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Comparative Durability Performance of HPC and GPC with Glass Fibers under Alkaline Attack, Shrinkage, Sorptivity, and RCPT.

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Abstract - *In modern construction, achieving durability alongside sustainability has become critical. This study compares the durability characteristics of high-performance concrete (HPC) and geopolymer concrete (GPC), both with and without glass fiber (GF) reinforcement, when exposed to aggressive conditions. For the purpose of investigation four concrete mixes (HPC, HPC+GF, GPC, GPC+GF) were considered, and the durability performance with a particular focus on alkaline attack, shrinkage, sorptivity, and rapid chloride permeability test (RCPT) were studied. Test specimens were prepared as per standard procedures and subjected to standard testing using ASTM C452-02 for alkaline attack, ASTM C157 for shrinkage, ASTM C1585 for sorptivity, and ASTM C1202 for RCPT. Experimental results showed that GPC mixes exhibited superior resistance to alkaline attack and RCPT as compared to HPC, with strength loss due to NaOH immersion being lowest at 0.146% and RCPT charge passed as low as 821.97 Coulombs, and shrinkage reduced by up to 38.63% in GPC + GF. The sorptivity rate was minimal for GPC+GF at 0.009 mm/min, indicating low water absorption. These findings demonstrate that GPC with fiber reinforcement yields enhanced long-term durability and can be used as a sustainable concrete alternative for harsh environments.*

Key Words: Alkaline attack; shrinkage; sorptivity; rapid chloride permeability test (RCPT); geopolymer concrete; glass fiber; durability

1. INTRODUCTION

Concrete, as the most widely utilized construction material globally, plays a pivotal role in modern infrastructure due to its compressive strength, versatility, and cost-efficiency. However, the longevity and performance of concrete structures are increasingly challenged by aggressive environmental exposures such as acid rain, chloride ingress, sulphate attack, and freeze-thaw cycles. These conditions often lead to deterioration, particularly in conventional concrete, underscoring the urgent need for more durable and sustainable alternatives. In response to these challenges, two advanced classes of concrete have gained prominence: High-Performance Concrete (HPC) **and** Geopolymer Concrete (GPC). HPC, an optimized variant of traditional cement concrete, is engineered through the judicious use of supplementary cementitious materials and admixtures to enhance strength, durability, and workability. While HPC demonstrates improved resistance to environmental stressors, it remains dependent on Ordinary Portland Cement (OPC), whose production is a major contributor to global CO_2 emissions. Conversely, Geopolymer Concrete represents a paradigm shift toward sustainability. Formulated by activating alumino-silicate-rich industrial by-products such as fly ash and ground granulated blast furnace slag (GGBS) with alkaline activators (e.g., NaOH and Na_2SiO_3), GPC offers significant environmental and performance advantages. Its dense microstructure imparts superior resistance to chemical attack, reduced shrinkage, and low permeability. Importantly, the production of GPC results in substantially lower greenhouse gas emissions compared to OPC-based concretes. Despite the promising attributes of both HPC and GPC, the majority of existing literature remains concentrated on their mechanical characteristics, such as compressive and flexural strength. However, the long-term performance of concrete is governed not merely by strength but by durability parameters including shrinkage behavior, water absorption, sorptivity, alkaline and acid resistance, and chloride ion permeability. These properties are critical in predicting service life and ensuring structural integrity, particularly in harsh environmental settings. Moreover, fiber reinforcement, especially with glass fibers, has emerged as a potential enhancement to both HPC and GPC systems. Fibers are known to mitigate microcracking, reduce permeability, and improve toughness thereby extending the material's resistance against degradation mechanisms. This study aims to comparatively evaluate the durability performance of High-Performance Concrete (HPC) and Geopolymer Concrete (GPC), with and without glass fiber reinforcement, under four key exposure conditions: alkaline attack, shrinkage, sorptivity, and rapid chloride permeability. The hypothesis is that fiber-reinforced GPC will demonstrate superior durability across all conditions.

2. LITERATURE REVIEW

Concrete durability under harsh environments has attracted growing attention, particularly regarding geopolymer concrete (GPC). Several studies have contributed to our understanding of concrete durability. Maruthachalam et al[1] tested M60 HPC with polypropylene fibers under sulfuric acid and reported a 53.5% weight loss in 28 days. Vijaya Sekhar Reddy et al[2].found that adding metakaolin improved M40 concrete's resistance to alkali and acid attacks.Together, these studies highlight HPC's vulnerability and the benefits of mineral additives. However, they do not directly compare HPC and GPC under the same conditions. Hsie et al.[3] showed that hybrid polypropylene fibers reduce drying shrinkage in concrete. Jayaranjini & Vidivelli[4] recorded a 174 με reduction in shrinkage by adding steel fibers and fly ash. These establish that fibers can affect shrinkage, but fail to explore geopolymer matrices. Dave & Bhogayata [5]demonstrated that GPC exhibits lower sorptivity than OPC concrete due to its dense binder. Lavanya & Jegan [6] confirmed enhanced water resistance in GPC subjected to aggressive conditions. Adanagouda & Murthy [7] documented low chloride ion penetrability in GPC with GGBS using RCPT. Whiting (1981) [8] introduced RCPT as a standard technique to quickly determine chloride ingress resistance . Smith, R. et al. [9] concluded that "geopolymer concrete exhibits superior resistance to chemical attacks and chloride penetration, though its carbonation resistance varies with precursor chemistry" . It also noted that higher calcium content transitions binding gels (N-A-S-H to C–(A)–S–H), which can boost compactness but increase shrinkage. This aligns with our observation that GPC shrinkage needs fiber mitigation. Zhang, Y. et al. [10] on GPC with recycled aggregate and ultrafine slag (UFS) reported that integrating UFS lowered 90-day RCPT values by almost 50%, showing that binder refinement significantly boosts chloride resistance. These findings collectively confirm that GPC generally offers superior resistance to sorption and chloride ingress compared to conventional concrete. Fibers and slag additives further enhance durability. While several studies have investigated durability metrics for HPC or GPC individually, few have conducted comparative analysis across multiple durability parameters especially with glass fiber inclusion. This study fills that gap.

3. MATERIALS AND MIX DESIGN

The materials and mix design details were as follows:

3.1Materials:

The materials used in this study included Ordinary Portland Cement (OPC) for the HPC mixes, while geopolymer concrete (GPC) mixes utilized a combination of fly ash and ground granulated blast furnace slag (GGBS) as binders, in proportions of 40% and 60%, respectively. Manufactured sand (M-sand) conforming to IS:383 standards was used as fine aggregate, and the coarse aggregate was 20 mm nominal size, angular in shape. For GPC activation, a 16M sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) were mixed in a ratio of 1:2.5 by weight. Potable water was used for all concrete mixes. Additionally, alkali-resistant glass fibers, 12 mm in length, were added at 1% by volume in fiber-reinforced mixes to enhance crack resistance and overall durability. GPC specimens were cured under ambient conditions (27 ± 2 °C), whereas HPC specimens were water-cured for 28 days.

3.2Mix Design Table:

Table -1: Materials to prepare 1meter cube Concrete

Material	HPC (kg/m^3)	HPC+GF (kg/m^3)	GPC (kg/m^3)	GPC+GF (kg/m^3)
Cement	450	450	-	-
Fly Ash	64	64	184	184
GGBS	128	128	276	276
Fine Agg.	468	468	533.5	533.5
Coarse Agg.	1125	1125	1291	1291
NaOH	-	-	33	33
Na_2SiO_3	-	-	82.5	82.5
Water	169	169	78.5	78.5
Glass Fiber	-	1% vol.	-	1% vol.

4. METHODOLOGY

Durability tests were conducted in accordance with relevant ASTM standards: C157 for shrinkage, C1585 for sorptivity, C452-02 for alkaline attack, and C1202 for RCPT.

4.1 Alkaline Attack Test

Concrete cubes of 150 mm were cast and compacted in two layers, with HPC specimens water-cured and GPC ambient-cured for 28 days. ASTM C452-02 was followed for assessing alkaline resistance using 5% NaOH solution. A 2000 kN compression testing machine was used to measure strength before and after exposure. Specimens were immersed in NaOH for 28 days and weighed before and after immersion. The strength loss percentage was computed, and results were averaged across triplicates.

4.2 Shrinkage Test

Prismatic specimens (100×100×500 mm) were cast and cured (HPC: water; GPC: ambient) after demolding at 24 hours. Shrinkage measurements were performed as per

ASTM C157. Dial gauges with 0.001 mm resolution and fixed frames ensured precise readings. Length changes were recorded at 7, 28, and 56 days under constant environmental conditions. Mean shrinkage was determined from three specimens per mix.

Fig -1: Shrinkage Test

4.3 Sorptivity Test

Cylinders (100 mm dia × 50 mm ht) were cast, cured (HPC: water; GPC: ambient), and oven-dried at 50°C for 24 hrs. ASTM C1585 was used to determine water absorption via partial immersion. Digital balances (0.01 g accuracy) and 3 mm water trays were used in the test setup. Mass gain was tracked at fixed intervals and plotted against √time. Sorptivity was computed from the slope of absorption vs. √time curve.

Fig -2: Sorptivity Test

4.4 Rapid Chloride Permeability Test (RCPT)

Cylindrical discs (100 mm dia × 50 mm) were cut from 28-day cured samples (HPC: water; GPC: ambient). ASTM C1202 was used to evaluate chloride permeability using a 60 V DC setup. Specimens were sealed with epoxy and vacuum-saturated before testing. NaCl (3%) and NaOH (0.3N) solutions were placed on either side of the specimen. Total charge passed over 6 hours was calculated in Coulombs from current-time readings.

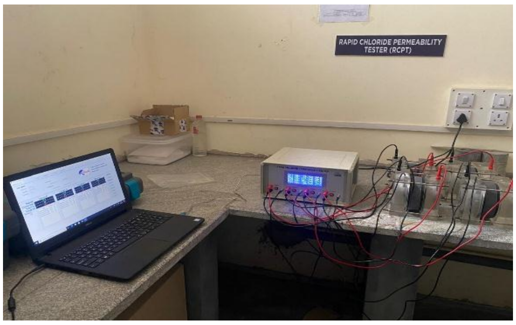


Fig -3: RCPT Test

5. RESULTS AND DISCUSSIONS

The below table shows the variation of values for all the 4 parameters under study.

Property	HPC	HPC+GF	GPC	GPC+GF
Alkaline attack weight loss (%)	0.196	0.187	0.168	0.146
Alkaline attack strength loss(%)	19.542	17.886	15.625	14.997
Shrinkage at 56d (mm)	3.501	2.823	2.418	2.145
Sorptivity (mm/min)	0.012	0.015	0.011	0.009
RCPT (Coulombs)	911.43	883.44	842.67	821.97

5.1 Alkaline Attack:

GPC+GF retained its weight most effectively with only a 0.146% loss after 28 days immersion in NaOH. HPC showed 0.196% loss. Similar results can be seen in strength loss as well. This validates that geopolymers offer higher chemical resistance owing to dense alumino silicate bonding.

Chart-1: Percentage Weight Loss of Different concrete Specimen in Alkaline Attack Test

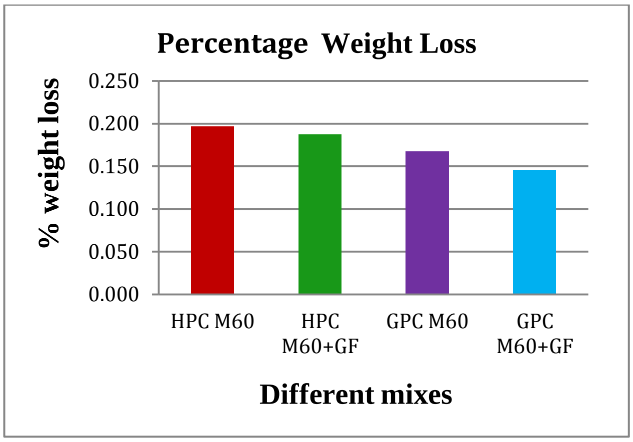
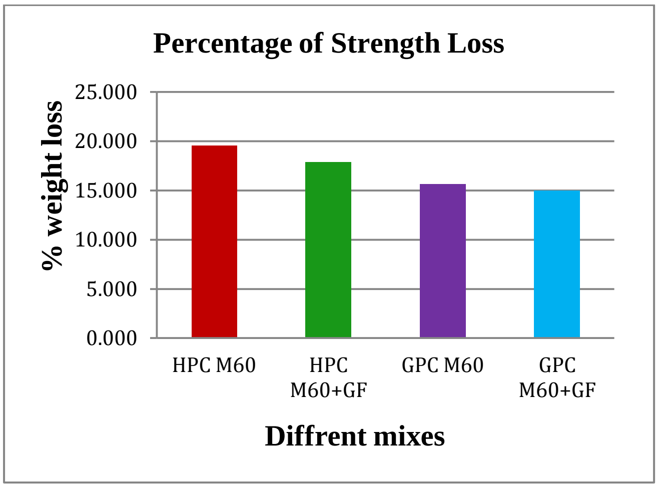
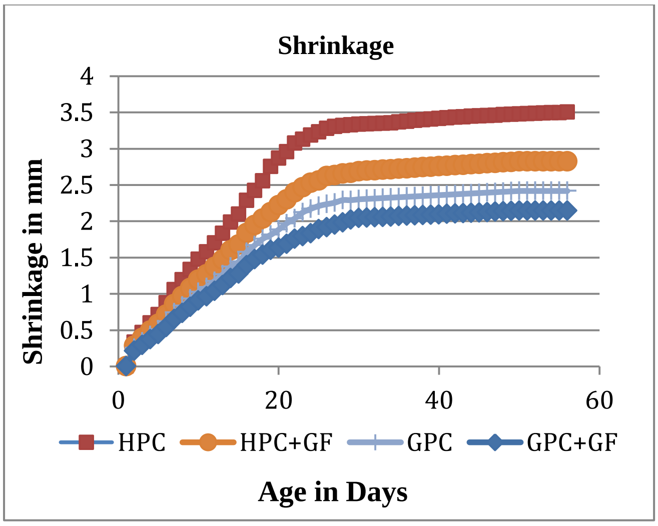


Chart-2: Percentage Strength Loss of Different concrete Specimen in Alkaline Attack Test



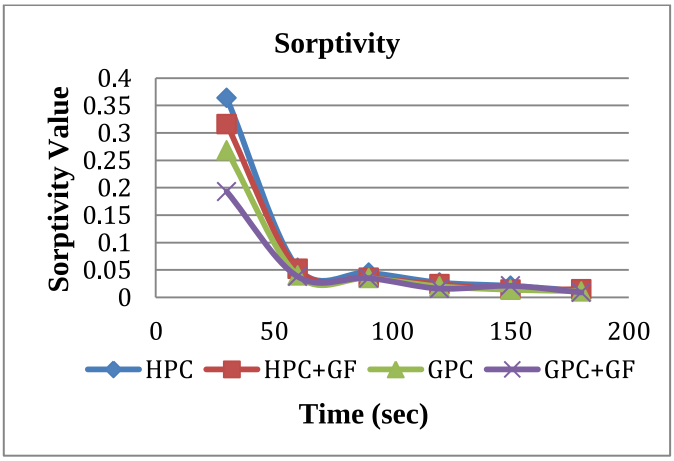
5.2 Shrinkage: Shrinkage reduced by up to 38.63% in GPC+GF at 56 days (2.145 mm vs. 3.501 mm in HPC). Fibers bridge micro-cracks and the geopolymer's low water demand minimizes drying shrinkage.

Chart-3: Shrinkage Test results of Different concrete Specimen in Shrinkage Test



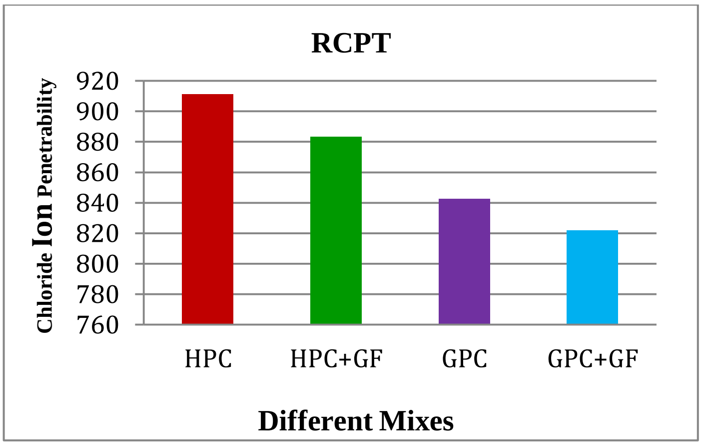
5.3 Sorptivity: Sorptivity rates were lowest for GPC+GF at 0.009 mm/min compared to HPC at 0.012 mm/min. The polymerized binder structure greatly reduces capillary suction and porosity.

Chart-4: Sorptivity Test results of Different concrete Specimen in Sorptivity Test



5.4 RCPT: RCPT values were significantly lower for GPC and GPC+GF mixes (~821.97 Coulombs) compared to HPC (~911.43 Coulombs), indicating high resistance to chloride ingress. This implies that GPC can enhance long-term durability in aggressive environments.

Chart-5: RCPT Test results of Different concrete Specimen in RCPT Test



The above findings show that glass fibers improve each measured durability parameter by mitigating micro-cracks and refining microstructure. GPC further amplifies these effects due to its dense matrix and low permeability. These observations align with the hypothesis that fiber-reinforced geopolymers can overcome the traditional shortcomings of HPC in aggressive conditions.

Limitations: This study was conducted under controlled laboratory conditions. Field-scale testing, long-term aging studies, and microstructural characterization (e.g., SEM, MIP) are recommended to validate performance in real-world applications

6. CONCLUSION

This study set out to examine the durability of HPC and GPC under aggressive conditions and to explore fiber reinforcement as a performance enhancer. The results confirm that:

- GPC + GF experienced minimal alkaline-induced strength loss (0.146%).
- Shrinkage was reduced by up to 38.63%.
- Sorptivity rates were minimal at 0.009 mm/min.
- RCPT indicated "Very Low" chloride permeability (~821.97 Coulombs).

Overall, geopolymers with glass fibers offer a superior and sustainable alternative to HPC. This research demonstrates the practical feasibility of fiber-reinforced GPC in infrastructure exposed to harsh environments.

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