Comparative Studies on Geopolymer Concrete And Conventional Concrete Columns Under Axial Compression

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Abstract- *Concrete remains one of the most extensively used materials in construction, with Ordinary Portland Cement (OPC) as its principal binder. However, OPC manufacturing is energy-intensive and a major contributor to global CO_2 emissions. In response to these environmental challenges, Geopolymer Concrete (GPC) has emerged as a sustainable alternative, utilizing industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS), activated by alkaline solutions. GPC not only reduces the carbon footprint but also delivers mechanical performance that is comparable to or exceeds that of conventional OPC concrete. This study investigates the axial compressive behavior of M25 grade OPC concrete and GPC activated with an 8M alkaline solution, both with and without the addition of 0.03% glass fiber (GF) by volume of concrete. Four column specimens measuring 1300 × 225 × 150 mm were cast and tested under axial loading: C-1 (M25), C-2 (M25 + GF), C-3 (GPC–8M), and C-4 (GPC–8M + GF). Among these, C-4 (GPC–8M + GF) exhibited the highest ultimate load capacity of 680.84 kN, which is 6.11% greater than the control specimen (C-1). The inclusion of glass fibers resulted in a 4.59% increase in 28-day compressive strength and a 10.75% improvement in flexural strength. Additionally, C-4 recorded the highest values for Young's modulus (29,432.15 N/mm²), stress (20.17 N/mm²), and microstrain (685.41), indicating improved stiffness and ductility. These findings demonstrate that incorporating glass fibers into GPC significantly enhances its load-bearing capacity and overall mechanical performance. Therefore, glass fiber-reinforced GPC presents a durable and eco-friendly alternative to conventional OPC concrete for structural column applications under axial compression.*

Keywords- Geopolymer Concrete, Compressive Strength, Flexural Strength, Young's Modulus, Microstrain, Stress

I. INTRODUCTION

Concrete is the most widely used construction material, with Ordinary Portland Cement (OPC) serving as its primary binder. However, OPC production is highly resource-intensive, requiring approximately 2.8 tons of raw materials and emitting nearly one ton of CO_2 per ton of cement produced. These environmental concerns have led to increased research into sustainable cementitious alternatives aimed at reducing the ecological footprint of concrete.

(1) In this study, Class F fly ash, a by-product of coal combustion in thermal power plants, was selected as the primary binder due to its high silica and alumina content, which is essential for geopolymerization. The alkaline activator solution was prepared using a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). A 13 M NaOH solution was used consistently throughout the experiment to ensure adequate alkalinity for activation. The sodium silicate-to-sodium hydroxide ratio was maintained at 1.0 by mass, which is critical for balancing workability and strength. To further refine the mix, a solution-to-fly ash ratio of 0.35 and a water-to-geopolymer binder ratio of 0.35 were adopted based on preliminary trial mixes, ensuring proper workability and compaction.

(2) The study confirms that geopolymer concrete (GPC), formulated with an alkaline activator and fly ash-based binder, can effectively develop sufficient compressive strength without relying on traditional water curing methods. When subjected to natural daylight curing, the GPC specimens demonstrated steady strength development over time, achieving structural adequacy comparable to conventional concrete. The findings emphasize that ambient curing conditions, such as exposure to sunlight, are capable of initiating the geopolymerization process effectively, making the curing process more sustainable and cost-efficient. This approach eliminates the need for energy-intensive ovens or steam curing, making GPC a viable option for practical construction applications. Overall, the performance of GPC under natural curing conditions illustrates its potential as an environmentally friendly and structurally reliable alternative to Ordinary Portland Cement (OPC) concrete.

(3) The experimental investigation revealed that hybrid fiber-reinforced geopolymer concrete short columns demonstrated enhanced structural performance under axial compression. Columns incorporating hybrid fibers showed improved load-carrying capacity, ductility, and crack resistance compared to those without fibers. Circular columns exhibited better performance than square columns due to their uniform stress distribution. The inclusion of steel and polypropylene fibers effectively delayed crack propagation and minimized spalling, contributing to a more gradual and ductile failure mode. Overall, the use of hybrid fibers significantly improved the behavior of geopolymer concrete columns under compressive loading.

(4) Based on IS 10262:2009 mix design guidelines for M25 columns, all tested mixes in the present study achieved compressive strengths exceeding their target values. One of the mixes closely approached the control strength, followed by others with slightly lower but still satisfactory performance. The variation between theoretical and experimental failure loads remained within acceptable limits, with some mixes exhibiting smaller deviations than others, indicating improved behavior. Overall, the results confirm that the mixes not only met the required strength criteria but also aligned well with theoretical expectations, demonstrating structural adequacy and reliability.

II. MATERIALS USED AND MIX DESIGN

Geopolymer concrete (GPC) offers a sustainable and efficient alternative to conventional concrete by utilizing industrial by-products rich in aluminosilicates, activated with alkaline solutions. In this investigation, Class F Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS) were used as the primary binders, both known for their high silica (SiO_2) and alumina (Al_2O_3) content, which are essential for the geopolymer reaction. The alkaline activator solution comprised sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), with NaOH prepared at an 8M concentration to facilitate effective geopolymerization. Manufactured sand served as the fine aggregate, while a mixture of 20 mm and 12.5 mm crushed stones was used as coarse aggregate, making up about 75–80% of the total volume, similar to traditional mix designs. A low water-to-binder ratio was adopted to ensure compactness and improved mechanical strength. Furthermore, certain mixes included alkali-resistant glass fibers to enhance ductility, minimize cracking, and improve overall structural performance.

Table No. 1: Mix Designation

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

Table No. 2: Details of the design Mix Proportions

Materials	C1	C2	C3	C4
Cement	312	312	-	-
Fly ash	-	-	164.4	164.4
GGBS	-	-	246.6	246.6
Fine Aggregate	756	756	533.5	533.5
Coarse aggregate	1197	1197	1291	1291
Glass Fiber	-	0.03	-	0.03
w/c ratio and binder ratio	0.43	0.43	0.4	0.4
NaOH Solution	-	-	47	47
Na_2SiO_3 Solution	-	-	117.5	117.5

III. EXPERIMENTAL PROGRAM

The experimental study was focused on investigating the axial compressive performance of four selected concrete mixes-two based on M25 grade Ordinary Portland Cement (OPC) and two using 8M Geopolymer Concrete (GPC). The mixes included plain OPC concrete, OPC combined with glass fibers, plain geopolymer concrete, and geopolymer concrete with glass fiber reinforcement. Each mix was designed and proportioned according to relevant Indian Standard guidelines to ensure uniformity and structural reliability. Concrete column specimens were cast using appropriate formwork and reinforcement, followed by placement of freshly mixed concrete in layers with proper vibration to eliminate air voids. All specimens were subjected to curing under ambient conditions. The axial compression tests were conducted using a manually operated hydraulic jack system capable of delivering up to 1000 kN, with steel plates ensuring uniform load transfer to the columns. This test setup allowed for precise evaluation of mechanical parameters such as compressive strength and flexural strength.

IV. RESULTS AND DISCUSSION

Compression Strength: Compressive strength tests were conducted on cube specimens for Mix 1 (M25 OPC), Mix 2 (M25 + Glass Fibers), Mix 3 (GPC 8M), and Mix 4 (GPC 8M

+ Glass Fibers) at 3, 7, and 28 days of curing. At 28 days, all mixes exceeded the characteristic strength specified in IS 456:2000, with Mix 4 achieving the highest strength at 34.65 MPa. Compared to the control mix (Mix 1, 33.13 MPa), Mix 2 showed a 1.81% increase, Mix 3 showed a 1.45% increase, and Mix 4 exhibited a 4.59% gain in compressive strength. These results confirm that both the use of geopolymer binders and the incorporation of glass fibers contribute positively to compressive performance, with the combination in Mix 4 offering the most significant improvement.

Table No. 3: Compressive Strength

Compressive Strength				
Days	**Mix-1**	**Mix-2**	**Mix-3**	**Mix-4**
3	13.25	13.86	13.71	14.52
7	21.53	22.70	22.15	23.25
28	33.13	33.73	33.61	34.65

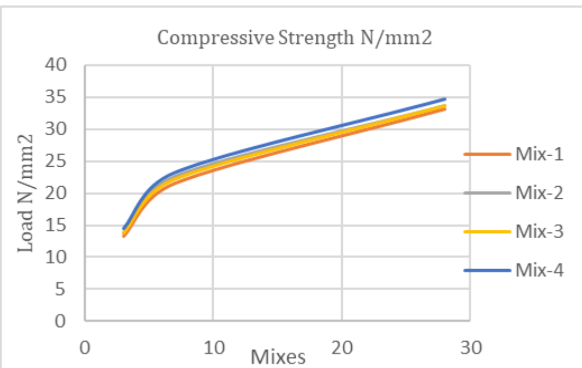

Fig No. 1 Compression Strength

Flexural Strength: Flexural strength tests were carried out on prism specimens of four concrete mixes-Mix 1 (M25 OPC), Mix 2 (M25 + Glass Fibers), Mix 3 (GPC 8M), and Mix 4 (GPC 8M + Glass Fibers) at 7, 14, and 28 days of curing. Compared to the Mix 1 (control mix), Mix 2, Mix 3, and Mix 4 showed an improvement of 3.71%, 2.35%, and 10.75% respectively. These results indicate that both the geopolymer matrix and glass fiber reinforcement significantly enhance the flexural strength, with the combined effect being most pronounced in Mix 4.

Table No. 4: Flexural Strength

Flexural Strength				
Days	**Mix-1**	**Mix-2**	**Mix-3**	**Mix-4**
3	1.66	1.77	1.73	1.95
7	2.69	2.80	2.77	3.12
28	4.15	4.31	4.25	4.65

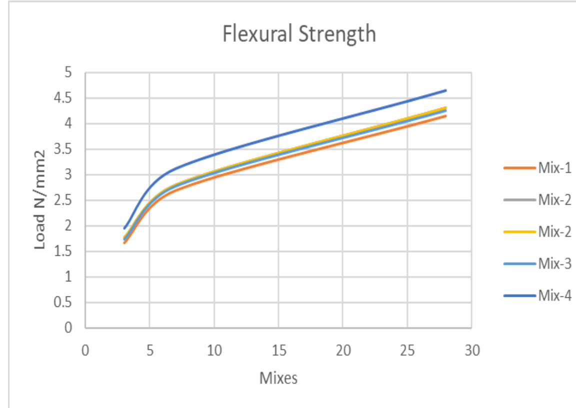

Fig No. 2 Flexural Strength

First Crack Load: The first crack load is the load at which visible cracks appear, marking the onset of non-linear behavior. Among the four mixes, Mix 4 demonstrated the highest resistance to early cracking.

Table No.5: First Crack Load

Designation	**First Crack Load (KN)**
C-1	215.25
C-2	220.1
C-3	221.795
C-4	228.88

Mix 4 (GPC + GF) showed a 5.95% increase in cracking resistance compared to Mix 1, highlighting the beneficial role of fiber reinforcement in delaying crack initiation.

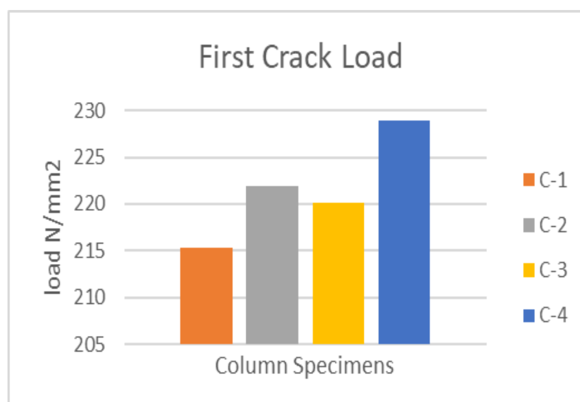

Fig No. 3 Comparison of First Crack Load

Ultimate Load: The ultimate load represents the maximum axial force each column could carry before failure. The results indicate that Mix 4 exhibited the highest load-bearing capacity.

Table No.6: Ultimate Load

Designation	ultimate load (KN)
C-1	639.21
C-2	663.37
C-3	654.28
C-4	680.84

The performance of Mix 4 surpassed that of Mix 1 by 6.11%, confirming the improved load resistance offered by the geopolymer matrix and glass fiber addition.

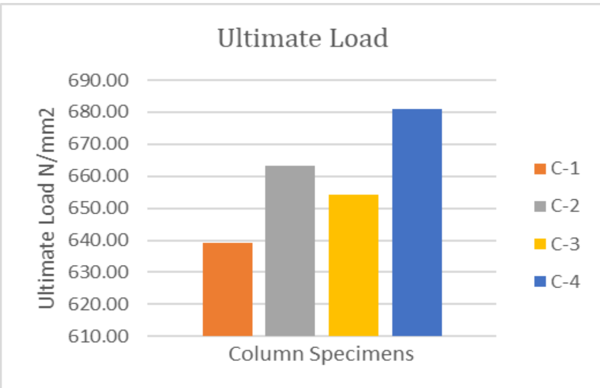

Fig No. 4 Comparison of Ultimate Load

Stress–Strain Behavior: The stress–strain response of the column specimens showed clear variations in mechanical behavior. Mix 1 (M25 OPC) had the lowest ductility, with an ultimate stress of 18.84 N/mm² and microstrain of 658.08. Mix 2 (OPC + Glass Fibers) improved to 19.65 N/mm² and 676.67 microstrain due to fiber reinforcement. Mix 3 (GPC) reached 19.38 N/mm² and 668.78 microstrain, confirming the effectiveness of geopolymer binders. Mix 4 (GPC + Glass Fibers) performed best with 20.17 N/mm² and 685.41 microstrain, demonstrating enhanced strength and ductility. These results highlight the combined benefit of the geopolymer matrix and fiber reinforcement in improving axial performance.

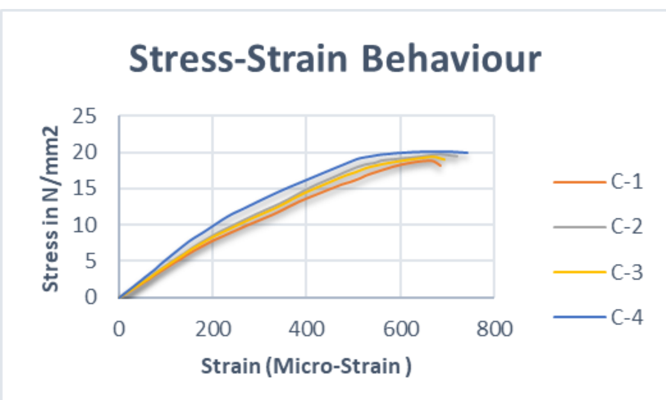

Fig No. 5 Stress-Strain Behaviour for all Mixes

Comparison of Theoretical and Experimental Results:

Theoretical load predictions were compared with experimental outcomes. The T/E ratio (Theoretical/Experimental) highlights the enhancement observed in real-world testing.

Table No.7: Comparison of Theoretical and Experimental Results

Designation	Theoretical failure load (KN)	Experimental failure load (KN)	T/E
C-1	615.58	639.21	0.951
C-2	620.00	663.37	0.927
C-3	619.54	654.28	0.938
C-4	635.79	680.84	0.912

All experimental results exceeded theoretical predictions. Mix 4 recorded the lowest T/E ratio, indicating the highest gain over expected load capacity due to improved material behavior. These outcomes validate the effectiveness of fiber reinforcement and geopolymer technology in enhancing axial compression performance.

V. CONCLUSION

The experimental investigation demonstrated that both geopolymer concrete and fiber reinforcement significantly influence the mechanical behavior of concrete under axial compression. Among the tested mixes, Mix 4 (GPC with Glass Fibers) consistently exhibited superior performance in terms of compressive strength, flexural strength, and axial load-bearing capacity.

The addition of glass fibers improved the ductility and crack resistance of both OPC and GPC specimens, while the geopolymer binder enhanced the sustainability and strength characteristics.

Stress–strain analysis revealed that Mix 4 achieved the highest strain capacity and stress values, indicating better energy absorption and post-peak behavior. Furthermore, experimental ultimate loads exceeded theoretical predictions in all cases, validating the structural benefits of using fiber-reinforced geopolymer concrete. These findings suggest that GPC, particularly when reinforced with glass fibers, is a viable and environmentally friendly alternative to conventional OPC in load-bearing structural applications.

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