STRENGTH AND DURABILITY OF STEEL FIBER REINFORCED HIGH STRENGTH GEOPOLYMER CONCRETE

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ABSTRACT

The goal of the current study is to better understand the limitations on the durability of geopolymer concrete manufactured from Class F fly ash and GGBS, two industrial waste leftovers. OPC and GPC concretes are created using the M50 grade under ambient curing. The produced concretes were evaluated for strength and sorptivity and water absorption properities as well as for strength and durability against sulphate and chloride attack.During 28and 90 days, 1, 3, and 5% concentrated solutions of H2SO4, HCl, and NaCl were applied to GPC and OPC concrete, respectively. In this investigation, a 2.5 alkaline liquid to binder ratio was used. For this investigation, a molarity concentration of 10 of NaOH was used. Steel fibers are used at a dosage of 0-2% with an increments of 0.5% by weight of cement. Tests were done on characteristics such density, surface degradation, and compressive strength. To explore microstructural qualities, samples were also subjected to XRD analysis and SEM image characteristics. GPC concrete performs better than OPC concrete in terms of resistance to sulphate and chloride attack.The test findings showed that under aggressive media, GPC concrete over the designated time period attained better strength and durability qualities to OPC concrete.

Keywords : Durability, Strength, Steel Fibers, Aggressive Media

1.0 Introduction

Geopolymer technology offers the potential to transform industrial wastes into cement-free, sustainable building materials. The geopolymers are created when alumino-silicate-rich industrial waste materials combine with dissolved alkaline solutions (sodium/potassium based)[1-2]. With its superior mechanical properties, greater bond strength, higher durability, and denser matrix, geopolymer concrete (GC), a replacement for conventional Portland cement (OPC) concrete, has been made using industrial wastes such as fly ash (FA), slag, and rice husk ash that are rich in alumino-silicate.Nonetheless, GC has been regarded as having a lower carbon footprint than concrete made with regular Portland cement (OPC) [5]. FA (class-F) and ground granulated blast boiler slag (GGBFS) have a stronger influence on the synthesis of geopolymers among all industrial wastes since these combinations have been primarily documented by several researchers. Yearly, both the abundance of these industrial waste materials and the rather constant geopolymeric reactions were noted.The production of geopolymer compounds is a complicated matrix that the researchers are currently having trouble identifying. Yet, it is crucial to recognise that published research have shown that the strength performance of GC is dependent on the source materials' chemical makeup, curing method, ratios of alkaline liquids, and the molarity of NaOH[3-10].

The inclusion of GGBFS increased the strength features of GC. Four different percentages of FA were swapped out for GGBFS to produce GC. It was discovered that the strength of the geopolymer concrete increased with the quantity of GGBFS present. Nevertheless, adding more GGBFS-based GC mix at greater percentages allowed for the achievement of 90% compressive strength after seven days of open atmospheric curing. In contrast, 20% of the strength was lost when the GC samples were subjected to a temperature increase of 500 °C[11].

The replacement of GGBFS is in the growth of FA-based GC's strength and durability qualities.According to the authors, the formation of C-A-S-H gel and other geopolymer products, particularly in the early years, is aided by the presence of greater amounts of CaO. Nevertheless, the particle size, amorphous content, morphology, and the origin of fy ash and GGBFS are the other characteristics that influenced the suitability of high calcium FA to be a GGBFS for the development of GC[12-13].Nevertheless, most researches observed that greater calcium content FA is more suited for geopolymers than lower calcium FA , with the latter being less appropriate. The high calcium based geopolymers are more likely to create C-A-S-H gel. Greater calcium concentrations in FA-based GCs cause the development of more geopolymeric products, which have superior mechanical characteristics. A charge-balancing cation is reportedly produced by calcium when it enters the geopolymer matrix in increasing concentrations of GC.The impact of GGBFS on the strength and microstructural performance of FA-based GC samples under various environmental conditions was recently described.The GC samples based on FA-GGBFS, however, have demonstrated improved morphology in the creation of geopolymeric end products without the need of an ovencuring[21]. According to the available literature, it is clear that GPC concrete outperforms OPC concrete in terms of strength and durability.

Investigating the mechanical, durability, and microstructural characteristics of FA-GGBFS based GC samples during ambient curing is the primary goal of this work. Based on the strength characteristics of the GC mixes with different substitutions of FA with GGBFS, the most advantageous combination of FA and GGBFS was determined.When evaluated for 28, and 90 days of ambient curing, the mechanical characteristics, such as compressive, splitting tensile, and flexural strengths, were compared with OPC (controlled mix). The durability investigations, however, are carried out on FA-GGBFS based GC samples using methods including the water absorption, and sorptivity. On GC samples following a 28-day curing period, SEM and XRD experiments were also carried out to assess the micro-level reactions.

2.0 EXPERIMENTATION

2.1 MATERIALS& METHODOLOGY

In this investigation, the binder for making geopolymer concrete is GGBS and class F flyash mixed 50:50. The flyash and GGBS were sourced from the VTPS Thermal Power Plant and the Visakhapatnam Steel Plant, respectively. The chemical properties of the binder as identified by X-Ray fluorescence are displayed in Table 1. Manufactured sand (M-Sand) and 20 mm down angular granite were obtained from readily available local sources for the fine and coarse materials, respectively.

Hook-end steel fibres with an aspect ratio of 80 were acquired from Chennai and used to create steel fiber-reinforced geopolymer concrete. Table 2 provides the mix percentage. The sodium-based activator used a mixture of sodium silicate solution and sodium hydroxide (10 M). The water glass modulus of the sodium silicate used in the experiment is around 2.34. The sodium hydroxide solution was made using the 97% pure NaOH flakes. The ratio of sodium silicate to sodium hydroxide solution was kept constant at 2.5. In this, the mechanical strength properties of the GPC mixes, which were cast with steel fibres containing 1.5%, are examined and given.

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Table 1: Chemical Characteristic of the Ingredients

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O
Class F-FA	66.81	24.52	4.1	1.52	0.46	0.41
GGBS	39.19	10.19	2.01	32.83	8.53	1.2

Table 2: Mix Ingredients of GPC concrete

S. No.	Constituents	M50 grade Quantity(kg/m^3)	
1.	Binder (FA+GGBS) (50%+50%)	410	
2.	Na_2SiO_3	117.14	
3.	NaOH	46.86 (10M)	
4.	Fine aggregate	554.4	
5.	Coarse aggregate	1294	20mm----776.16Kg 12mm----517.44Kg

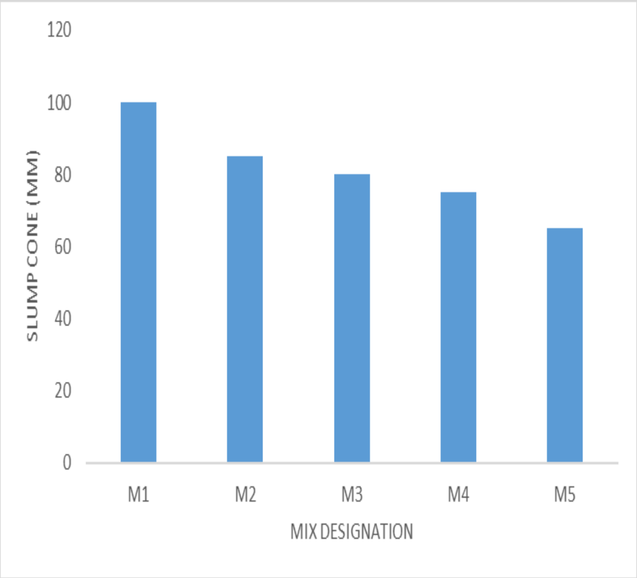
The IS:456-2019 specifications were used to manufacture the geopolymer concrete, and Table 2 displays the mix fraction that was taken into account for the study. Using this mix ratio, concrete was created that had outstanding tensile, flexural, and compressive properties. The fresh properties of the concrete were evaluated using a slump test in accordance with IS 1199-1959. (1959).

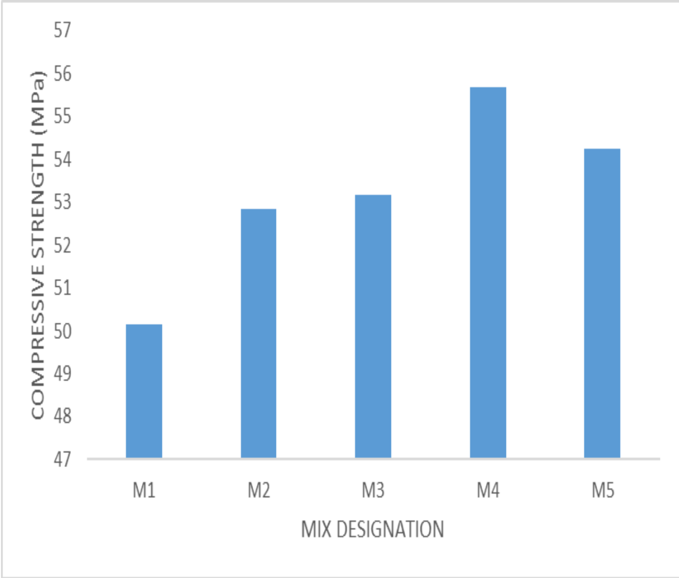
Specimens were made in accordance with IS 516 in order to evaluate the compressive strength, flexural strength, and split tensile strength of geopolymer concrete. After being cast, the specimens were demolded after 24 hours at room temperature.

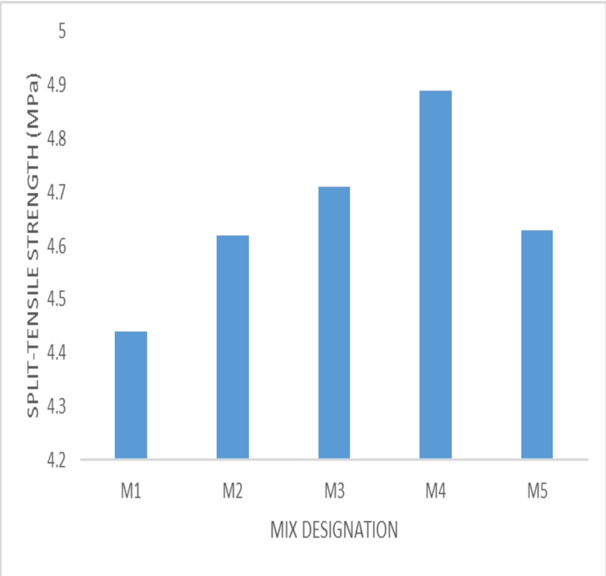
The specimens were tested for compressive strength after 14 and 28 days, split tensile and flexural strength after 28 days (1959) in accordance with IS 516-1959[22].

Table 3: Fresh and Hardened Properties of GPC

Mix	Slump	Compressive Strength (MPa)	Split-tensile strength (MPa)	Flexural Strength (MPa)
M1-CM-GPC	100	50.16	4.44	4.59
M2-0.5% SF	85	52.83	4.62	4.67
M3-1% SF	80	53.18	4.71	4.78
M4-1.5% SF	75	55.69	4.89	4.91
M5-2% SF	65	54.25	4.63	4.46







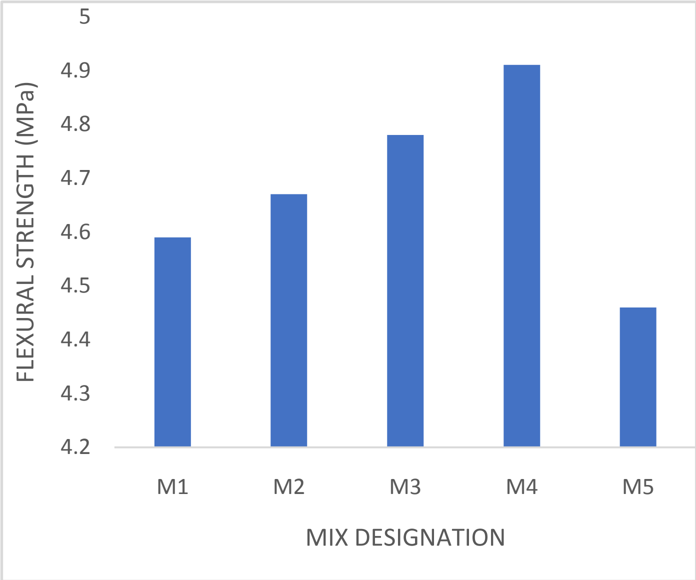


Fig.1 Slump Cone ValuesFig.2 Compressive Strength of GPC

Fig.3 Split-tensile strength of GPCFig.4 Flexural strength of GPC

It can be concluded from the above test findings, represented in fig.2,3 and 4, that M50 grade GPC with 1.5% dose of steel fibres exhibited greater mechanical strength properties when compared to other mixtures and it is chosen for the further study i.e., modulus of elasticity (E),SEM& XRD analysis and durability studies.

2.2 Modulus of Elasticity

The stress-strain curve's ratio of stress to strain up to the elastic limit was used to determine the GPC's modulus of elasticity (the secant modulus). The tests were carried out in accordance with IS: 516-1959. To record any deformations at the appropriate stresses, an extensometer was linked to each of the produced cylinder specimens. A testing machine with a 2000 kN capacity was used for the tests. Figure 5 depicts the test configuration and Figure 6 shows the stress-strain curve for the GPC specimens evaluated under compression, and Table 4 displays the results for the modulus of elasticity.

The method outlined in ASTM Standard C469-02 was used to estimate the modulus of elasticity for the cylindrical geopolymer specimen. The cylindrical geopolymer specimen's elastic modulus was calculated using the equation below (Giasuddin, 2014).

$E_c = 1450 \sqrt{(fc_1)}$

(fc_1) Highest axial stress is equal to half of fc_1 in MPa.

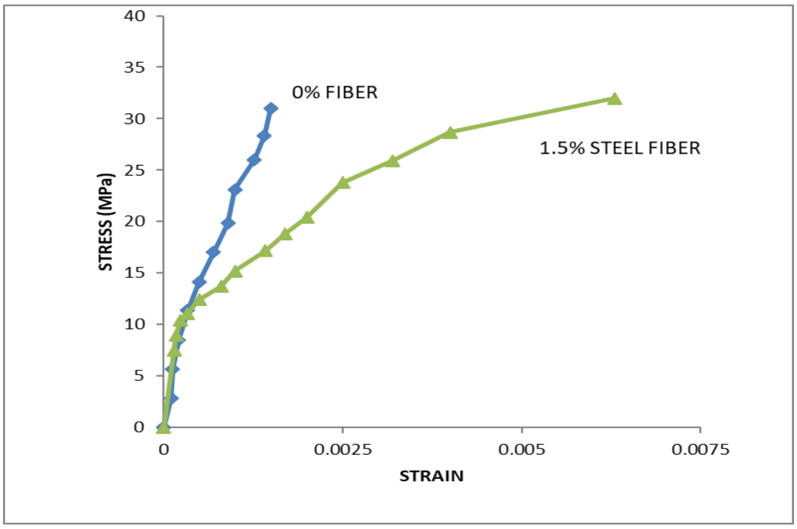


Fig.5 Test Setup for E of GPC   Fig.6 Stress-strain curve for M50 grade GPC

Figure 6 demonstrates how the ultimate stress increased as the concrete's compressive strength increased. With a rise in compressive strength, it is discovered that the maximum strain decreases.

Table 4 : E Values for different mixes of GPC

Mix	Modulus of Elasticity (E) (GPa)
M1	15.74
M4	17.35

The elastic modulus of GPC concrete is exactly related to its compressive strength, however it is significantly lower than that of OPC concrete for comparable compressive strengths. With 1.5% steel fibre GPC with a control mix of M50 grade concrete, the modulus of elasticity improved by 10% with an increase in compressive strength.

2.3 SEM & XRD analysis

Figs. 7 provide SEM images of Class F-fly ash with GGBS in the percentage of (50% + 50%) for M50 grade GPC.

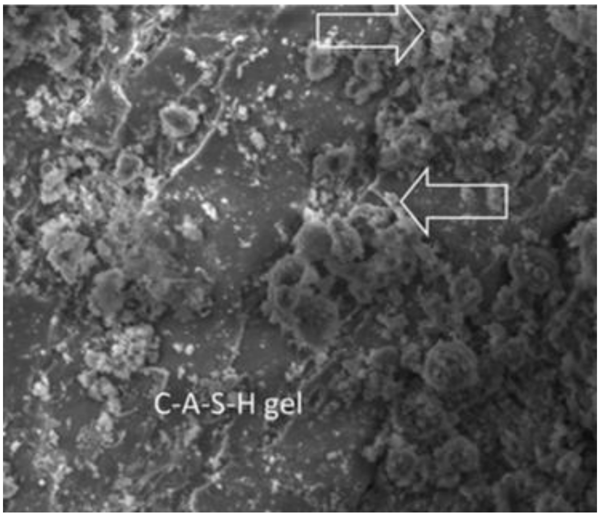


Fig.7 SEM image of M50 GPC with FA & GGBFS

In Fig. 8, XRD pictures revealed an exceptional peak in the fly ash that is quartz (2-theta = 270), identifying the presence of SiO_2 in the fly ash. Mullite is the second prominent peak in fly ash at various 2-theta range values. The CaO concentration detected in GGBS is 33%, and the remarkable peaks for calcite and quartz were seen at a variety of range values. The exceptional peaks for alite, pentlandite, and belite were found in cement at various ranges.

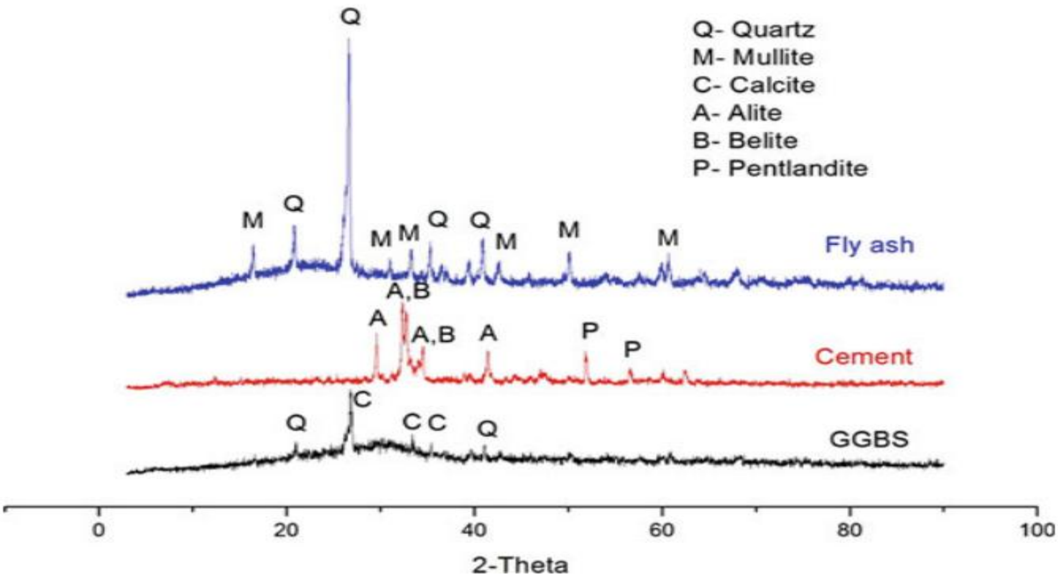


Fig.8 XRD analysis for the materials used in this study

2.4 Durability Studies

2.4.1 Compressive Strength of GPC under different exposure conditions

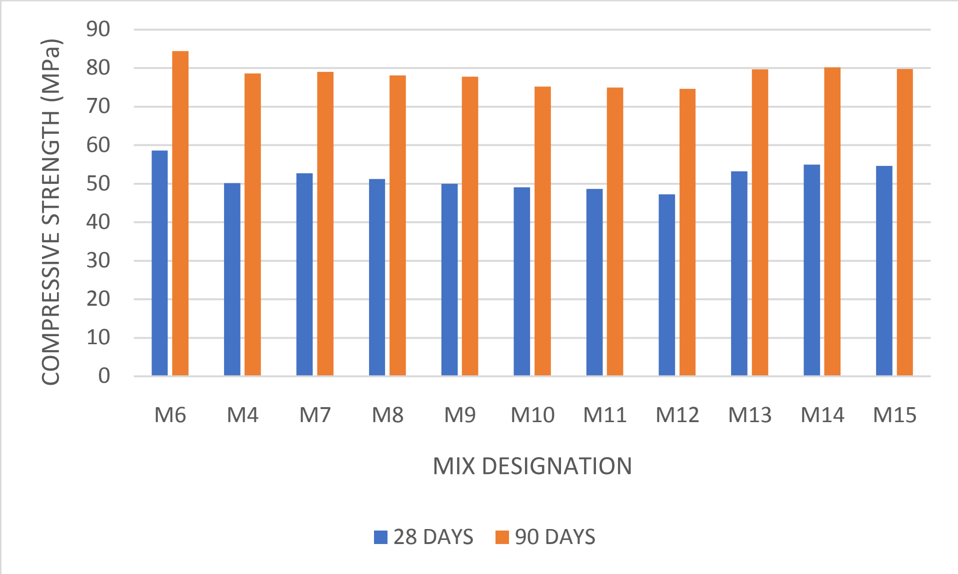


Fig.9 Compressive Strength of M50 grade GPC under various exposure conditions

In the above graph, M6 represents OPC M50 grade concrete and M4 represents M50 GPC with 1.5% steel fiber and from M7-M9 represents M50 GPC with 1.5 % steel fiber exposed to 1,3 and 5% H_2SO_4 and M10-M12 exposed for HCl and M13-M15 exposed for NaCl respectively.

OPC and GPC specimens' performance in sulfuric acid (H2SO4) containing sodium chloride (NaCl) and hydrochloric acid (HCl), by submergingthe cube specimens in 1, 3, and 5% solutions independently following a single casting day. The concentration and solution of choice were determined by the practical requirementsuse of concrete for sewer lines, mining, etc. The test specimens were stored inwater by immersing them in solutions for an amount of time that is four times the specimen volume.90 days long. These solutions were used to maintain the solution concentration as is customary.7-day cycles are replaced with new solutions of the same composition.Visual examination, weight changes, and strength tests were frequently used to track the effects of the solution on the specimens. Because the SSD weight is used as the beginning weight, the specimens were primed in water for three days prior to being immersed in the testing solutions. The specimens were then collected, weighed, and measured under various exposure settings at comparable phases.

The compressive strengths of the OPC and GPC are shown in Fig 9. The use of ground granulated blast furnace slag produced extra CA-S-H gel, according to test findings, which complemented the compressive strength properties of GPC. GPC outperformed OPC in terms of strength qualities. With the increment in curing periodvalues for compressive strength were shown to be rising over this time. More compressive strength was achieved with the GPC mix created by blending fly ash of Class F grade with GGBS at levels of 50% content compared with other blend levels.

2.4.2 Sorptivity

Cube specimens were subjected to sorptivity testing in accordance with ASTM C 1585-04. The following calculation is used to calculate how much water was absorbed over a 30-minute period:

$$S = I/\sqrt{T} \quad (1)$$

S stands for the sorptivity coefficient in millimetres, and t stands for pass by time in minutes. Consider

$$I = \Delta W/AD \quad (2)$$

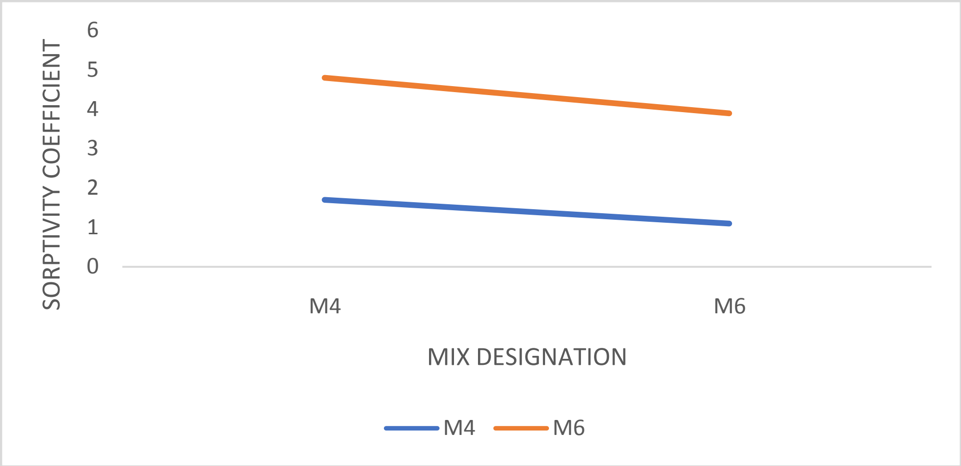


Fig.10 Sorptivity coefficient for GPC and OPC mix

W = Change in weight = W2 W1, where W1 represents the weight of an oven-dried cube in grammes and W2 indicates the weight of the same cube after 30 minutes of capillary suction. A represents the surface area of the specimen that is permeable to water, and D represents the water density.

2.4.3 Water Absorption

The samples were immersed in water for 90 days to conduct the water absorption test. The specimens were then dried in an oven at 110 °C for 24 hours to produce a consistent specimen mass before being weighed once again. The specimen dry weight is indicated as W1. The specimen is then weighed after being submerged in hot water for 3.5 hours at 85 °C (W2)

$$\text{Percentage absorption of water} = \frac{W_2 - W_1}{W_1} \times 100 \quad (3)$$

where W1 is the weight of a dried cube (in grammes) and W2 is the weight of a wet cube (in grammes) after 3.5 hours (gms)

Figure 11 shows a linear rise in concrete water absorption with concrete grade, which suggests the presence of voids from insufficient polymerization. In both grades, GPC concrete showed less water absorption than OPC concrete. Lower water absorption rate is caused by increased silica content being converted into higher alumino-silicate content, which improves the bonding between interstitial particles and fills up the spaces between the source materials.

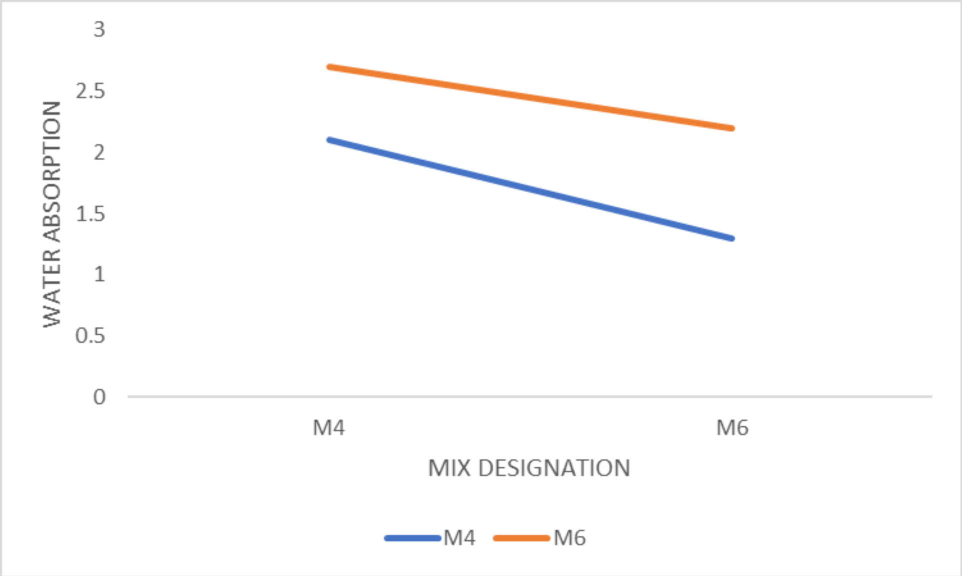


Fig.11 Water absorption coefficients for OPC and GPC

2.5 Resistance to various exposure conditions

2.5.1 Sulphate & chloride attack

GPC and OPC have relatively comparable appearances under sulphuric acid and NaClexposure. There was no discernible visual difference in the GPC cubes. High levels of calcium hydration compounds in GPC cubes allowed researchers to detect the presence of efflorescence on the specimen surface. Under NaCl exposure, high levels of calcium hydration compounds in GPC cubes allowed researchers to detect the presence of efflorescence on the specimen surface.

3.0 Conclusions

The effect of GGBFS and NaOH molarity on the mechanical, long-term stability, and microstructural characteristics of FA-blended GC was carefully studied in the current work. To create GPC, the FA and GGBFS were mixed at (50+50)%.Together with durability traits including sorptivity and water absorption, the mechanical qualities of the FA-GGBFS blended GC were investigated. Geopolymer samples underwent XRD and SEM testing to get access to their micro level characteristics. The experiment's findings on samples of geopolymer concrete led to the following conclusions.

1. In acidic and alkaline environments, GPC concrete performs better than OPC concrete in terms of resistance.
2. With a 50% substitution of FA for GGBFS, together with a 10 M NaOH solution and a 1.5% dose of steel fibre, the denser microstructure was seen. It was evident that the pores were purposefully created by GGBFS particles to strengthen and stabilise the structure and promote the production of superior geopolymeric structures.

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3. The geopolymeric reaction in the pore structure of GGBFS is held in place by the presence of calcite, which is required to increase the structure of Ca2+, Si4+, and Al3+ ions. These ions then accelerate the production of geopolymer products. This results in the creation of improved C-A-S-H gels and the development of microstructural characteristics of GC samples at a 10 M NaOH solution.
4. For two types of concrete, the percentage reduction in compressive strength is in the range of 2-8% for different exposure conditions.

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