

Experimental Studies on Durability Characteristics of Geopolymer Concrete And Conventional Concrete

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Abstract- Concrete is widely used in construction for its strength, adaptability, and ease of availability. Despite these advantages, durability under harsh environmental conditions remains a significant concern. This thesis examines the durability performance of four concrete mixes: Mix 1 (Conventional M40 concrete), Mix 2 (M40 with glass fiber), Mix 3 (Geopolymer concrete), and Mix 4 (Geopolymer concrete with glass fiber). The study evaluates critical durability parameters including water absorption, acid and alkali resistance, shrinkage, and sorptivity. The addition of glass fiber improved micro-crack resistance and internal bonding, while geopolymer binders offered enhanced chemical durability. Among the mixes, Mix 4 showed the most promising results, with reduced water absorption, lower shrinkage, and superior resistance to chemical attacks. Sorptivity testing further confirmed that geopolymer-based mixes exhibited lower capillary absorption, indicating better moisture resistance. These findings demonstrate the potential of geopolymer concrete, especially when combined with glass fibers, as a durable and sustainable alternative to traditional concrete in aggressive environments.

Keywords- M40 Concrete, Geopolymer Concrete, Durability, Glass Fiber, Sorptivity, Water Absorption, Shrinkage, Acid Resistance, Alkaline Resistance

I. INTRODUCTION

Concrete is widely used in construction for its strength and versatility, with Ordinary Portland Cement (OPC) as the traditional binder. However, OPC production is energy-intensive and emits large amounts of CO₂, prompting the search for sustainable alternatives. Geopolymer Concrete (GPC), made from industrial by-products like fly ash and GGBS and activated with alkaline solutions, offers reduced emissions and improved durability. This study evaluates the durability of M40 grade Conventional Concrete and GPC, both designed with a water-binder ratio of 0.40, through tests on water absorption, acid and alkaline resistance, drying shrinkage, and sorptivity to identify sustainable, long-lasting alternatives to OPC concrete. {1} this study investigates the potential of geopolymer concrete as a sustainable alternative

to conventional concrete. Using industrial by-products such as fly ash and GGBS, mixes were prepared with 10M sodium hydroxide, varying NaOH/Na₂SiO₃ ratios, and different GGBS contents (F100G0 to F60G40). Ambient-cured specimens were tested at 7 and 28 days. Results showed that compressive strength improved with increasing GGBS content, with the highest strength of 66 MPa recorded for mix F60G40 at a 2.50 ratio. The findings confirm that geopolymer concrete offers enhanced strength and durability compared to traditional OPC concrete. {2} this study reviews the use of steel fibres as a reinforcement material in concrete. Concrete remains a widely used construction material due to its workability and versatility. Steel fibres are increasingly used to control cracking and enhance strength, serving as an alternative to traditional reinforcement. The paper highlights the growing role of steel and poly fibres in modern applications such as tunnels (shotcrete, lining) and structural elements like girders, crash barriers, beams, columns, and slabs, demonstrating their effectiveness in improving concrete performance and durability. {3} this study experimentally examined the water absorption capacity of concrete cubes in relation to the sorptivity coefficient. Seventy-two concrete cubes of varying grades were tested to assess the effects of compressive strength, water-cement ratio, and slump. Results showed that higher strength concrete exhibited lower water absorption and sorptivity, while lower strength mixes had higher values. Mixes with constant strength but varying slump showed only a slight increase in sorptivity. Overall, increased concrete strength was found to enhance resistance to water penetration, thereby improving durability. {4} this study explores the durability of geopolymer concrete as a sustainable alternative to Portland cement-based concrete. Using fly ash and GGBS, geopolymer concrete cubes with glass fiber reinforcement were tested against traditional high-performance concrete. A total of 26 cubes of each type were evaluated for compressive strength, water absorption, acid resistance, and water penetration. Results highlight the effectiveness of glass fibers in enhancing durability, supporting the development of environmentally friendly and long-lasting concrete structures.

II. MATERIALS AND MIXES

Geopolymer concrete (GPC) is an eco-friendly alternative to conventional concrete, produced by activating aluminosilicate-rich industrial by-products using an alkaline solution. The primary binders are Class F fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBS), both rich in silica (SiO₂) and alumina (Al₂O₃), which contribute to the geopolymerization process. The alkaline activator is typically a combination of sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃). Fine and coarse aggregates, similar to those used in conventional concrete, make up approximately 75–80% of the total volume. A low water-to-binder ratio is maintained to enhance strength and durability. In this study, 10M NaOH solution was used, which significantly influenced the reactivity and strength development of the geopolymer matrix.

environmental conditions. Eight different mixes were prepared using standardized proportions to ensure consistency. Conventional mixes used OPC 53 grade as the primary binder, while GPC mixes incorporated fly ash and GGBS activated with a 10M sodium hydroxide and sodium silicate solution. All specimens were cast, cured, and tested for mechanical and durability performance. Mechanical tests included compressive and flexural strength evaluation. Durability tests were conducted as per ASTM standards and included water absorption (ASTM C 642), acid resistance (ASTM C 267), alkaline resistance (ASTM C 452), drying shrinkage (ASTM C 157), and sorptivity (ASTM C 1585). These tests provided insights into the long-term performance of both concrete types in chemically aggressive environments

Table -1: Mix Designation

Mixes	Designation
MIX 1	M-40
MIX 2	M-40 + GF
MIX 3	GPC +10M
MIX 4	GPC + 10M + GF

Table 2: Details of the design Mix Proportions of CC and GPC

Mix	Cement	Flyash	GGBS	FA	CA	GF	CC-W/B	GPC-A/B	NaOH Solution	Na ₂ SiO ₃ Solution
	kg/m ³	(%)			kg/m ³	kg/m ³				
Mix 1	372	-	-	710	1224	-	-	0.36	-	-
Mix 2	372	-	-	710	1224	0.3	-	0.36	-	-
Mix 3	-	162.9	244	539	1291	-	0.4	-	46.5	116.3
Mix 4	-	162.9	244	539	1291	0.3	0.4	-	46.5	116.3

III. EXPERIMENTAL PROGRAM

The experimental program was designed to evaluate the durability performance of both conventional M40 grade concrete and geopolymer concrete (GPC) under aggressive

IV. RESULTS AND DISCUSSIONS

i) COMPRESSIVE STRENGTH

Compressive strength tests were performed on standard cube specimens of size 150 × 150 × 150 mm for each concrete mix. The specimens were tested after curing periods of 3, 7, and 28 days to assess the strength development over time. The compressive strength results for all mixes are systematically presented in the corresponding table, providing a clear comparison of performance at different curing ages.

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

Mixes	Compressive Strength in N/mm ²		
	3 days	7 days	28 days
MIX 1	19.42	31.56	48.56
MIX 2	20.24	33.15	49.25
MIX 3	20.04	32.37	49.12
MIX 4	21.28	34.08	50.79

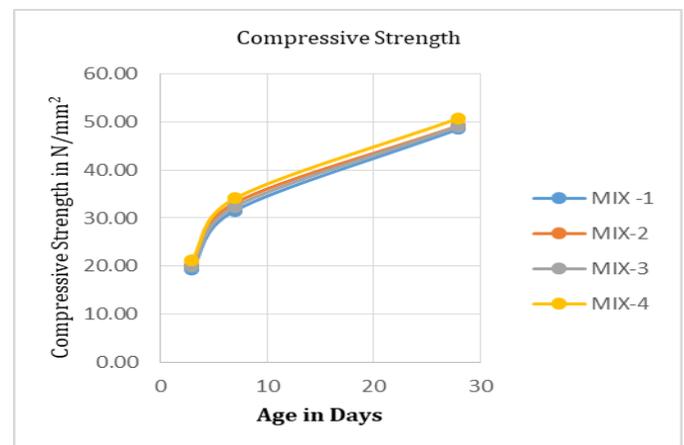


Chart -1: Comparison of Compressive Strength with Age of different concrete matrices

ii) FLEXURAL STRENGTH

Flexural strength tests were conducted on beam specimens with dimensions of 100 × 100 × 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 -4: Summary of 3, 7 and 28 days Flexural Strength of Test Specimens

Mixes	Flexural Strength in N/mm ²		
	3 days	7 days	28 days
MIX 1	2.0	3.25	5.01
MIX 2	2.15	3.39	5.23
MIX 3	2.11	3.36	5.16
MIX 4	2.28	3.66	5.45

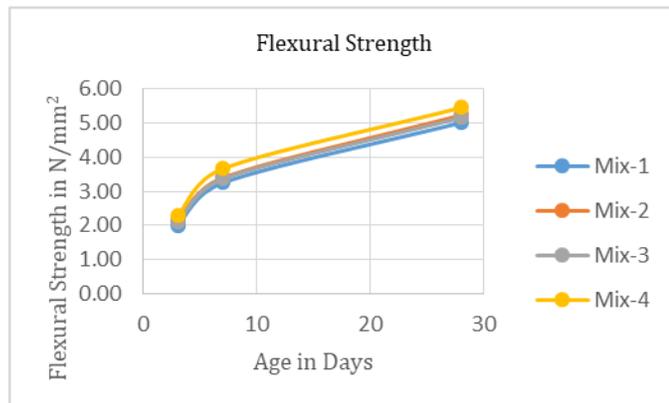


Chart -2: Comparison of Flexural Strength with Age of different concrete matrices

iii) WATER ABSORPTION TEST RESULTS

The water absorption test was conducted as per ASTM C 642 (2006) using 150 mm cube specimens cured for 28 days. The test measured the percentage of water absorbed by each sample based on the difference between oven-dry and saturated weights. The mixes evaluated included conventional M40 and its fiber and silica fume variations, as well as geopolymer concrete (GPC) with and without fiber/silica fume. The results provided comparative insights into the permeability and pore structure of each mix.

Table 5: Water absorption of different concrete matrices

MIXES	Weight of Oven Dried Sample (W_1)	Weight of Sample After 24 hours of Immersion in Water (W_2)
MIX-1	8.20	8.45
MIX-2	8.18	8.39
MIX-3	8.05	8.27
MIX-4	8.03	8.23

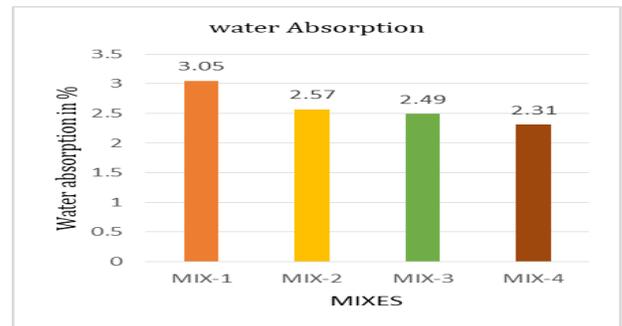


Chart -3: Water absorption of different concrete mix

iv) ACID RESISTANCE TEST RESULTS

The acid resistance test was conducted as per ASTM C267-01 (2012) to assess the durability of concrete under acidic conditions. Hardened 150 mm cube specimens were immersed in a 5% sulfuric acid (H₂SO₄) solution for 28 days and 56 days. After exposure, specimens were evaluated for residual compressive strength to determine their deterioration resistance. The results helped compare the acid durability of conventional and geopolymer concrete mixes.

Table 6: Compressive strength before, after 28 days and Percentage Strength loss after 28 days of concrete matrices after immersion in 5% H₂SO₄ solution

MIXES	Compressive Strength Before 28 days of Immersion in Acid (N/mm ²)	Compressive Strength after 28 days of immersion in Acid (N/mm ²)	Percentage Strength Loss After 28 days of Acid Immersion
MIX-1	48.56	37.71	22.34
MIX-2	49.25	39.06	20.69
MIX-3	49.12	38.55	21.52
MIX-4	50.79	41.124	19.03

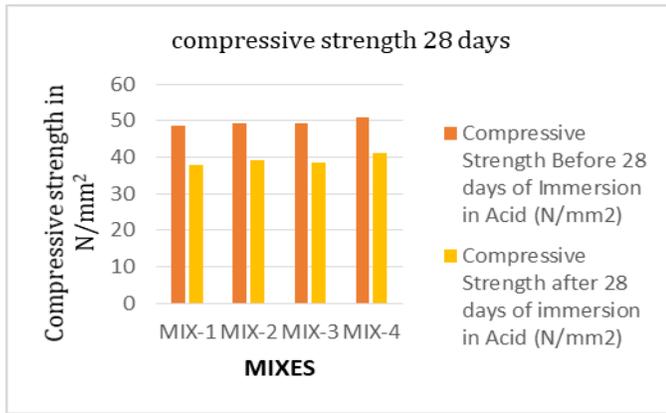


Chart -4: Compressive Strength before and after immersed in 5% H₂SO₄ Solution (28 days)

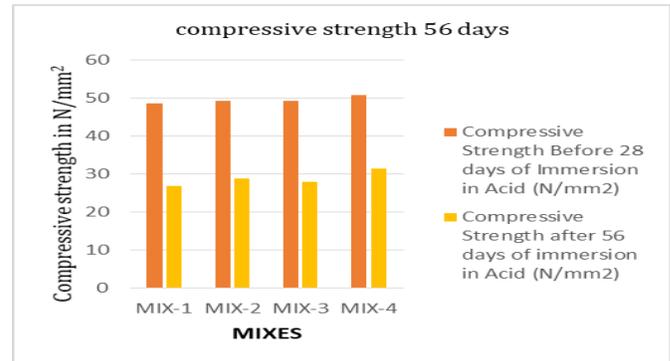


Chart -6: Compressive Strength before and after immersion immersed in 5% H₂SO₄ Solution (56 days).

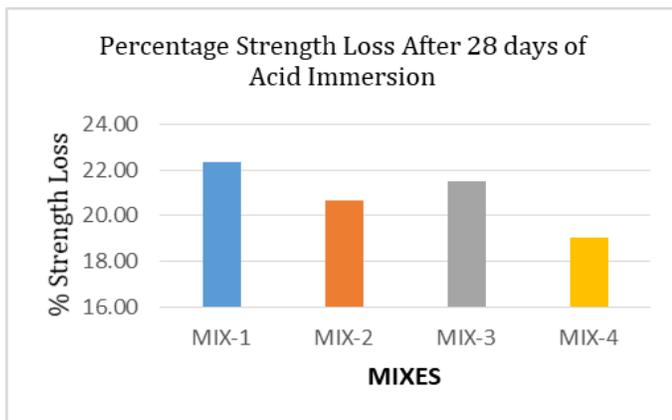


Chart -5: Percentage strength loss after 28 days of concrete matrices immersed in 5% H₂SO₄ Solution.

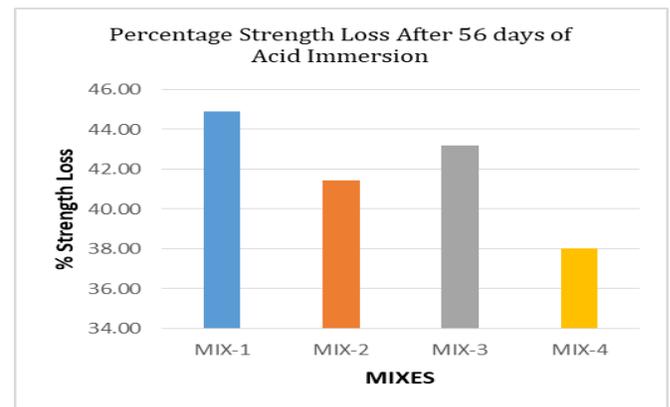


Chart -7: Percentage strength loss after 56 days of concrete matrices immersed in 5% H₂SO₄ Solution.

Table 7: Compressive strength before, after 56 days and Percentage Strength loss after 56 days of concrete matrices after immersion in 5% H₂SO₄ solution

MIXES	Compressive Strength Before 28 days of Immersion in Acid (N/mm ²)	Compressive Strength after 56 days of immersion in Acid (N/mm ²)	Percentage Strength Loss After 56 days of Acid Immersion
MIX-1	48.56	26.75	44.91
MIX-2	49.25	28.83	41.46
MIX-3	49.12	27.91	43.17
MIX-4	50.79	31.48	38.02

v) ALKALINE RESISTANCE TEST RESULTS

The alkaline resistance test was performed as per ASTM C452-02 (2002) to evaluate the durability of concrete in alkaline environments. Hardened 150 mm cube specimens were immersed in a 5% sodium hydroxide (NaOH) solution for 28 days. After exposure, changes in weight and compressive strength were measured to assess the impact of alkali-induced deterioration across different concrete mixes.

Table 7: Compressive strength before, after 28 days and Percentage Strength loss after 28 days of concrete matrices after immersion in 5% H₂SO₄ solution

MIXES	Compressive Strength Before 28 days of Immersion in Alkaline (N/mm ²)	Compressive Strength after 28 days of immersion in Alkaline (N/mm ²)	Percentage Strength Loss After 28 days of Immersion in Alkaline
MIX-1	48.56	42.407	12.67
MIX-2	49.25	44.73	9.18
MIX-3	49.12	44.27	9.87
MIX-4	50.79	46.71	8.03

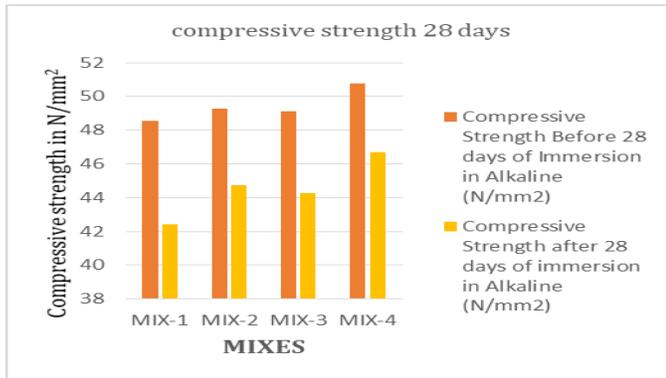


Chart -8: Compressive Strength before and after 28 days immersion immersed in 5% NaOH Solution.

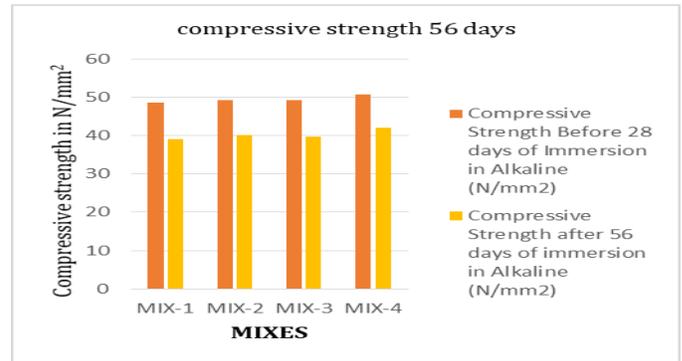


Chart -10: Compressive Strength before and after 56 days immersion immersed in 5% NaOH Solution.

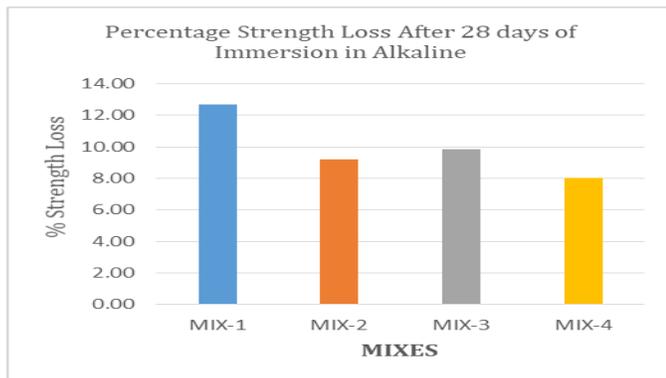


Chart -9: Percentage strength loss after 28 days of concrete matrices immersed in 5% NaOH Solution.

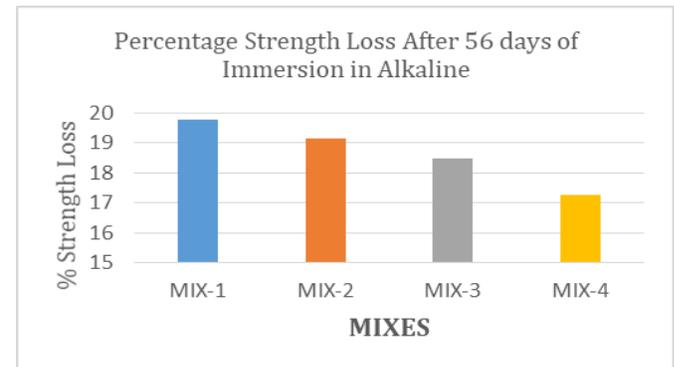


Chart -11: Percentage strength loss after 56 days of concrete matrices immersed in 5% NaOH Solution.

Table 8: Compressive strength before, after 56 days and Percentage Strength loss after 28 days of concrete matrices after immersion in 5% H₂SO₄ solution

MIXES	Compressive Strength Before 28 days of Immersion in Alkaline (N/mm ²)	Compressive Strength after 56 days of immersion in Alkaline (N/mm ²)	Percentage Strength Loss After 56 days of Immersion in Alkaline
MIX-1	48.56	38.96	19.77
MIX-2	49.25	40.141	19.14
MIX-3	49.12	39.72	18.50
MIX-4	50.79	42.03	17.25

vi) SHRINKAGE TEST RESULTS

The shrinkage test on concrete was carried out in accordance with the specifications outlined in ASTM C157 (2017). The test specimens were prisms with dimensions of 75 × 75 × 285 mm. These specimens were cast, cured, and monitored for shrinkage behavior over a period of 56 days.

Table -9: Shrinkage test results

Day	MIX 1	MIX 2	MIX 3	MIX 4
1	0	0	0	0
28	3.319	2.655	2.987	2.292
56	3.501	2.823	3.151	2.418

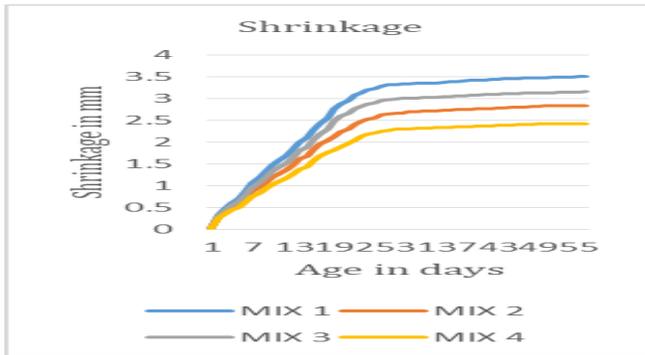


Chart -12: Comparison of shrinkage values of different concrete mixes

vii) SORPTIVITY TEST RESULTS

This process measures water absorption due to capillary action. Concrete cylinders of size 100×200 mm are cut into 100×50 mm discs, then oven-dried for 28 hours followed by 24 hours at room temperature. The discs are then partially immersed in water to a depth of 5 mm, and their weights are recorded at specified time intervals to determine the rate of absorption.

Table -9: Sorptivity test results

Time (min)	MIX 1	MIX 2	MIX 3	MIX 4
30	0.362	0.3	0.324	0.27
60	0.051	0.045	0.048	0.042
90	0.043	0.038	0.042	0.035
120	0.028	0.023	0.025	0.021
150	0.022	0.017	0.018	0.015
180	0.014	0.012	0.013	0.01

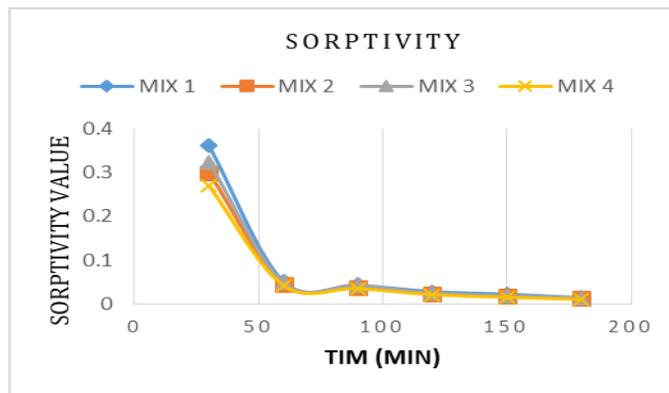


Chart -13: Comparison of sorptivity with time

V. CONCLUSIONS

- The 28-day compressive strength results for the selected concrete mixes are as follows: Mix 1 (CC) achieved 48.56

N/mm², Mix 2 (CC with glass fiber) reached 49.25 N/mm², Mix 3 (GPC) recorded 49.12 N/mm², and Mix 4 (GPC with glass fiber) showed the highest strength of 50.79 N/mm². Comparing Mix 1 and Mix 4, there is a notable improvement of approximately 4.6% in compressive strength, indicating that the combined use of geopolymer binder and glass fiber significantly enhances the mechanical performance of concrete.

- The 28-day flexural strength results for the selected mixes are as follows: Mix 1 (CC) achieved 5.01 N/mm², Mix 2 (CC with glass fiber) reached 5.23 N/mm², Mix 3 (GPC) recorded 5.16 N/mm², and Mix 4 (GPC with glass fiber) attained 5.45 N/mm². Among these, Mix 4 showed the highest strength, marking a 8.78% increase over Mix 1. This indicates that the incorporation of both geopolymer binder and glass fiber contributes to a noticeable enhancement in the flexural performance of concrete.
- The 28-day water absorption values for the selected mixes are as follows: Mix 1 (CC) exhibited 3.05%, Mix 2 (CC with glass fiber) showed 2.57%, Mix 3 (GPC) recorded 2.73%, and Mix 4 (GPC with glass fiber) had 2.49%. Among these, Mix 4 demonstrated the lowest water absorption, representing an 18.36% reduction compared to Mix 1. This trend indicates that the use of geopolymer binder and glass fiber effectively enhances the durability of concrete by reducing its water absorption capacity.
- The 28-day acid resistance test results, measured by percentage strength loss, are as follows: Mix 1 (CC) experienced a loss of 22.34%, Mix 2 (CC with glass fiber) had 20.69%, Mix 3 (GPC) showed 21.52%, and Mix 4 (GPC with glass fiber) recorded 19.03%. Among these, Mix 4 exhibited the lowest strength loss, indicating a 14.86% improvement over Mix 1. This demonstrates that the incorporation of geopolymer binder and glass fiber enhances concrete’s resistance to acid attack.
- The 56-day acid resistance test results, based on percentage strength loss, are as follows: Mix 1 (CC) exhibited a loss of 44.91%, Mix 2 (CC with glass fiber) showed 41.46%, Mix 3 (GPC) recorded 43.17%, and Mix 4 (GPC with glass fiber) had 38.02%. Among the selected mixes, Mix 4 showed the least strength loss, reflecting a 15.34% improvement over Mix 1. These results confirm that the combination of geopolymer binder and glass fiber significantly improves long-term resistance to acid attack in concrete.
- The 28-day alkaline strength loss for the selected mixes is as follows: Mix 1 (CC) showed a loss of 12.67%, Mix 2 (CC with glass fiber) had 9.87%, Mix 3 (GPC) recorded 8.02%, and Mix 4 (GPC with glass fiber) exhibited the lowest loss at 7.60%. Compared to Mix 1, Mix 4 showed an improvement of 39.97%, indicating enhanced

resistance to alkaline environments due to the combined effect of geopolymer binder and glass fiber.

- At 56 days, alkaline strength loss was slightly higher for all mixes. Mix 1 recorded a loss of 19.77%, Mix 2 had 18.50%, Mix 3 (GPC) showed 19.14%, and Mix 4 (GPC with glass fiber) again exhibited the lowest loss at 17.25%. When compared to Mix 1, Mix 4 showed an improvement of approximately 12.74%, reaffirming the durability benefits of using both geopolymer binder and glass fiber over time.
- At 28 days, the shrinkage values for the selected mixes were as follows: Mix 1 (CC) showed the highest value at 3.328, Mix 2 (CC with glass fiber) was 2.665, Mix 3 (GPC) recorded 2.995, and Mix 4 (GPC with glass fiber) showed the lowest at 2.291. Compared to Mix 1, Mix 4 exhibited a significant reduction of approximately 31.16%, indicating the effectiveness of geopolymer binder and glass fiber in controlling early-age shrinkage.
- At 56 days, the shrinkage values slightly increased for all mixes. Mix 1 (CC) reached 3.501, Mix 2 was 2.823, Mix 3 (GPC) showed 3.151, and Mix 4 recorded the lowest value at 2.418. Mix 4 showed a 30.92% reduction in shrinkage compared to Mix 1, confirming improved long-term dimensional stability when both geopolymer binder and glass fiber are used.
- The 28-day sorptivity test results for the selected mixes are as follows: Mix 1 (CC) recorded 0.014 mm/min, Mix 2 (CC with glass fiber) showed 0.012 mm/min, Mix 3 (GPC) had 0.013 mm/min, and Mix 4 (GPC with glass fiber) exhibited the lowest value of 0.010 mm/min. These results indicate a consistent reduction in sorptivity with the incorporation of glass fibers and geopolymer binders, with Mix 4 showing the most significant improvement in resistance to capillary water absorption compared to Mix 1.
- Overall, Mix 1 met the basic standards but lacked durability. Mix 2 showed moderate improvements. Mix 3 (GPC) offered much better performance, and Mix 4 (GPC + GF) consistently outperformed all others in strength and durability, making it the most efficient and sustainable mix in this study.

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