Experimental Studies On Axial Compression Strength Of Geopolymer Concrete And Conventional Concrete Columns

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Abstract- *The high carbon emissions and energy consumption associated with Ordinary Portland Cement (OPC) have prompted the development of sustainable alternatives in the construction sector. Geopolymer Concrete (GPC), incorporating industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS), presents an eco-efficient substitute for conventional concrete. This study investigates the axial compression performance of GPC columns, with and without glass fiber reinforcement, in comparison to M40-grade OPC concrete columns. Four mix series were designed: C-1 (M40), C-2 (M40 with glass fiber), C-3 (GPC with 10M), and C-4 (GPC with 10M and glass fiber), each measuring 1300 × 225 × 150 mm. Among these, Mix C-4 showed superior mechanical properties, with a 4.39% and 8.07% increase in compressive and flexural strength, respectively, compared to C-1. Additionally, C-4 achieved a 3.64% higher axial compressive strength than C-1. Stress-strain analysis under axial loading demonstrated improved ductility and load-bearing capacity due to the inclusion of glass fibers. The results confirm that fiber-reinforced GPC, particularly with 10M, is a structurally reliable and environmentally sustainable alternative for reinforced concrete columns.*

Keywords- Geopolymer Concrete(GPC),Ordinary Portland Cement(OPC), Axial Compression(AC), FlyAsh(FA), Ground Granulated Blast Furnace Slag (GGBS),Compressive Strength(CS), Glass fibre(GF).

I. INTRODUCTION

Ordinary Portland cement (OPC) production is energy-intensive and responsible for nearly 8% of global CO_2 emissions, posing serious environmental challenges. As the construction industry seeks sustainable alternatives, Geopolymer Concrete (GPC) has emerged as a promising solution.[1] GPC is produced using industrial by-products such as fly ash and ground granulated blast furnace slag (GGBS), which are activated by alkaline solutions to form a hardened binder without the use of conventional cement.[2]GPC offers several advantages, including reduced carbon footprint, enhanced chemical resistance, and improved durability. Moreover, studies have shown that geopolymer concrete can achieve comparable or even superior compressive strength compared to traditional OPC concrete.[3] Despite these benefits, its structural behavior, especially under axial loads in columns, requires further exploration to ensure practical applicability. [4]This study aims to experimentally evaluate and compare the axial compression strength of GPC and conventional M40-grade OPC concrete columns, including variationof glass fiber the findings will support the adoption of GPC as a viable, eco-friendly alternative in structural applications.[5]Concrete columns are fundamental structural components in buildings, primarily designed to resist axial loads. Traditionally, these columns are constructed usinggeopolymer concrete a material known for its high strength and durability.[6]

II.AIM AND SCOPE OF PRESENT INVESTIGATION

This experimental study involves casting and testing concrete columns made with both geopolymer and conventional cement mixes. The geopolymer concrete utilizes a blend of Ground Granulated Blast Furnace Slag (GGBS) and fly ash, activated using an alkaline solution (10M sodium hydroxide and sodium silicate), while the conventional mix uses OPC 53 Grade cement. Key parameters such as axial load capacity, deformation behavior, failure patterns, and compressive strength are measured. The investigation aims to understand the effectiveness of geopolymer concrete in structural applications, promote sustainable construction practices by utilizing industrial by-products, and explore the Feasibility of replacing traditional cement with environmentally friendly alternatives without compromising structural integrity.

III.MATERIALS

In this study, 53 Grade Ordinary Portland Cement (OPC) from Ramco was used, known for its high compressive strength of at least 53 MPa after 28 days. It is ideal for RCC, bridges, and precast structures, offering rapid setting and complies with IS 269:2015 standards. Class F fly ash, sourced from Cashutec Nirmithi Kendra (Raichur), is rich in silica, alumina, and iron oxides with excellent pozzolanic properties. It contributes to strength, workability, and sustainability in geopolymer concrete. Ground Granulated Blast Furnace Slag (GGBS), supplied by Ultratech RMC (PeenyaBengaluru), has a specific gravity of 2.95 and fineness above 400 m²/kg, complying with IS 16714:2018. GGBS improves durability, reduces CO_2 emissions, and enhances sulphate and chloride resistance. Manufactured sand (M-sand) passing 4.75 mm sieve with specific gravity 2.60 and 2.8% water absorption was used as fine aggregate. Alkali-resistant glass fiber (12 mm, 14 µm) at 0.03% by volume was incorporated to boost tensile strength and crack resistance. Alkaline activators (10M sodium hydroxide and sodium silicate) initiated geopolymerization. Naphthalene-based superplasticizer SP-430 (0.4% by cement weight) was added to enhance workability, reduce water content, and meet IS:9103 and ASTM C494 Type F standards.

IV.MIX DESIGN AND MIX PROPORTION

In this study, a concrete mix of M40 grade was developed using the design mix proportions based on IS 10262:2019 guidelines. The target compressive strength for M40 concrete was successfully achieved. The experimental work incorporated a 10 Molar (10M) alkaline solution, where molarity (M) refers to the number of moles of solute per litre of solution.Standard concrete cubes and prisms were cast and tested to evaluate the mechanical properties of the concrete four different mix variations were studied, and the proportions of materials were finalized through trial mixes. The adopted mix proportions for each concrete matrix are presented in this investigation.

A well-graded coarse aggregate mix of 30% 12.5 mm and 70% 20 mm enhances packing density, reduces voids, and improves concrete strength and workability. This blend minimizes segregation and shrinkage while ensuring better compaction. In this study, geopolymer concrete uses a 60% GGBS and 40% fly ash blend, offering improved durability, chemical resistance, and reduced carbon footprint. GGBS boosts early strength, while fly ash enhances workability and long-term performance. The alkaline activator, composed of sodium silicate and 10M sodium hydroxide solution, initiates geopolymerization, forming a stable aluminosilicate matrix essential for high-strength, eco-friendly concrete in aggressive environments**.**

Table 1:Mixes of the specimen

Mixes	Designation
MIX-1	M-40
MIX-2	M-40+Glass Fiber
MIX-3	GPC-10M
MIX-4	GPC-10M+Glass fiber

Table 2:Mix Proportions

Materials	CC (kg/m3)	CC+GF (kg/m3)	GPC (kg/m3)	GPC+GF (kg/m3)
Cement	372	372	-	-
Fly ash	-	-	162.9	162.9
GGBS	-	-	244	244
FA	710	710	539	539
CA	1224	1224	1291	1291
Glass fiber	---	0.3%	-	0.3%
CC-W/B	0.36	0.36	-	-
GPC-W/B	-	-	0.4	0.4
NaoH Solution	-	-	46.5	46.5
Na2SiO3 Solution	-	-	116.3	116.3

V. MOULDS PREPARATION

Steelmoulds of required dimensions were cleaned, oiled, and reinforced cages were placed accurately inside the moulds Proper cover blocks were used to maintain the clear cover (25mm).

VI. CASTING &TESTING PROCEDURE OF COLUMN SPECIMEN

The casting began by cleaning and oiling steelmoulds (1300×225×150 mm) and placing reinforcement cages with 12 mm bars and 25 mm clear cover. M40 concrete was prepared using OPC 53-grade cement, M-sand, granite aggregates, water, and superplasticizer, then compacted in layers using a needle vibrator. Geopolymer concrete (GPC) was mixed by combining fly ash, GGBS, a 10M NaOH and sodium silicate solution and superplasticizer. Four columnsCCM40, CCM40+GF, GPC10M, and GPC10M+GFwere cast. M40 specimens were water-cured for 28 days; GPC was ambient-cured. All columns were tested under axial compression using a 2000kN UTM to assess load capacity and failure behavior.
The test column measured 1300 mm in length, 225 mm in breadth, and 150 mm in depth. It was reinforced with four 12 mm diameter main bars and lateral ties spaced at 150 mm

centertocenterA clear cover of 25 mm was provided to ensure durability and proper reinforcement protection.

VII. EXPERIMENTAL PROGRAM

Compression strength testing process

The 150 mm × 150 mm × 150 mm cube is tested after 28 days to determine compressive strength. It is centrally placed in a compression testing machine, and load is applied at 140 kg/cm² per minute until failure. The strength is calculated by dividing the ultimate load by the cross-sectional area, ensuring accurate, reliable results.

Figure No 1:Compression Testing

Flexural strength testing process

Flexural strength testing of a concrete prism (500 mm × 100 mm × 100 mm) Flexural strength testing evaluates concrete's bending resistanceprism is tested after 28 days of curing using a two-point loading.Load is applied uniformly at two points Load is applied until failure, and strength is calculated using $f=P \cdot L/b \cdot d^2$andResults from three specimens are averagedThis test is crucial for assessing concrete's structural performance under flexural stress.

Figure No 2: Flexural strength

The axial compression test

The axial compression test used a 2000-ton loading frame with pinned ends, 25 mm thick plates, and proper vertical alignment. Strain gauges and dial gauges recorded strain and deformation. Load was applied in 10kN increments, observing cracks and failure. four specimens were tested identically, and results were recorded.

Figure No 3: Axial compression testing

VIII. TESTS AND RESULT

The experimental investigation compared four different concrete mixes, including conventional M40 concrete and geopolymer concrete (GPC) with varying combinations of glass fibre The primary focus was to evaluate compressive strength, flexural strength, and axial load performance of the columns.

Mechanical Properties of Concrete:

Compression Strength Test:

The results are presented in tabular form for comparative analysis of the mixes at different curing ages.

f = P/A N/mm2 Where f= is compressive strength of concrete in N/mm2
P = ultimate load at which specimen fail in Newton
A=Cross sectional area in mm2

Table 3:Summary of 3,7&28 days Compressive Strength of Test Specimen

Properties	Age in days	M-40 (N/mm2)	M40+GF (N/mm^2)	GPC-10M (N/mm^2)	GPC-10M+GF (N/mm^2)
Compressive strength	3	19.42	20.24	20.04	21.28
	7	31.56	33.15	32.37	34.08
	28	48.56	49.25	49.12	50.79

The geopolymer mix with glass fibre (mix-4) demonstrated the highest compressive strength of 50.59 N/mm², control mix (Mix-1) with 48.56 N/mm².

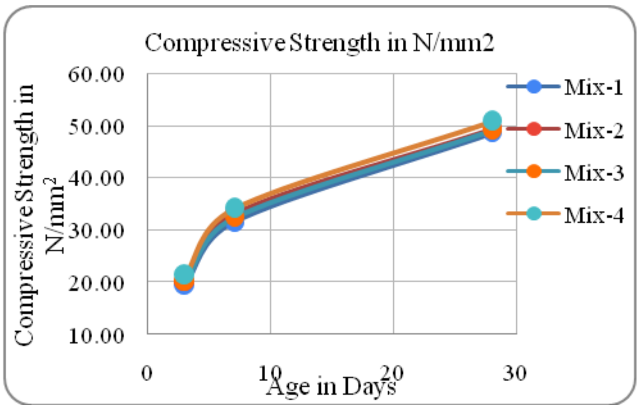

Figure 4 :Comparison of Compressive Strength with Age of different concrete matrices

Flexural strength: Flexural strength tests were carried out on prism specimens measuring 100 × 100 × 500 mm. Each specimen was properly aligned in the testing machine, and load was applied gradually until failure occurred. The maximum load at failure was recorded, and flexural strength was calculated

Table 4:Summary of 3,7&28 days flexural Strength of Test Specimen

properties	Age in days	M40-(CC) (N/mm^2)	M40-GF (N/mm^2)	GPC- 10M (N/mm^2	GPC 10M+GF (N/mm^2)
Flexural strength	3	2.00	2.15	2.11	2.28
	7	3.25	3.39	3.36	3.36
	28	5.01	5.23	5.16	5.45

The geopolymer mix with glass fibre (mix-4) demonstrated the highest Flexural strength of 5.45 N/mm², control mix (Mix-1) with 5.01 N/mm².

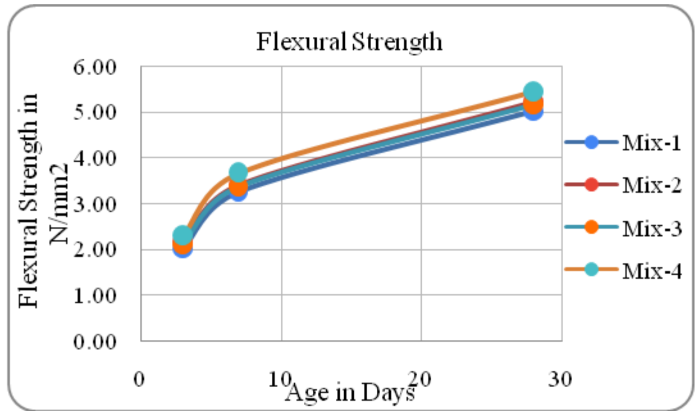

Figure 5: Comparison of flexural Strength with Age of different concrete matrices

First crack load:The initial cracking load at which the first visible crack appears on the column surface indicating the onset of compressive stress induced failure The first crack load obtained for the specimens (i)C-1(M40),(ii)C-2(M40+GF),(iii)C-3(GPC-10M),(iv)C-4(GPC-10M+GF)

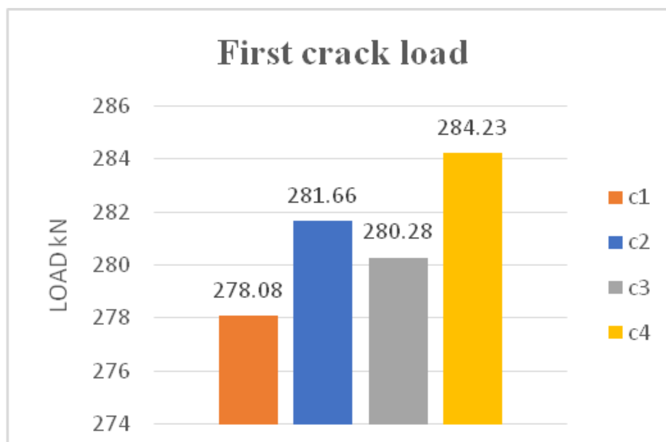

Figure 6: Comparison of first crack load

The test result shown that the crack load for the conventional concrete (C-1) is 278.08kN, (C-2) is 281.66kN, (C-3) is 280.28kN, (C-4) is 284.23kNThe percentage for different mixes with respect to conventional and geopolymer 3.04%, 3.75%, 3.88%, 4.84%

ULTIMATE LOAD CALCULATIONS

The ultimate strength of a structural member denotes the peak internal resistance it can generate against applied loads before collapsing. It reflects the maximum internal stress distribution achieved through deformation, which may or may not coincide with material rupture. This critical value marks the final load-bearing threshold that precipitates failure in the tested specimens**.**

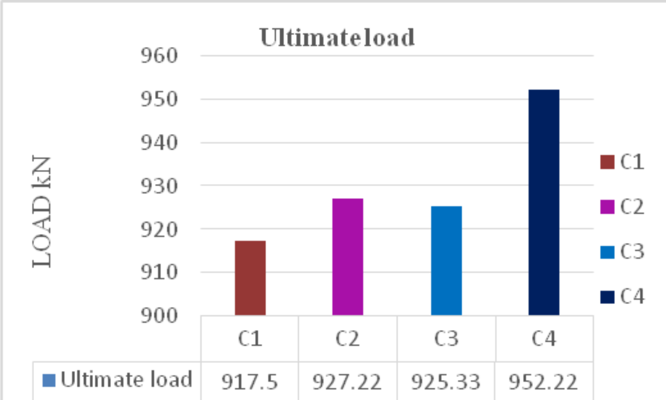

Figure 7:Ultimate load value

The ultimate load bearing capacities for the four concrete column specimens are follows C-1 is 914.22 kN,C-2 is 924.56kN,C-3 is 916.61 kN,C-4 is 947.64kN

These values represent the maximum loads sustained before failure highlighting the variation in strength among the different concrete mix combinations

Stress- Strain Behavior

The column specimens showed clear variations in the stress strain response Mix-1 (M40 OPC) 27.18N/mm^{2}and microstrain of 780.23, Mix-2(OPC+ Glass fiber) improved to 27.47N/mm^{2}and 782.95, Mix-3(GPC 10M)Reached 27.41N/mm^{2,} Mix-4(GPC 10M+Glass fiber)28.21N/mm^{2}and 791.77 these results the combined the benefit of the geopolymer matrix and fiber reinforcement in improving axial performance.

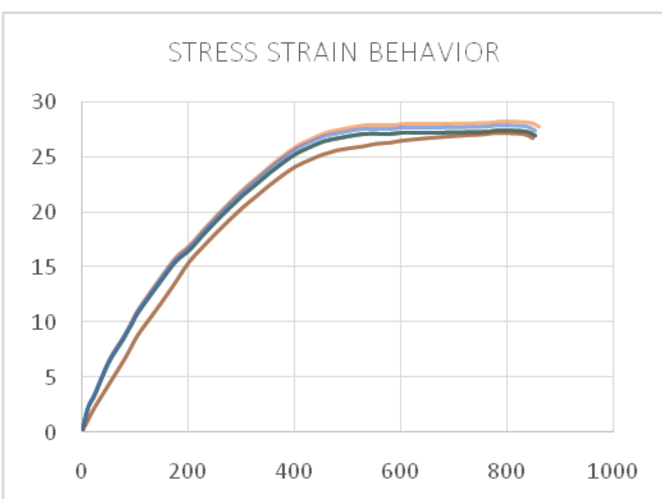

Figure 8:combination of stress strain curve

Comparison of Theoretical And Experimental Results:

Theoretical load were compared with experimental loads the T/E Ratio observed in below Table

Designation	**Theoretical failure load (kN)**	**Experimental failure load (kN)**	**T/E**
C-1	914.22	917.5	0.996
C-2	924.56	927.22	0.997
C-3	916.14	925.33	0.99
C-4	947.64	952.22	0.995

IX. CONCLUSION

1. The Compression strength of Mix-1 (M-40) is 48.56N/mm^2,Mix-2 (M40+GF) is 49.25 N/mm^2,Mix-3 (GPC-10M) is 49.12N/mm^2,Mix-4 (GPC-10M+GF) is 50.79N/mm^2.
2. The Flexural strength 0f Mix-1 (M-40) is 5.01N/mm^2, Mix-2 (Mix-2) is 5.23N/mm^2, Mix-3 (GPC-10M) is 5.16 N/mm^2, Mix-4 (GPC-10M+GF) is 5.45 N/mm^2.
3. The First crack load of Mix-1(M-40) is 278.08kN, Mix-2(M40+GF) is 281.66 kN, Mix-3 (GPC-10M) is 280.28 kN Mix-4 (GPC-10M+GF) is 284.23kN
4. The ultimate loadof Mix-1(M-40) is 917.5kN ,Mix-2 (M40+GF)927.22 kN,Mix-3(GPC-10M) IS 925.33 kN,Mix-4 (GPC-10M+GF) is 952.22 kN,

The experimental investigation demonstrates that Geopolymer Concrete (GPC), especially when reinforced with glassfibersis a sustainable and high-performing alternative to conventional M40 grade concrete. GPC columns exhibited excellent compressive strength, durability, and crack resistance under axial loads, matching or exceeding conventional concrete. Its use of industrial by-products significantly reduces environmental impact by minimizing CO_2 emissions. These findings confirm the structural reliability and eco-efficiency of GPC in real-world applications, particularly in load-bearing elements. This research encourages the adoption of GPC as a viable solution for sustainable construction, contributing to both performanceenhancement&environmentalpreservation.

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