SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I7P114

Volume 12 Issue 7, 159-167, July 2025

Original Article

Investigation on the Addition of Basalt and Glass Fibers on the Durability Characteristics of High-Performance Concrete

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Received: 11 May 2025 Revised: 15 June 2025 Accepted: 14 July 2025 Published: 31 July 2025

Abstract *- The current study aims to investigate the durability characteristics and behavior under elevated temperatures for high-performance concrete with various amounts of mono glass fibers and mono basalt fibers. The glass fibers in volume fractions between 0.1 to 0.4% and basalt fibers in volume fractions between 0.1 to 0.4% were used in this study. Furthermore, four sets of specimens with a total fiber volume fraction of 0.5% of the volume of concrete were assessed to ascertain the impact of hybrid glass-basalt fibers on the properties of the concrete. This study is divided into two parts. Firstly, the durability parameters like acid resistance, chloride permeability and sorptivity were evaluated. Secondly, the behavior of HPC exposed to elevated temperatures was studied. The present study evaluated the durability effects of mono glass fibers, mono basalt fibers, and hybrid fibers integrated into HPC. The findings revealed that HPC with mono basalt fibers performed better in terms of durability and increased temperatures than HPC with mono glass fibers. HPC with hybrid fibers outperformed all other mixes.*

Keywords *- High-performance concrete, Basalt fiber, Glass fiber, Hybrid fibers, Durability, Elevated temperature.*

1. Introduction

Concrete is the predominant material in the construction sector, attributed to its exceptional mechanical characteristics and durability. Extensive utilization of concrete increases the requirement for cement, consequently resulting in heightened carbon emissions. The incorporation of fly ash, silica fume, and slag, as partial substitutes for cement, is a significant approach to mitigate these issues [1, 2].

High Performance Concrete (HPC) has greater workability, increased strength, a high Young's modulus, lower permeability, and chemical resistance. To produce HPC, it is important to lower the water-to-cement ratio and improve the transition zone's quality by adding silica fume. [5]. HPC often has a diminished pore volume due to a reduced water-cement ratio; yet its performance is constrained by inherent brittleness [3]. Small, discrete synthetic or natural fibers greatly improve the mechanical properties of concrete. Fiber inclusion increases tensile strength, toughness, and impact resistance. Using different fiber kinds in concrete is clearly seen to increase its durability and sustainability [2, 4].

Basalt fiber is a multifunctional fiber that possesses a variety of exceptional qualities, including acid and alkali resistance, low and high-temperature resistance (ranging from -260°C to 700°C, compared to glass fiber's -50°C to 300°C), and good wettability [7]. The melting point of glass ranges from 1400 to 1600 °C. Glass fibers exhibit less alkali resistance compared to basalt fibers, although they exhibit superior performance in acidic environments [13, 14]. The main disadvantage of glass is its degradation in alkaline environments owing to its limited alkali resistance [12, 14].

Stefania Justin soaked samples of the concrete in acidic solutions with pH values of 3 and 5 for 28 days to examine its durability. The research concludes that concrete incorporated with glass fibers and silica fume exhibits enhanced mechanical capabilities and durability under acidic conditions. [2]. Gang Wu investigated the deterioration of tensile characteristics of basalt fibers in diverse corrosive conditions. The test results show that basalt fibers are quite resistant to damage from water and salt, have some resistance to acid, but break down a lot in alkaline (basic) solutions [11]. Mehrdad Abdi Moghadam studied the mechanical characteristics and durability of concrete reinforced with steel and glass fibers and exposed to elevated temperatures. The study reveals that increased temperature may reduce the durability qualities of concrete, while the incorporation of fibers has mitigated the effect [10].

Guo et al. observed that including basalt fibers into concrete can enhance the charge passing through the concrete in comparison to normal concrete. The charge went up because the concrete had more pores and soaked up more water [9, 15]. Nonetheless, despite the elevated charge, these mixes can still be categorized as having low chloride permeability in accordance with ASTM standard requirements [19]. Saradar et al. demonstrated that the water absorption of BFRC increases linearly as the basalt fibers dose increases. It is evident that the water absorption increases by approximately 13% and 33% at a basalt fiber dose of 0.1 and 0.5 vol%, respectively [9, 16]. Alaskar et al. conducted a study to compare the effects of elevated temperatures (300 ºC and 600 ºC) on concrete samples with a basalt fiber concentration of 0.5% to those without fibers. When compared to the wider cracks in control specimens, BRFC specimens exhibited numerous smaller cracks. Fiber-reinforced specimens did not exhibit any spalling. This was due to the fiber's ability to hold the concrete together and prevent it from cracking or breaking under high heat. The author also reported that the residual mechanical properties of concrete were relatively higher as a result of the addition of basalt fibers [9, 17].

Many researchers in the past have conducted distinct studies on the durability of glass fibers and basalt fibers. However, there is a research gap in the area of concrete reinforced with hybrid fibers. The present study examined the durability of HPC reinforced with both mono and hybrid forms of a synthetic fiber and a natural fiber, i.e. alkali-resistant glass fibers and basalt fibers.

2. Experimental Program

2.1. Materials

HPC was prepared by using OPC 53 grade cement, Ggbs, micro silica, Zone III River sand, 12mm and 6mm coarse aggregate, Mac Hyperplast PC 310 super plasticizer and water. The chemical properties of Ggbs are shown in Table 1. The physical and chemical composition of silica fume is shown in Table 2.

Table 1. Chemical composition for Ggbs

CaO %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO%	MnO%
37.6	34.8	17.9	0.66	7.80	0.21

Table 2. Physical & Chemical composition for silica fume

CaO %	SiO_2 %	Fineness (M^2/kg)	Specific Gravity
<1%	94% (Avg)	21000 (Avg)	2.2-2.8

Mono basalt fibers of size 6mm were used. Owens corning anti-crack HD mono glass fibers of size 12mm were used. The physical parameters of the fibers are presented in Table 3.

The aggregates were initially blended in the concrete mixer for 2-3 minutes. Cement, GGBS, and micro silica were subsequently included in the concrete mixture and permitted to blend for an additional 2 minutes. Subsequently, water and superplasticizer were included in the mixture. The concrete mix was then allowed to mix for another 5 minutes until it became uniform and homogeneous. Fibers were added to the mix while mixing, such that the fibers were distributed uniformly.

Table 3. Properties of fibers

Property	Basalt	AR Glass Fiber
Length (mm)	6	12
Diameter (mm)	0.015	0.0135
Length-to-diameter ratio	400	888
Density (g/cm^3)	2.75	2.68
Elastic Modulus (Gpa)	93	72
Tensile Strength (Mpa)	3500	1400

2.2. Mix Proportions

Table 4 shows the mix proportions for the control HPC mix, which is named Conv (Conventional Mix). The study used 13 different test mix proportions to assess the influence of the two fiber types on HyFRHPC (Table 5). The two fibers were non-metallic and easy to agglomerate when used in large fractions. Hence, the volume fraction of fibers individually and combined was limited to 0.5%.

Table 4. M70 Mix proportion

Mix	M70
Cement (kg/m^3)	343
Ggbs (kg/m^3)	200
Micro Silica (kg/m^3)	29
Water (kg/m^3)	156
Coarse Aggregate (kg/m^3)	1055
Fine Aggregate (kg/m^3)	697
Super Plasticizer (kg/m^3)	2.57

Table 5. Mono fiber mix designation

Specimen Designation	V_f (%)	Basalt Fiber	AR Glass Fiber
Conv	-	-	-
B0.1	0.1	100%	-
B0.2	0.2	100%	-
B0.3	0.3	100%	-
B0.4	0.4	100%	-
G0.1	0.1	-	100%
G0.2	0.2	-	100%
G0.3	0.3	-	100%
G0.4	0.4	-	100%
B0.1G0.4	0.5	20%	80%
B0.2G0.3	0.5	40%	60%
B0.3G0.2	0.5	60%	40%
B0.4G0.1	0.5	80%	20%

2.3. Test Methods

To evaluate the compressive strength, 150mm size concrete cube samples were cast. Each mix had 15 samples cast to test its compressive strength preceding and following acid exposure. Compressive strength was checked on three samples after 28 days of curing, following IS 516 guidelines (Part 1/Sec 1) 2021 [22]. Six samples were soaked in 1% H_2SO_4 solution, while another six samples were soaked in 3% H_2SO_4 solution under acidic conditions. Among the 6 samples, 3 samples were evaluated for compressive strength after being subjected to acidic conditions for 28 days, and another 3 samples were examined after acid conditioning for a period of 180 days. Prior to and following exposure to acidic conditions, all of the combinations indicated in Table 2 underwent casting and compressive strength testing. The samples subjected to acid conditioning are shown in Figure 1.

Fig. 1 Acid conditioning

To assess chloride permeability, six concrete cylinders (100 mm diameter × 200 mm length) were cast for each mix. After 28 days of curing, the cylinders were cut into 50 mm thick slices. These slices were coated with epoxy and dehydrated. The test was carried out using a test cell filled with 3% NaCl solution on one side and a 0.3 N NaOH solution on the other. A voltage of 60.0 ± 0.1 V was applied across the sample for 6 hours, and the charge passed (in coulombs) was recorded every 30 minutes. The procedure followed the ASTM C1202 standard [20]. The RCPT apparatus is shown in Figure 2.

Fig. 2 RCPT apparatus

Concrete cylinders measuring 100 mm × 200 mm were cast to evaluate sorptivity. After 28 days of curing in fresh water, the cylinders were cut into 50 mm thick slices. The specimens were prepared according to ASTM C1585 [21]. A silicon sealant was applied to all surfaces except the top and bottom. The samples were then placed on glass rods in a watertight pan, and tap water was added until the water level was 2–3 mm above the base of the specimens. A timer was started as soon as the water was added. The initial weight and weights at intervals from 60 seconds to 6 hours were recorded using a weighing balance. Before weighing, the surface was lightly wiped to remove excess water. The absorption, initial rate of absorption (I), and sorptivity were calculated as per ASTM C1585 [21]. Samples subjected to sorptivity tests are shown in Figure 3.

Fig. 3 Sorptivity testing

Fig. 4 Elevated temperature

150mm size concrete cubes were cast to evaluate the concrete's resistance to elevated temperatures. A total of 15 samples were cast for each mix. Three samples were evaluated for compressive strength following a curing duration of 28 days. 3 samples each from the remaining 12 samples were subjected to 200 ˚C, 400 ˚C, and 600 ˚C in a muffle furnace. The temperature in the muffle furnace was set to the desired temperature. The temperature increases to the desired temperature at a rate of 20 ˚C/min from room temperature. Then the muffle furnace with concrete cube samples was maintained at a constant temperature for a period of 120 minutes after attaining the desired temperature. The muffle furnace was powered off and samples were subjected to air curing. Concrete cube specimens were then tested for residual compressive strength and mass loss.

Table 6. Specimen details

Specimen	Size (mm)	Type of Test
Cube	150 x 150 x 150	Residual compressive strength - post acid conditioning
Cube	150 x 150 x 150	Mass loss and residual compressive strength of concrete subjected to elevated temperature
Cylinder	100 x 200	Rapid chloride permeability
Cylinder	100 x 200	Sorptivity

3. Results and Discussion

3.1. Acid Resistance

Concrete cube samples that had been acid-conditioned for 28 days and 180 days were removed from the acid solution and allowed to dry. The samples were weighed before and after acid conditioning using a weighing balance to determine the mass loss. Figures 5a and 5b depict the mass loss of concrete cube specimens treated to acidic conditioning after 28 days and 180 days.

The samples were subsequently examined in a CTM, and their residual compressive strength was determined. After obtaining the individual data, they were compared to the compressive strength of the control specimen under normal conditions. Based on this, the performance of HPC with fibers subjected to acid conditioning is evaluated. Figure 6 illustrates the compressive strength of concrete samples following acid conditioning.

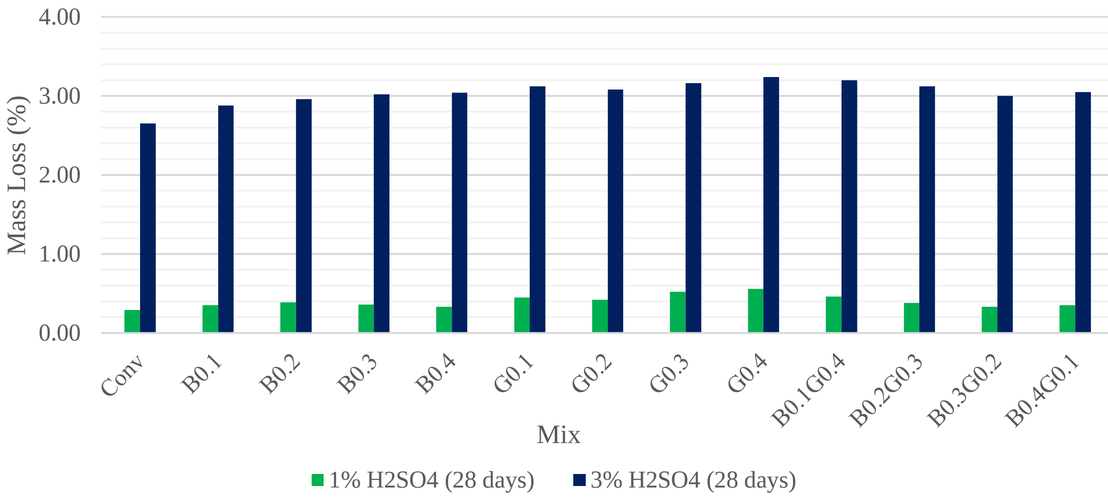

Fig. 5(a) Mass loss after acid conditioning (28 days)

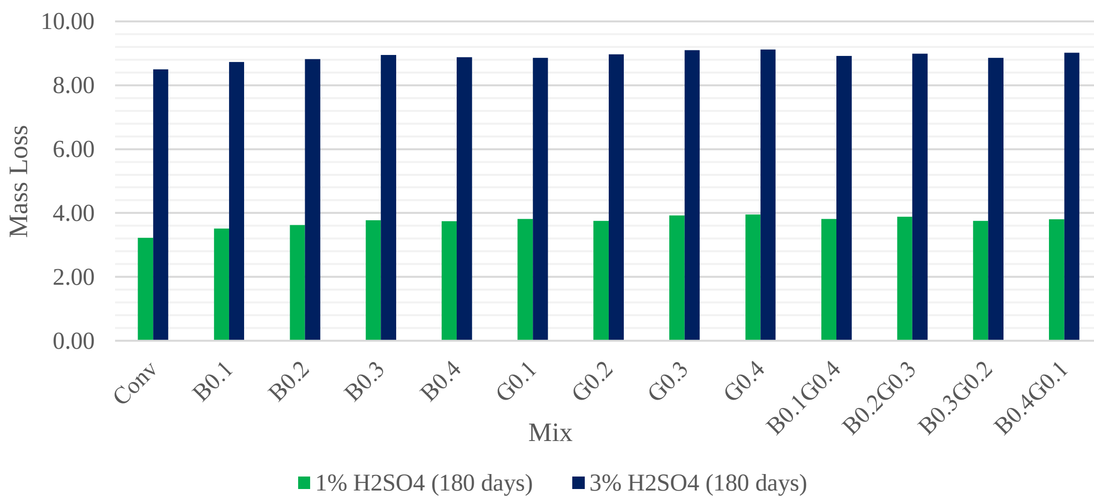

Fig. 5(b) Mass loss after acid conditioning (180 days)

Concrete mass loss occurs when H2SO4 penetrates and reacts with portlandite and calcium silicate hydrates (C-S-H). During these reactions, the two components dissolve and gypsum precipitates. The process may reduce concrete performance due to gypsum's low strength [18].

The HPC with basalt fibers showed less mass loss when compared to the remaining HPC mixes with fibers. Whereas the HPC with hybrid fibers has less mass loss when compared to the HPC with glass fibers.

Glass fibers when treated with acid, get damaged, and spiral cracks will form on the surface. The metal ions in the glass fibers deplete and become more susceptible to acid attack [19]. This further leads to a loss of mass and strength.

After 180 days of 1% and 3% H_2SO_4 acid conditioning, the HPC with hybrid fibers had superior results in terms of residual compressive strength, ranging from 48.89 to 52.44 Mpa and 37.93 to 42.07 Mpa, respectively. HPC with glass fibers showed lower residual compressive strength values of 48.30 - 50.52 Mpa and 35.36 - 36.89 Mpa after 180 days of 1% and 3% H2SO4 acid conditioning, respectively. After 180 days of 1% and 3% H_2SO_4 acid conditioning, the residual compressive strength values for HPC containing basalt fibers ranged from 48.74 to 52.00 Mpa and 37.04 to 40.30 Mpa, respectively. This is because basalt fibers are more resistant to acids. In contrast, glass fibers were very susceptible to acid attack. Hybrid fibers, which contain a high proportion of basalt fibers and a low proportion of glass fibers, provide greater acid resistance than monoglass fibers. This is due to the synergistic effects of the two fibers.

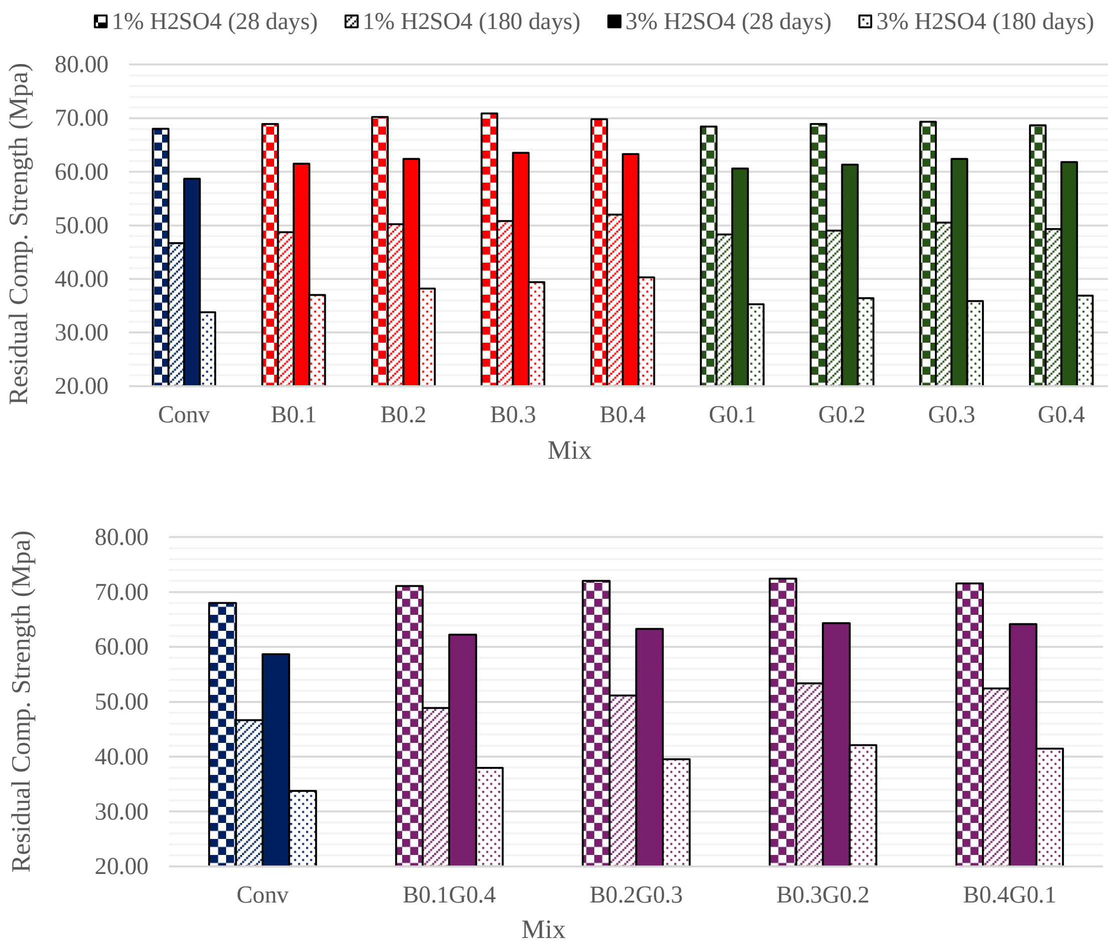

Fig. 6 Compressive strength after acid conditioning

3.2. Rapid Chloride ion Permeability

The charge transmitted measures the permeability of concrete to chloride ions in accordance with ASTM C1202. Figure 7 presents the results of the rapid chloride permeability tests performed on HPC samples incorporating mono basalt fibers, mono glass fibers, as well as hybrid fibers. The incorporation of basalt fiber enhances the chloride permeability of HPC by 10.8% to 15.2%, yielding values between 1443 and 1500 Coulombs. The incorporation of AR glass fibers elevates the chloride permeability of HPC by 19.6% to 21.7%, with results between 1548 and 1584 Coulombs. The rise in charge can be attributed to the heightened porosity and water absorption of the concrete. The chloride permeability of hybrid fiber HPC exceeds that of the control mix and mono basalt fiber mixtures. Nonetheless, the chloride permeability is lower than that of the mono glass fiber mixtures. This decrease in charge can be attributable to the synergistic action of hybrid fibers of varying sizes. All mixes yield values beneath the threshold of 2000 coulombs, categorizing them as lower tier per ASTM C1202 standards. This is due to the incorporation of pozzolanic elements such as GGBS and silica fume in the mixture.

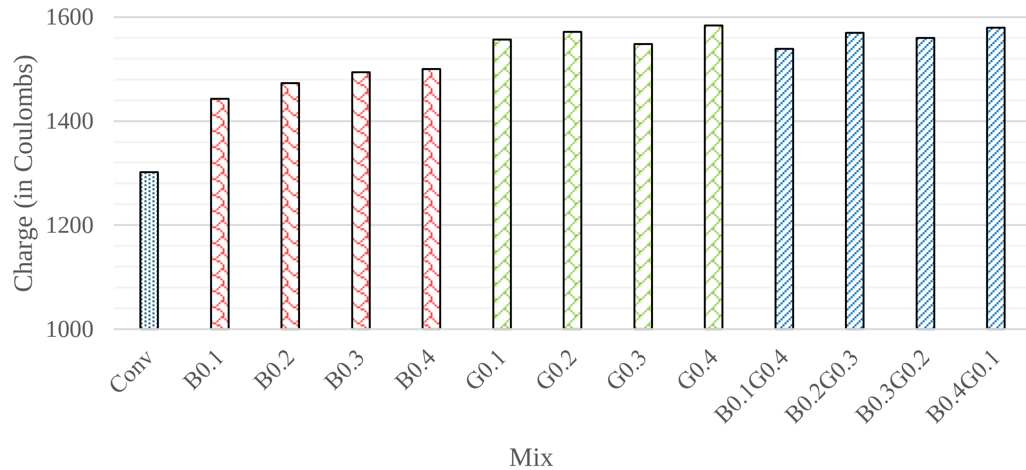

Fig. 7 Chloride permeability results

3.3. Sorptivity

Sorptivity is a measurement that quantifies the rate at which a porous material, such as concrete, absorbs water through capillary action. The expansion of the internal cavities of concrete is the primary cause of the increase in water absorption. The High-Performance Concrete (HPC) using basalt fibers exhibited lower sorptivity values in comparison to the HPC containing glass fibers. This phenomenon is ascribed to the increased surface area of the glass fibers, resulting from their size and the channels created around them, which contribute to an increase in voids inside the concrete. Nevertheless, the HPC with hybrid fibers exhibited lower sorptivity values in comparison to the glass fibers. This is ascribed to the synergistic impact of both fibers.

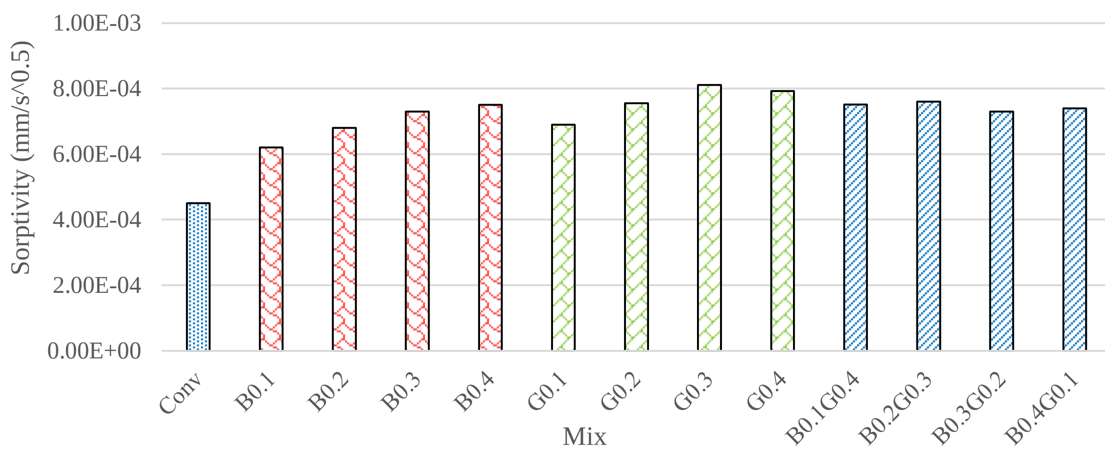

Fig. 8 Sorptivity

3.4. Elevated Temperatures

The HPC incorporated with fibers is subjected to elevated temperatures of 200 ˚C, 400 ˚C, and 600 ˚C for 120 minutes in a muffle furnace. The samples were then allowed to drop to room temperature naturally. The concrete samples were subsequently tested in compressive testing equipment to measure the residual compressive strength. The concrete samples were weighed on the weighing scale before and after being subjected to extreme temperatures. The mass reduction is evaluated based on these weights. Figure 9 displays the residual compressive strength values of HPC that contains both mono and hybrid fibers.

Figure 10 depicts the mass loss of HPC with and without fibers under increased temperatures. Mass loss is quite minimal at 200 ˚C, but increases dramatically at 400 ˚C. This occurs as a result of internal water evaporation and interfacial bond breakdown in the cement paste-aggregate transition zone.

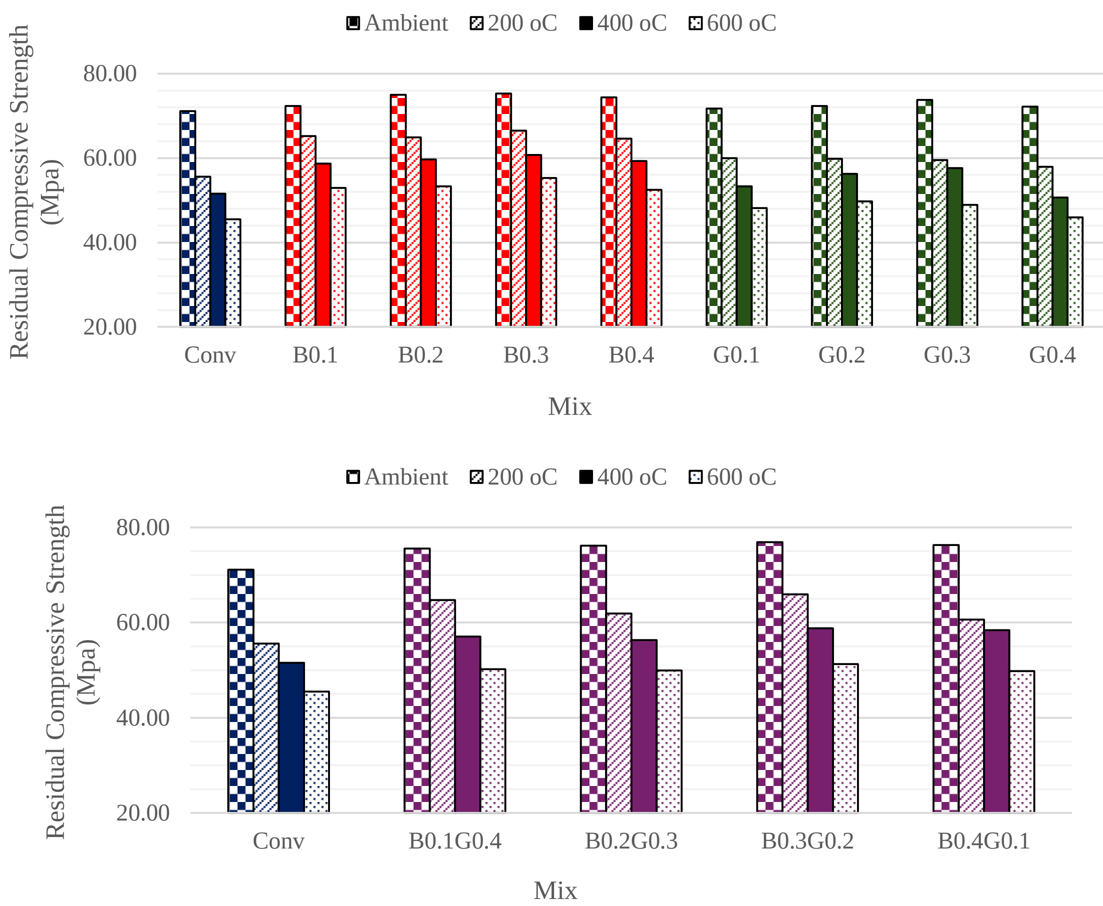

Fig. 9 Residual compressive strength

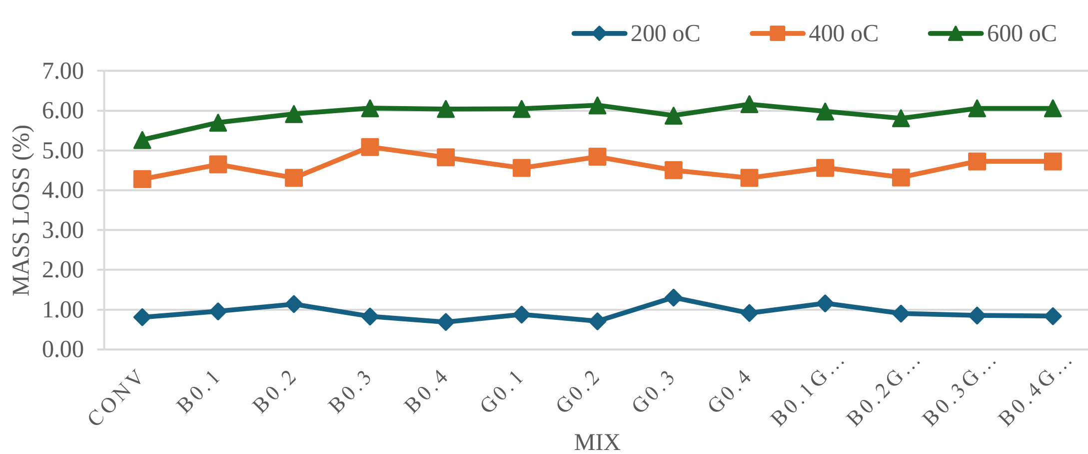

Fig. 10 Mass loss

At a temperature of 200°C, the specimens turned a light yellow color. Minor cracks were visible on the surface of the control HPC specimens. There were cracks visible on the surfaces of all specimens at 400°C. Nevertheless, the number of cracks on the surface of HPC specimens without fibers is greater. The presence of fibers in the specimens signifies that the internal bridging of fibers reduced the formation of cracks. The HPC with mono basalt fibers exhibited the least amount of crack formation and no spalling among all the mixtures. While the HPC with mono glass fibers and hybrid fibers showed moderate crack development and no spalling. Conversely, the control HPC specimens had more surface cracks.

4. Conclusion

- The HPC with mono basalt fibers offered better residual compressive strength after being subjected to acids than the glass HPC with mono glass fibers. However, HPC with a hybrid fiber B0.3G0.2 mix offered superior results in terms of strength due to the synergy effect of the fibers.
- Mass loss was observed more in the HPC with glass fibers than in the remaining mixes. This suggests that glass fibers are less resistant to acids, both in regard to mass loss and residual compressive strength.
- The rate of water absorption is higher in HPC with glass fibers. It is modest in HPC with mono basalt fibers and HPC with hybrid fibers. This suggests that the insertion of fibers increases sorptivity. However, basalt fibers perform better in terms of sorptivity.
- Similar results were obtained in terms of chloride permeability. HPC with mono glass fibers had higher chloride permeability values than other mixtures. Glass fibers exhibited low resistance to chloride penetration.
- HPC with basalt fibers has been shown to be more resistant to high temperatures than HPC with monoglass fibers. However, the HPC with the hybrid fibers B0.3G0.2 combination outperformed the other mixes.
- Overall, in the durability aspect, HPC with mono glass fibers exhibited superior results when compared to the normal HPC, but lower results in comparison with HPC with mono basalt fibers. The HPC with hybrid fibers exhibited overall superior outcomes in acid conditioning and increased temperatures due to the synergy effect. Whereas, it demonstrated similar findings to HPC with mono basalt fibers in terms of sorptivity and chloride permeability.

References

[1] Mark Alexander, Arnon Bentur, and Sidney Mindess, *Durability of Concrete: Design and Construction*, 1st ed., CRC Press, pp. 1-345, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Stefania Justin, Kannan Thushanthan, and Gobithas Tharmarajah, "Durability and Mechanical Performance of Glass and Natural Fiber-Reinforced Concrete in Acidic Environments," *Construction and Building Materials*, vol. 465, pp. 1-35, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[3] Mahmoud Nili, and Afroughsabet, "Combined Effect of Silica Fume and Steel Fibers on the Impact Resistance and Mechanical Properties of Concrete," *International Journal of Impact Engineering*, vol. 37, no. 8, pp. 879-886, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[4] Jianqiang Wei, Siwei Ma, and D'Shawn G. Thomas, "Correlation between Hydration of Cement and Durability of Natural Fiber-Reinforced Cement Composites," *Corrosion Science*, vol. 106, pp. 1-15, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[5] M.S. Shetty, and A.K Jain, *Concrete Technology (Theory and Practice), 8e*, S. Chand Publishing, pp. 1-636, 2019. [Google Scholar] [Publisher Link]

[6] Dehong Wang et al., "Mechanical Properties of High Performance Concrete Reinforced with Basalt Fiber and Polypropylene Fiber," *Construction and Building Materials*, vol. 197, pp. 464-473, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[7] Zeynep Algin, and Mustafa Ozen, "The Properties of Chopped Basalt Fibre Reinforced Self-Compacting Concrete," *Construction and Building Materials*, vol. 186, pp. 678-685, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[8] Yuanxun Zheng et al., "A Review of the Mechanical Properties and Durability of Basalt Fiber-Reinforced Concrete," *Construction and Building Materials*, vol. 359, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ehab T. Al-Rousan, Hammad R. Khalid, and Muhammad Kalimur Rahman, "Fresh, Mechanical, and Durability Properties of Basalt Fiber-Reinforced Concrete (BFRC): A Review," *Developments in the Built Environment*, vol. 14, pp. 1-17, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mehrdad Abdi Moghadam, and Ramezan Ali Izadifard, "Effects of Steel and Glass Fibers on Mechanical and Durability Properties of Concrete Exposed to High Temperatures," *Fire Safety Journal*, vol. 113, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Gang Wu et al., "Durability of Basalt Fibers and Composites in Corrosive Environments," *Journal of Composite Materials*, vol. 49, no. 7, pp. 873-887, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[12] Shi Yin et al., "Use of Macro Plastic Fibres in Concrete: A Review," *Construction and Building Materials*, vol. 93, pp. 180-188, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[13] Tamás Deák, and Tibor Czigány, "Chemical Composition and Mechanical Properties of Basalt and Glass Fibers: A Comparison," *Textile Research Journal*, vol. 79, no. 7, pp. 645-651, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[14] Jawad Ahmad et al., "Glass Fibers Reinforced Concrete: Overview on Mechanical, Durability and Microstructure Analysis," *Materials*, vol. 15, no. 15, pp. 1-23, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Yihong Guo, Xinyu Hu, and Jianfu, "Experimental Study on the Resistance of Basalt Fibre-Reinforced Concrete to Chloride Penetration," *Construction and Building Materials*, vol. 223, pp. 142-155, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Ashkan Saradar et al., "Prediction of Mechanical Properties of Lightweight Basalt Fiber Reinforced Concrete Containing Silica Fume and Fly Ash: Experimental and Numerical Assessment," *Journal of Building Engineering*, vol. 32, pp. 1-12, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] Abdulaziz Alaskar et al., "RETRACTED: Performance Evaluation of High-Strength Concrete Reinforced with Basalt Fibers Exposed to Elevated Temperatures," *Journal of Building Engineering*, vol. 35, pp. 1-9, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[18] Haifeng Yuan et al., "Degradation Modelling of Concrete Submitted to Sulfuric Acid Attack," *Cement and Concrete Research*, vol. 53, 267-277, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[19] Dan Xing et al., "What Happens to Glass Fiber under Extreme Chemical Conditions?," *Journal of Non-Crystalline Solids*, vol. 548, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] ASTM C1202-22, "*Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*," American Society for Testing and Materials, pp. 1-8, 2012. [Google Scholar] [Publisher Link]

[21] ASTM C1585-20, "*Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes*," American Society for Testing and Materials, 2020. [Google Scholar] [Publisher Link]

[22] IS 516 (Part 1/Sec 1):2021, "*Hardened Concrete - Methods of Test: Part 1 Testing of Strength of Hardened Concrete: Section 1 Compressive, Flexural and Split Tensile Strength (First Revision)*," Bureau of Indian Standards, 2021. [Google Scholar] [Publisher Link]

[23] IS 3085:1965, "*Method of Test for Permeability of Cement Mortar and Concrete*," Bureau of Indian Standards, 1965. [Google Scholar] [Publisher Link]