2) CC + GF, (B3) GPC M25with 8M, (B4) GPC + GF. Beams were subjected to two-point loading; instrumentation included load cells and LVDTs. Key performance metrics included crack load, ultimate load, deflections, ductility, toughness, and energy absorption. The hybrid geopolymer mix (B4) outperformed all others, showing a 2.50% increase in compressive strength and 10.75% in flexural strength over B1. It achieved a ductility index of 16.42, toughness index of 14.59, and 23.004% higher energy*

***Keywords*- (CC) Conventional concrete,(GPC)Geopolymer Concret,(GF)Glassfiber,(8M)8molarity, GGBS, FLYASH, Cement, Compressive strength, flexural strength**

I. INTRODUCTION

Concrete is widely used in construction due to its strength and availability, but poor quality concrete remains a major cause of building collapse in developing countries like Nigeria. Key factors such as aggregate size, mix ratio, and cement grade significantly affect concrete's workability and strength. Despite established standards, on-site practices often involve inaccurate volume batching and inconsistent material selection(1). Geopolymer concrete (GPC), an eco-friendly alternative to conventional concrete, is synthesized using industrial by-products like Ground Granulated Blast Furnace Slag (GGBS) and activated with alkaline solutions. Although GPC offers excellent strength and durability, it remains inherently brittle. To address this, fibre reinforcement is employed to improve ductility and post-cracking behavior.

This study explores the flexural performance of geopolymer concrete reinforced with hybrid fibres. Unlike continuous reinforcement, these discrete fibres are randomly distributed, helping control crack propagation and enhance load-bearing capacity. The research focuses on evaluating the effectiveness of hybrid fibre reinforcement in improving the flexural strength of GPC beams under ambient curing conditions.(2). Glass fiber, made from fine strands of glass, is a cost-effective material with high strength, flexibility, and chemical resistance. When added to concrete, it helps improve mechanical properties such as strength and crack resistance. Unlike other fibers like carbon or polymer, glass fiber offers similar performance at a lower cost and with reduced brittleness. Research shows that incorporating 0% to 1.6% glass fiber into concrete can significantly enhance its mechanical behavior, making it a valuable additive for sustainable and durable construction.(3). Flexural strength is a crucial property that measures a concrete beam's ability to resist bending and cracking under load. In geopolymer concrete (GPC), this test helps assess its structural viability compared to conventional concrete. This study focuses on evaluating the flexural performance of GPC, especially when enhanced with hybrid fibers.(4).

1.1 EXPERIMENTAL INVESTIGATION

This experimental investigation focuses on the structural behavior of reinforced concrete beams under flexural loading. The study aims to assess the load-bearing capacity, deflection characteristics, cracking patterns, and failure modes of beams fabricated with different material compositions or reinforcement strategies. Standardized beam specimens were cast and cured, followed by testing under a two-point or three-point loading system using a universal testing machine or hydraulic actuator. Parameters such as span-to-depth ratio, reinforcement details, concrete grade, and curing conditions were carefully controlled. Load-deflection data were recorded, and the results were compared with theoretical predictions or code-based calculations to evaluate performance improvements. The outcomes of this investigation provide critical insights into the structural efficiency and applicability of alternative materials.

1.2 MATERIAL AND MIXES

The concrete mix in this investigation comprises a blend of cement, fly ash, and ground granulated blast furnace slag (GGBS) as the primary binders. An alkaline activator solution, typically a combination of sodium hydroxide and sodium silicate, is used to initiate the geopolymerization process when applicable. Superplasticizers are added to enhance workability and flowability of the mix without increasing water content. Coarse aggregates and fine aggregates, such as crushed stone and M sand respectively, provide the necessary strength and bulk to the mix, ensuring proper compaction, durability, and structural integrity.

Table -1: Mix Designations

Mixes	Designation
MIX 1	M-25
MIX 2	M-25+GF
MIX 3	GPC-8M
MIX 4	GPC-8M+GF

1.3 MIX PROPORTION

FOR ONE BEAM

- Cement=21.3Kg/m^3
- Fine aggregates = 48.81 Kg/m^3
- Coarse aggregate = 83.19 Kg/m^3
- Glass Fiber=0.03 Kg/m^3
- Flyash=12.9 Kg/m^3
- GGBS=19.4 Kg/m^3
- Coarse aggregate(GPC)=87 Kg/m^3
- Fine aggregates(GPC)=35.9 Kg/m^3
- Sodium hydroxide(NaOH)=2.98 Kg/m^3
- Sodium Silicate(Na$_2$SiO$_3$)=7.6 Kg/m^3

II. TESTING PROCEDURE

2.1 STATIC TEST SETUP FOR BEAMS

The experimental setup involves testing beam specimens under flexural loading using a bending testing machine with a capacity of approximately 30 tons (300 kN). A load of up to 25 tons (245 kN) is applied during testing. Prior to testing, all beam specimens are whitewashed to facilitate the clear marking of cracks. The beams are then placed on a loading frame supported by two rollers of 30 mm diameter— one fixed and the other free to rotate—maintaining an effective span of 1300 mm. The beams are subjected to two-point loading, applied through two additional rollers (also 30 mm in diameter) placed 300 mm apart at the center of the

span. The entire testing is conducted on a loading frame with a capacity of approximately 500 kN, and load is applied using a 200 kN hydraulic jack. A seating load is initially applied to ensure proper contact between the specimen and all attachments. Load is then incrementally applied at 2.5 kN intervals. At each interval, deflection is measured using dial gauges or LVDT sensors. Observations such as the first crack load, ultimate load, and crack patterns are recorded. The loading continues gradually until the final failure of the beam specimens is observed.
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III. RESULT AND DISCUSSIONS

3.1 COMPRESSIVE STRENGTH

Compressive strength tests were performed on standard cube specimens of size $150 \times 150 \times 150$ mm for all mix variations. The specimens were tested after curing periods of 3, 7, and 28 days to evaluate the strength development over time. The compressive strength values obtained for each mix at these intervals are summarized in the table below.

Table -2 : Summary of 3, 7and 28 days Compressive Strength of Test Specimens

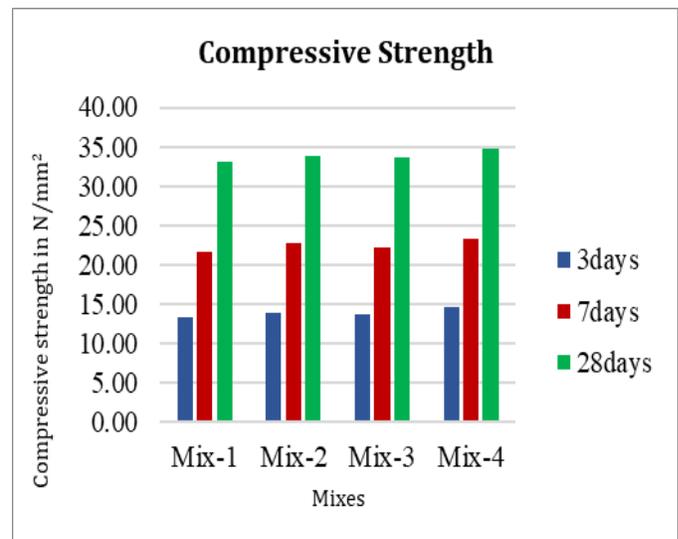| Mixes	Compressive Strength in N/mm^2		
	3 days	7 days	28 days
MIX 1	13.25	21.53	33.13
MIX 2	13.86	22.70	33.73
MIX 3	13.71	22.15	33.61
MIX 4	14.24	22.80	34.65

Chart -1: Comparison of Compressive Strength with Age of different concrete matrices

3.2 FLEXURAL STRENGTH

Flexural strength tests were conducted on beam specimens with dimensions of $100 \times 100 \times 500$ mm. During testing, the maximum load at failure was recorded for each specimen. Using this data, the flexural strength was calculated in accordance with standard procedures. The flexural strength values obtained for all concrete mixes are summarized in the table below.

Table -3: Summary of 3,7and 28 days Flexural Strength of Test Specimens

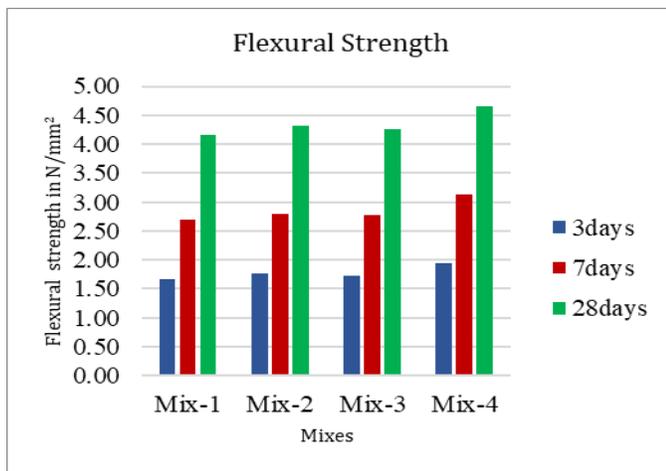| Mixes	Flexural Strength in N/mm^2		
	3 days	7 days	28 days
MIX 1	1.66	2.69	4.15
MIX 2	1.77	2.80	4.31
MIX 3	1.73	2.77	4.25
MIX 4	1.95	3.12	4.65

Chart -2: Comparison of Flexural Strength with Age of different concrete matrices

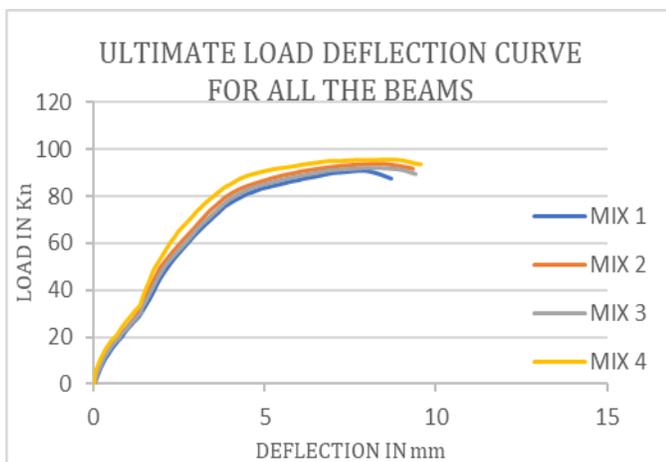## 3.3 RESULTS OF ULTIMATE LOAD DEFLECTION CURVE

CHART-3: LOAD DEFLECTION CURVE UPTO ULTIMATE LOAD

Load–deflection curves provide critical insight into the structural response of beam specimens under applied loads. They are particularly useful for evaluating behavior within the service load range and identifying the working load limit. For all beam specimens tested in this study, the corresponding load–deflection curves have been plotted and presented in the form of graphs.

3.4 FIRST CRACK LOAD

This is the load at which the first visible crack appears on the surface on the beam due to development of tensile stresses.

Table-4:Experimental and theoretical valves of first crack load

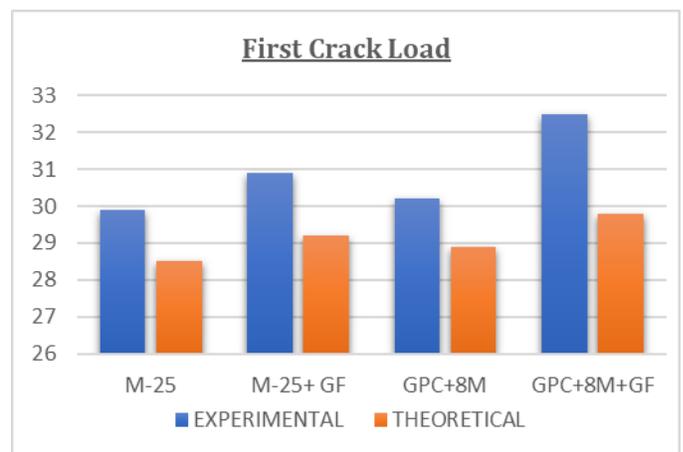| Designations	Theoretical first crack load (kN) - T	Experimental first crack load (kN) - E
MIX 1	29.9	28.5
MIX 2	30.9	29.2
MIX 3	30.2	28.9
MIX 4	32.5	29.8

CHART-4: FIRST CRACK LOAD

3.5 ULTIMATE LOAD

The term "ultimate strength" refers to the maximum internal resistance a structural member can develop against external loads, often associated with either peak stress capacity or the onset of material rupture. These two conditions may not coincide, but both indicate the load at which failure occurs.

Table-5:Experimental and theoretical valves of Ultimate load

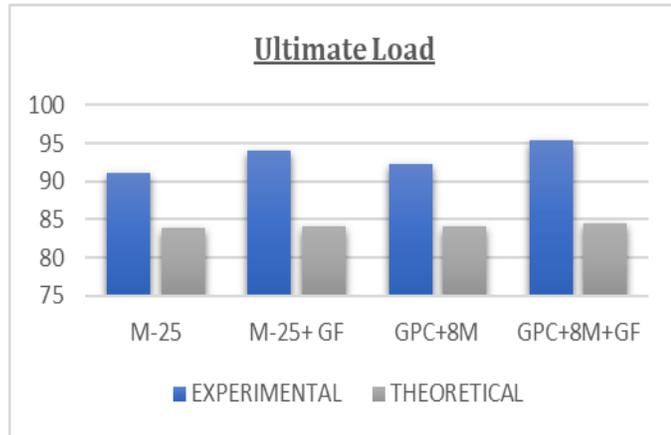| Designations	Theoretical Ultimate load (kN)	Experimental Ultimate load (kN)
MIX 1	91.07	83.98
MIX 2	94.1	84.17
MIX 3	92.3	84.03
MIX 4	95.36	84.58

CHART-5: ULTIMATE LOAD

3.6 DUCTILITY INDEX

The ductility index of a beam is a measure of its ability to undergo significant plastic deformation before failure. It is an important factor in structural engineering, particularly in seismic design, where structures need to absorb and dissipate energy through large deformations without collapsing.

Table-6: Ductility Index

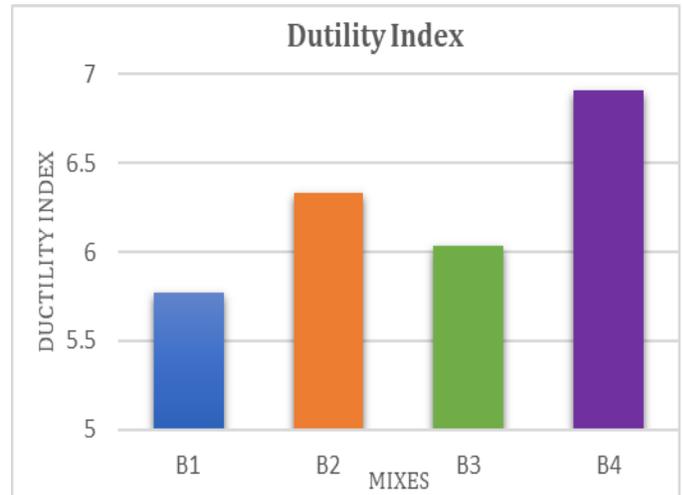| Designation	Ultimate Deflection (mm)	Yield Deflection (mm)	Ductility Index
MIX 1	7.85	1.36	5.77206
MIX 2	8.29	1.31	6.32824
MIX 3	8.09	1.34	6.03731
MIX 4	8.84	1.28	6.90625

CHART-6:DUCTILITY INDEX

3.7 TOUGHNESS INDEX

Table-6: Toughness Index

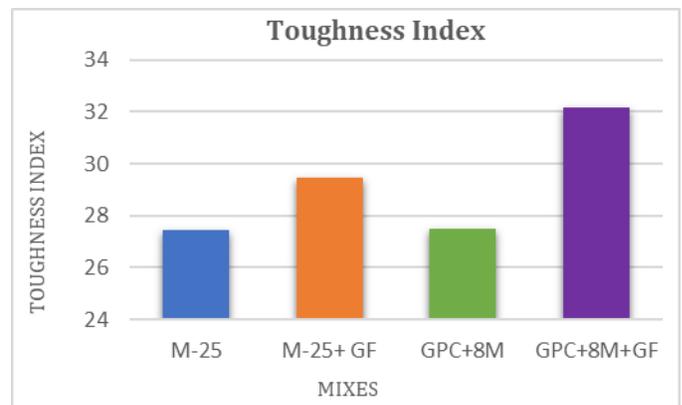| Designation	Area under curve upto 0.8 Pu (kN-mm)	Area under curve upto first crack load (kN-mm)	Toughness Index
MIX 1	583.21	23.329	24.99
MIX 2	669.72	24.167	27.71
MIX 3	661.97	24.051	27.52
MIX 4	744.113	25.878	30.85

CHART-6:TOUGHNESS INDEX

3.8 ENERGY ABSORPTION CAPACITY

The energy absorption capacity of various concrete mix beams under examination was calculated by calculating the area under the load deflection curve.

Table-7: Energy Absorption Capacity

Designations	Energy Absorption Capacity (kN-mm)
MIX 1	583.21
MIX 2	669.72
MIX 3	661.97
MIX 4	798.46
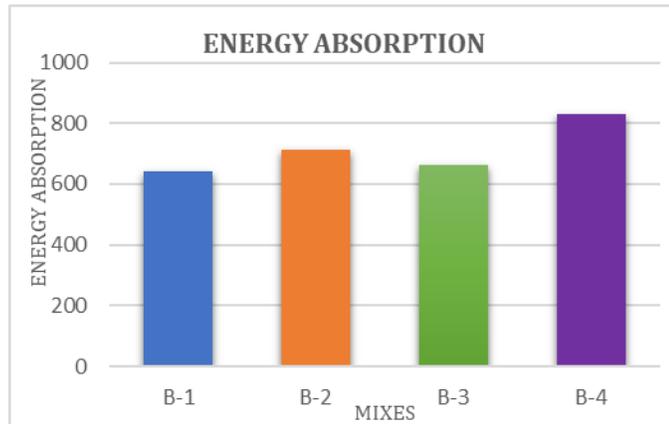
CHART-7:ENERGY ABSORPTION CAPACITY

IV. CONCLUSIONS

1. The compressive strength is increased in mix 4 from mix 1 upto 4.38% for 28 days.
2. The flexural strength is increased in mix 4 from mix 1 upto 10.75% for 28 days.
3. The first crack load is increased in mix 4 from mix 1 upto 4.36%.
4. The ultimate load is increased in mix 4 from mix 1 upto 0.709%.
5. The ductility index is increased in mix 4 from mix 1 upto 16.376%.
6. The toughness index is increased in mix 4 from mix 1 upto 18.99%.
7. The energy absorption capacity is increased in mix 4 from mix 1 upto 26.958%.

This study investigated the behavior of geopolymer concrete reinforced with glass fibers. The inclusion of hybrid fibers significantly improved structural performance by delaying crack initiation and transforming failure behavior from brittle to ductile, enabling better load redistribution. These enhancements make fiber-reinforced geopolymer concrete well-suited for applications such as seismic-resistant structures, bridge decks, and blast-resistant components. The dense matrix formed through polymerization reduced shrinkage and permeability, contributing to durability. An 8M NaOH solution was found optimal for achieving a balance between workability and reactivity, resulting in a uniform, compacted mix.

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