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Experimental Evaluation of Mechanical and Durable Behaviour of Fly Ash and GGBS Incorporated Alkaline Geopolymer Concrete

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ABSTRACT

The study presents a comprehensive investigation into the experimental and numerical assessment of geopolymer concrete (GPC) formulated with fly ash class F and ground granulated blast furnace slag (GGBS). This research encompasses three distinct mixtures: conventional concrete (CC), GPC-1A (comprising 70% fly ash and 30% GGBS), and GPC-1B (comprising 60% fly ash and 40% GGBS). The evaluation of these mixtures is conducted through an analysis of their fresh properties, mechanical characteristics, and durability, alongside an examination of their flexural behaviour. This is achieved through various tests, including slump tests, compressive strength assessments, flexural strength evaluations, modulus of elasticity measurements, water absorption tests, and resistance tests against acid and sulphate, as well as reinforced concrete (RC) beam testing. The GPC mixtures demonstrated a workability range of 70-to-72mm. Notably, the compressive strength exhibited a marked enhancement, with GPC-1A achieving 43.55 MPa and GPC-1B reaching 45.62 MPa, representing increases of approximately 46% and 53% over the CC, which recorded a strength of 29.85 MPa. Furthermore, both the flexural strength and modulus of elasticity indicated improved stiffness and enhanced load-bearing capacity. In terms of durability, the mixtures displayed reduced water absorption and superior resistance to acid and sulphate ingress, attributed to the dense matrix structure. In conclusion, the GPC mixtures based on fly ash and GGBS demonstrated exceptional performance, establishing them as a viable and sustainable alternative to traditional concrete.

Keywords: Geopolymer; Fly ash; GGBS; Mechanical and Durability Properties; Flexural Strength; Alkaline

1. INTRODUCTION

The cement manufacturing process is highly energy-intensive, prompting interest in alternative and sustainable building materials. The construction industry is a significant contributor to carbon dioxide emissions, primarily due to the widespread use of ordinary Portland cement (OPC). In this regard, geopolymer concrete (GPC) has emerged as a viable alternative to traditional concrete, mainly due to its reduced carbon footprint, enhanced structural performance, and superior durability (Duxson et al., 2007). Geopolymer concrete (GPC) exhibits an outstanding performance over decades in construction field and indeed in the research area of special concrete development. But it has also been noticed since from the very beginning that, the mix design adaptation, and the fixation of the material quantities are not standardized in any of the research program, which is important for the upcoming researchers to make a significant progress in the development of GPC. While being eco-friendly, GPC development reduces the carbon foot-print significantly with compare to conventional OPC concrete development, (Keun-Hyeok Yang et al., 2013). Whatever the binder elements we used along with the alkaline solution eventually plays a significant role in the formation of GPC, and on its strength. Most commonly the binder elements that are used in the GPC are fly ash, Ground Granulated Blast Furnace Slag (GGBS), Metakaolin, and other binders or ashes which contains silica and alumina content. The prime elements of GPC formation are aluminosilicate compound with either sodium or potassium based on the type of alkaline solution used in the GPC. Being cost effective, most of the researchers or industries bend towards sodium based alkaline solution. The most typical mix proportions that can be obtained from numerous literature reviews in this field, is cloudy on the calculation part of the mix design especially in the determination of alkaline solution based on their molarity and also on fixing the quantity of the activator content. This study focuses the easy method of developing GPC with clear mix design approach that can be compared and adapted with respect to OPC mix design. (Motohiro et al.,

2018) discussed about the usage of different types of fly ash and their percentile combination to achieve optimum mix design of GPC. The incorporation of both class – C and class – F fly ash with a combination of 08 and 02 by mass respectively given better strength and ductility of the GPC. They arrived their design mix through an orthogonal array with some matrix design phases. This sort of design does not provide any valid justification of the standard concrete mix design adapted by different codes and the usage of water content, binder to liquid ratio and many other aspects. The vital justification, and the concrete strength may look quite valid but when it comes into the picture of comparing with conventional concrete, it is hard to map those justifications. The effect of fly ash on geopolymer mortar under hot curing and on prolonged curing was explained by (Andi Arham Adam et al., 2014), where they had observed the optimum strength can be achieved on hot curing of 120°C for 20 hours. Another comprehensive review done by (Ismail Luhar et al., 2022) explains the pros of fly-ash based GPC viz. being as industrial by-products, it is easily available, also prevents nine times emission of CO_2 as compared with conventional OPC, short ambient curing can also lead to significant gain in the strength with almost minimize shrinkage by 80% than OPC. The geopolymerization that happens in the GPC make a durable paste of aluminosilicate gel making it more compact in structure and durable so that it can be used in preventing corrosion for marine structures and also in the rehabilitation work of marine structures and especially usage of binders like metakaolin with silica fume along with hot curing process of precast GPC plays a vital role in preventing the chloride penetration reducing the chance of corrosion in concrete structures which was explained by (Noor Fifinatasha Shahedan et al., 2024). As per (Mugahed Amran et al., 2020), fly-ash based GPC is such a revolutionary engineered composite element that significantly gives strength in short period of time with long term durability and minimize the shrinkage issues in concrete structure thus making it appropriate for hash environmental conditions. At a very initial stage of GPC race, (D. Hardjito et al., 2005), proposed the development of GPC where one can conclude that the workability and the compressive strength of the GPC with respect to time is vice-versa. An evaluation method of alkali activator adjustment with respect to void percentage of fine aggregate in the GPC has been proposed by (Tanakorn Phoo-ngernkham et al., 2018) where, some discrete values of alkali activator contents were derived for 10 and 15 molar NaOH solution with same content by differentiating the quantity of fine aggregates making it more complex to adopt a quick-start GPC preparation. Molarity of NaOH in the alkaline solution, ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH), and solution – binder ratio types of source activator content all these factors play a vital role in the outcome of GPC and its performance, (Hemn Unis Ahmed at al., 2022). Higher the molarity of NaOH in the alkaline solution provides more strength in the GPC and also the curing temperature varies the GPC performance. A range of 6 to 12 molarity of NaOH was adopted by (Gum Sung Ryu et al., 2013) and came to this conclusion. The blend of the activator content in GPC holds a prime parameter in the development of the homogeneous and dense micro structure which in turn provides supreme strength and durability of GPC, (Nada Hadi Jumaa et al., 2022). The performance of source material like metakaolin in GPC was studied by (D. Parthiban et al., 2019) where they have mentioned for getting a sustainable performance of the concrete mix an elevated temperature curing at 75ºC for 24 hours were required. A partial replacement of high calcium fly ash with metakaolin in GPC mix can results in high strength variations taking the molarity of NaOH in the alkaline solution and curing conditions in considerations, (Peem Nuaklong et al., 2018). The performance of GPC by using red mud and rice husk ash was evaluated by (Jian He et al., 2012) where they found for better performance of the GPC, curing at elevated temperature was required. The compressive strength of GPC upsurge with the increase of curing temperature up to a certain limit.

The efflorescence may cause some issue in the GPC which can be reduced by using alumina rich source materials or by using some arrangement of steam curing process, as per the investigation done by (Ebrahim Najafi Kani et al., 2012), it has been revealed the binder element rich in alumina content along with curing in elevated temperature overall increase the performance of GPC. In most of the oven curing process of GPC an elevated temperature of 50ºC to 80ºC is maintained for 12 to 48 hours to get the optimum strength of GPC, (S. Geetha et al., 2013). High strength GPC was developed by using high volume copper slag with MS by replacing 100% river sand with copper slag as fine aggregate and a dosage of 1% to 5% of MS along with fly ash by (Nagarajan Arunachelam et al., 2022) with ratio of Na_2SiO_3 to NaOH as 2.5 to achieve a good compressive strength of GPC. Consequently, the present study is dedicated to exploring the efficacy of GPC mixtures, including GPC-1A and GPC-1B, in conjunction with CC. This research delves into the fresh characteristics as well as the performance of

GPC, particularly regarding its durability, mechanical properties, and flexural behaviour, to gain insights into the structural response of GPC.

2. MATERIALS

The materials employed in this research consist of Ordinary Portland Cement (OPC), Fly Ash Class F, Ground Granulated Blast Furnace Slag (GGBS), fine aggregate, coarse aggregate, and an alkaline activator. OPC of grade 53, with a specific gravity of 3.14, was utilized in accordance with IS 12269:2013 as a binder for traditional concrete. Class F fly ash, which has a specific gravity of 2.28, serves as the primary aluminosilicate binder material. Its significant contribution to geopolymerization is attributed to its elevated silica and alumina content, which facilitates the development of geopolymeric gel (Ahmaruzzaman, 2010; Diaz et al., 2010). GGBS was utilized as a binding agent in this research to enhance strength development. The calcium content in GGBS facilitates the overall mechanical performance (Li et al., 2019; Komljenović et al., 2010).

River sand, in accordance with IS 383:2016, was utilized as fine aggregate. Its physical characteristics were evaluated to confirm its appropriateness for concrete production. The specific gravity of the fine aggregate employed in this research was 2.64, with a fineness modulus of 2.72 and a water absorption rate of 1.05%. The bulk density of the fine aggregate was recorded at 1680 kg/m3. Crushed coarse aggregate with a nominal size of 20mm served as the coarse aggregate, exhibiting a specific gravity of 2.71, a bulk density of 1525 kg/m3, and a fineness modulus of 6.95.

Figure 1. Coarse and Fine Aggregate Batching

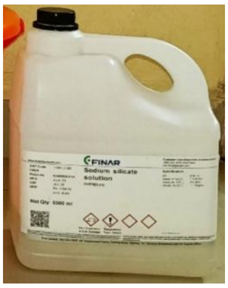

Figure 2. Na_2SiO_3

Figure 3. NaOH

Figure 4. Alkaline Activator

The alkaline activator consisted of a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The primary function of the alkaline solution was to commence the geopolymerization process. The concentration and proportion of the solution played a crucial role in the enhancement of strength and resistance to chemical assaults (Duxson et al., 2007; Provis and Van Deventer, 2014). In this research, an alkaline solution with a concentration of 8M and a Na_2SiO_3/NaOH ratio of 2.5 was utilized, consistent with prior studies. (T. Porphadam and S. Thirugnanasambandam, 2024). Figure 2, 3, and 4 represent the Na_2SiO_3, NaOH, and the alkaline solution prepared respectively.

3. MIX PROPORTIONS

The ratios of the mixtures utilized in this research were formulated through a systematic experimental methodology to assess the performance of Geopolymer Concrete (GPC). The concrete grade employed is M20, characterized by a mix ratio of 1:2.43:3.75 and a water-to-cement (W/C) ratio of 0.50, designed in accordance with IS 10262:2009. In Stages I and II, the mixtures were developed, while in Stage III, the fresh and mechanical properties were evaluated, and in Stage IV, the durability characteristics were assessed.

During Stage – I, the mixture was created using Ordinary Portland Cement (OPC) of 53 grade as the primary binder. The mix design adhered to IS 10262:2009 to achieve the target strength of M20 grade concrete. In the subsequent stage, the geopolymer concrete was formulated using a blend of two binder materials: Class F fly ash and Ground Granulated Blast Furnace Slag (GGBS). The two binary GPC mixtures were GPC-1A, comprising 70% Fly Ash and 30% GGBS, and GPC-1B, consisting of 60% Fly Ash and 40% GGBS. These proportions were derived from prior research (T.Porphadam and S.Thirugnanasmbandam, 2024).

The incorporation of GGBS significantly improved strength development, primarily attributed to the presence of calcium, while fly ash contributed to enhanced long-term strength through the process of geopolymerization (Li et al., 2019; Duxson et al., 2007). The optimized mixtures of fly ash class F and GGBS enhanced both mechanical and durability performance, primarily due to a denser matrix and improved reaction kinetics (Phoo-Ngernkham et al., 2018; Dave and Bhogayata, 2020).

4. CASTING OF SPECIMENS

The concrete specimens were prepared to investigate the fresh properties, durability, and mechanical characteristics of the GPC mixes. Standard molds were utilized for the formation of prisms, cubes, and cylinders in accordance with IS 516:1969. The concrete was mixed thoroughly and placed into the molds with adequate compaction to eliminate entrapped air and ensure uniformity. All specimens were demoulded after a period of 24 hours and underwent ambient curing for 7 days prior to testing. The total number of specimens cast and their details are provided in Table 1, while the casting of the specimens is depicted in Figure 5.

Figure 5. Casting of Specimens

5. EXPERIMENTAL EXAMINATIONS

Table 1. Total Specimens Cast

Sl.No.	Specimens Types	Tests	Specimens Specifications	Total Count
1.	Cubes	Compressive strength	100 mm × 100 mm × 100 mm	9
		Durability Properties	100 mm × 100 mm × 100 mm	18
2.	Prisms	Flexural Strength	100 mm × 100 mm × 500 mm	9
3.	Cylinders	Modulus of Elasticity	150 mm dia. and 300 mm Height	9
Total number of specimens				**45**

5.1 Slump Cone Test

The workability of the GPC mixes was assessed through the slump test in accordance with IS 1199:1959. The fresh concrete was placed into a standard slump mould in three distinct layers, which were then compacted with 25 tamping strokes using a tamping rod to ensure uniform consolidation. Once the cone was completely filled, it was lifted vertically, allowing the concrete within the mould to settle under its own weight. The vertical difference between the actual height of the cone and the displaced concrete was recorded as the slump value; Figure 6 illustrates the slump obtained. This test offered insights into the consistency and flow characteristics of fresh concrete, which were primarily affected by the binder composition and water content **(Neville, 2011; Mehta and Monteiro, 2014).** The slump values obtained from different mixes are shown in Table 2.

Table 2. Slump Cone Values

Sl.No.	Mix Specifications	Slump (mm)	Remarks
1.	CC	72	CC
2.	GPC-1A	70	GPC
3.	GPC-1B	71	

Figure 6. Slump Cone Test

5.2 Compression Testing Process

The compressive strength of the concrete specimens was assessed in accordance with IS 516:1959. The cubes, sized as specified, were evaluated following the curing period utilizing a calibrated compression testing machine (CTM), as depicted in Figure 7. The specimens were positioned on the loading platform, and a uniform load was applied at a constant rate until failure occurred. The maximum load at the point of failure was recorded, and the compressive strength was computed by dividing the load by the cross-sectional area of the cube. Table 3 shows the values of the compressive strength obtained after the test.

Figure 7. Compression Test Set up

Figure 8. Flexural Test Set up

Figure 9. Elasticity Modulus

5.3 Flexural Testing Procedure

The flexural strength of the GPC was assessed using prism specimens measuring 100 mm × 100 mm × 500 mm in accordance with IS 516:1959. The evaluation was conducted utilizing a two-point loading method in a flexural testing apparatus as depicted in Figure 8. The load was incrementally applied, and the peak load at the point of failure was noted as the flexural strength. Table 3 presents the flexural strength obtained for the concrete mixes.

Table 3. Compressive and Flexural Strength Test Results

Sl.No.	Mix Specification	Compressive Strength (N/mm^2)	Flexural Strength (N/mm^2)	Remarks
1.	CC	29.85	3.84	CC
2.	GPC-1A	43.55	3.92	GPC
3.	GPC-1B	45.62	4.32	

5.4 Modulus of Elasticity Testing Process

The concrete's elasticity was evaluated by using cylindrical specimens measuring 150 mm in diameter and 300 mm in height, in accordance with IS 516:1959. The testing involved the gradual application of a compressive load on the specimen, while the resulting strain was measured with a Demountable Mechanical Gauge, as illustrated in Figure 9. This parameter indicates the stiffness of the concrete and affects the composition of the binder. Table 4 presents the modulus of elasticity obtained for GPC mixes.

Table 4. Modulus of Elasticity Test

Sl.No.	Mix ID	Modulus of Elasticity (MPa) ($x10^4$)	Remarks
1.	CC	2.82	CC
2.	GPC-1A	3.38	GPC
3.	GPC-1B	3.54	

5.5 Durability Properties

The objective of Stage IV in this research was to investigate the durability characteristics of the GPC mixtures. The tests conducted are elaborated upon in the sections that follow.

5.5.1 Water absorption test procedure

The water absorption test was conducted to assess the permeability characteristics of the concrete in accordance with ASTMC642. Initially, the cubes were dried in an oven, as illustrated in Figure 10, and their weights were recorded. Subsequently, the cubes were submerged in water for a duration of 24 hours. After the immersion period, the specimens were surface dried and weighed again to ascertain their mass. The calculation of water absorption was based on the difference between the dry and saturated weights. Table 5 displays the water absorption test results for various GPC mixes.

Table 5. Water Absorption Test Results

Sl.No.	Mix	Initial Weight Before Immersion (kg)	Final Weight After Immersion (kg)	Absorption (%)	Remarks
1.	CC	2.42	2.53	4.43	OPC
2.	GPC-1A	2.45	2.54	3.70	GPC
3.	GPC-1B	2.86	2.95	3.12	

Figure 10. Oven Dried Cubes

5.5.2 Acid resistance test process

The concrete's resistance to acid was assessed by placing the specimens in a highly acidic environment. Figure 11 illustrates the specimens following their immersion in the acidic solution. Upon finishing the initial curing phase, the specimens were submerged in a 5% sulfuric acid solution (H_2SO_4) for a duration of 30 days.

Table 6. Acid Resistance Test Values

Sl.No.	Mix	Initial Wt. Before Immersion (kg)	Final Wt. After Immersion (kg)	Loss in Wt. (%)	Comp. strength before Immersion (MPa)	Comp. strength after Immersion (MPa)	Loss in Strength (%)
1.	CC	3.32	3.03	8.75	29.85	19.76	33.80
2.	GPC-1A	2.45	2.27	7.23	43.55	32.07	26.36
3.	GPC-1B	2.67	2.51	5.81	45.62	34.62	24.12

Subsequent to this, the specimens were extracted, and the reductions in weight and compressive strength were evaluated. This test assesses the resilience of concrete when subjected to harsh environmental conditions. (Bakharev, 2005; Amran et al., 2021). Table 6 displays the weight loss and strength reduction results for GPC mixtures after the acid test.

Figure 11. Samples After Acid Immersion

5.3.3 Sulphate resistance test process

The resistance of GPC to sulphate was assessed by submerging the specimens in a 5% sodium sulphate (Na_2SO_4) solution following a designated curing period. The specimens remained in the solution for a predetermined duration of 30 days, after which both weight loss and strength loss were measured. Figure 12 illustrates the samples following their exposure to the sulphate environment, while Table 7 details the weight and strength losses recorded for the GPC mixes.

Table 7. Sulphate Resistance Test Values

Sl.No.	Mix	Initial Wt. Before Immersion (kg)	Final Wt. After Immersion (kg)	Loss in Wt. (%)	Comp. strength before Immersion (MPa)	Comp. strength after Immersion (MPa)	Loss in Strength (%)
1.	CC	2.64	2.58	2.36	29.85	26.16	12.36
2.	GPC-1A	2.49	2.45	1.75	43.55	40.00	8.15
3.	GPC-1B	3.14	3.09	1.67	45.62	41.85	8.27

Figure 12. Samples After Sulphate Immersion

6. OUTCOMES AND DISCUSSIONS

The experimental results are methodically presented and thoroughly discussed in this section as per the tests that were carried out.

6.1 Slump Test

The workability of the mixtures was analysed, and the findings are illustrated in Figure 13. The CC mix exhibited a slump measurement of 72 mm, whereas GPC-1A recorded 70 mm and GPC-1B showed 71 mm, which is marginally lower. The slight decrease in the slump of GPC mixtures can be attributed to the fine and angular nature of the fly ash and GGBS particles, which diminishes flowability. Nevertheless, the variation in slump is minimal, indicating the workability of the mixtures. The incorporation of GGBS enhances the packing density and uniformity of the mixtures (Li et al., 2019; Amran et al., 2021).

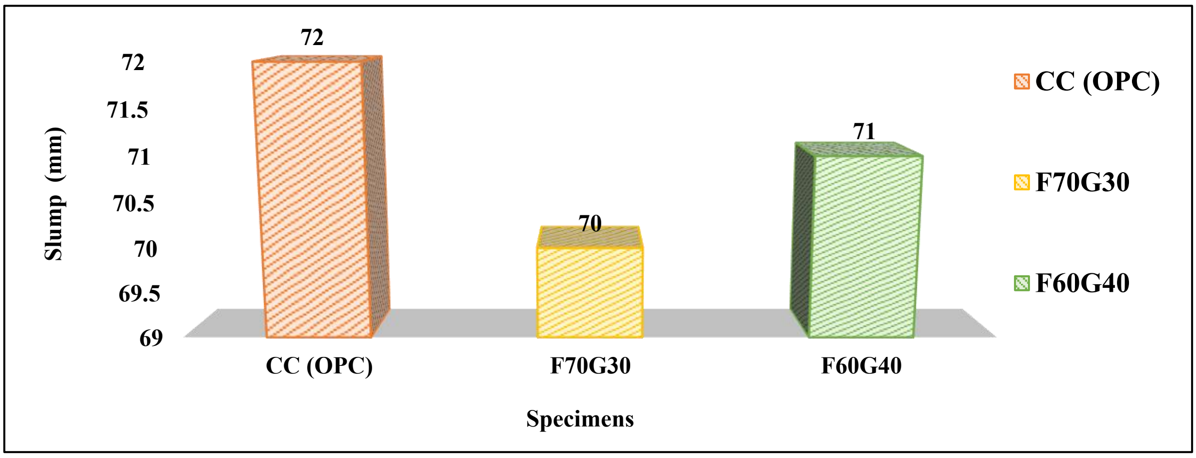

Figure 13. Slump Cone Tendency of the Concrete Mixes

6.2 Compressive Behaviour

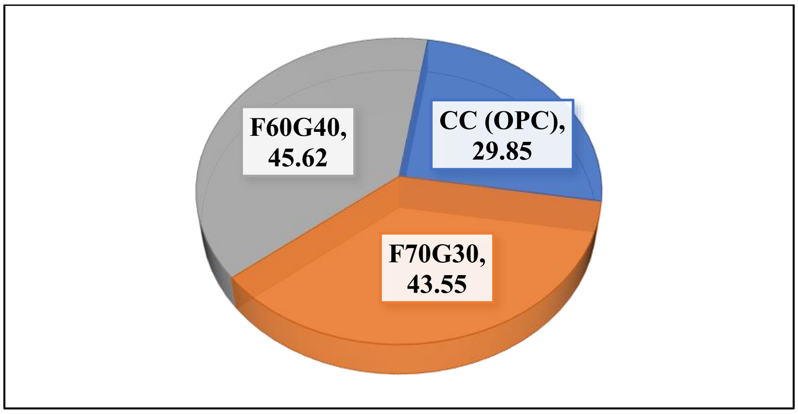

Figure 14. Compressive Strength Behaviour

The results of the compressive strength tests for the GPC mixes are illustrated in Figure 14. The CC mix recorded a strength of 29.85 MPa, while GPC-1A and GPC-1B achieved strengths of 43.55 MPa and 45.62 MPa, respectively, both surpassing the CC mix. This increase in strength represents approximately 46% for GPC-1A and 53% for GPC-1B when compared to CC. The enhancement in strength can primarily be attributed to the improved geopolymeric reaction facilitated by the synergistic effects of fly ash and GGBS, where the calcium content in GGBS aids in the formation of additional binding phases, resulting in a denser matrix. Among the various mixes, GPC-1B exhibited the highest compressive strength, demonstrating that the inclusion of GGBS not only accelerates early strength development but also enhances the kinetics of the reaction (Diaz et al., 2010; Abdel-Gawwad and Abo-El-Enein, 2016; Mustakim et al., 2021).

6.3 Flexural Behaviour of the Specimens

The results pertaining to flexural strength are depicted in Figure 15. The control sample (CC) demonstrated a flexural strength of 3.84 MPa, in contrast to the GPC-1A, which recorded 3.92 MPa, and the GPC-1B, which achieved 4.32 MPa. This represents an increase of approximately 2% for GPC-1A and 12.4% for GPC-1B when compared to the CC. This enhancement can be attributed to the improved bonding within the geopolymer matrix and the more effective transfer of stress across the micro cracks. The Ground Granulated Blast Furnace Slag (GGBS) plays a significant role in the geopolymerization process, enhancing the tensile strength. The GPC-1B demonstrates exceptional flexural performance along with a high resistance to crack initiation and propagation under applied loads (Albidah et al., 2021; Nuaklong et al., 2018; Phoo-Ngernkham et al., 2018).

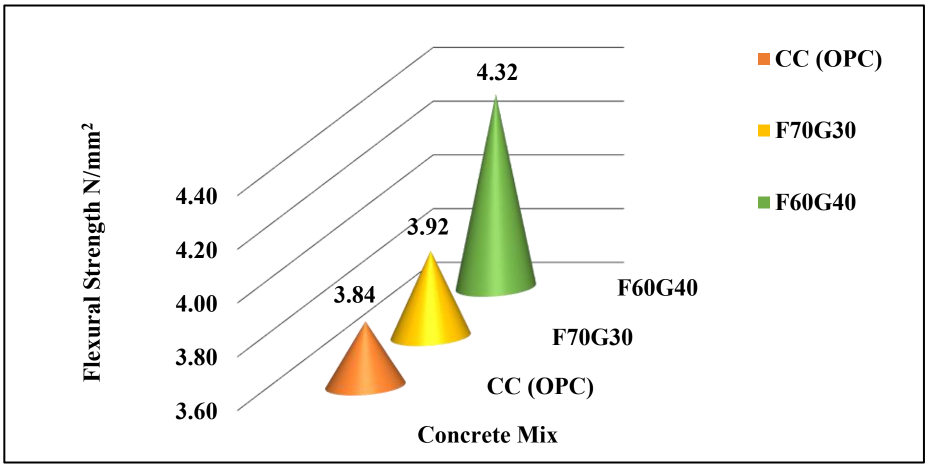

Figure 15. Flexural Strength Behaviour

6.4 Modulus of Elasticity Behaviour

The elasticity values of the mixtures are illustrated in Figure 16. The CC demonstrated an elasticity of 2.82×10^4 MPa, whereas the GPC-1A and GPC-1B mixes exhibited values of 3.38×10^4 MPa and 3.54×10^4 MPa, respectively. This represents an increase of nearly 20% for GPC-1A and 24% for GPC-1B in comparison to the CC. This enhancement is primarily attributed to the stiffness of the GPC, which improves interfacial bonding, thereby increasing rigidity and minimizing elastic deformation. Notably, the GPC-1B mix achieved the highest modulus of elasticity, signifying its superior stiffness and resistance to deformation (Bernal et al., 2011; Nath and Sarker, 2014; Fernández-Jiménez et al., 2006).

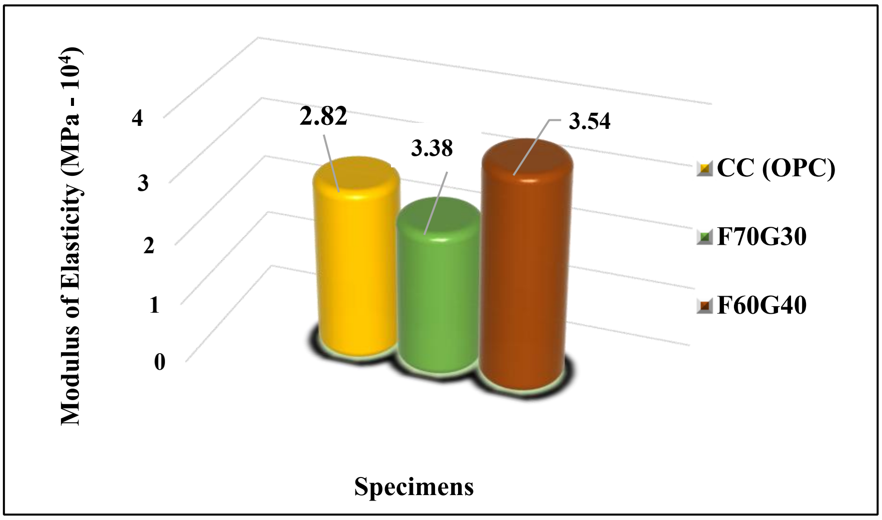

Figure 16. Modulus of Elasticity Behaviour

6.5 Water Absorption Trend

The water absorption outcomes for the concrete mixtures are depicted in Figure 17. The C mix exhibited an absorption rate of 4.43%, whereas the GPC mixtures GPC-1A and GPC-1B recorded absorption rates of 3.70% and 3.12%, respectively. This indicates a reduction of nearly 16% for GPC-1A and 30% for GPC-1B in comparison to the control concrete (CC). The reduced water absorption noted in the GPC mixtures suggests a denser and less permeable structure. The incorporation of fly ash and GGBS facilitates the reaction and reduces pore connectivity, thereby limiting water ingress. Importantly, GPC-1B showed the lowest absorption rate, coupled with high resistance to permeability and enhanced durability performance (Singh and Middendorf, 2020; Deb et al., 2014; Islam et al., 2021)

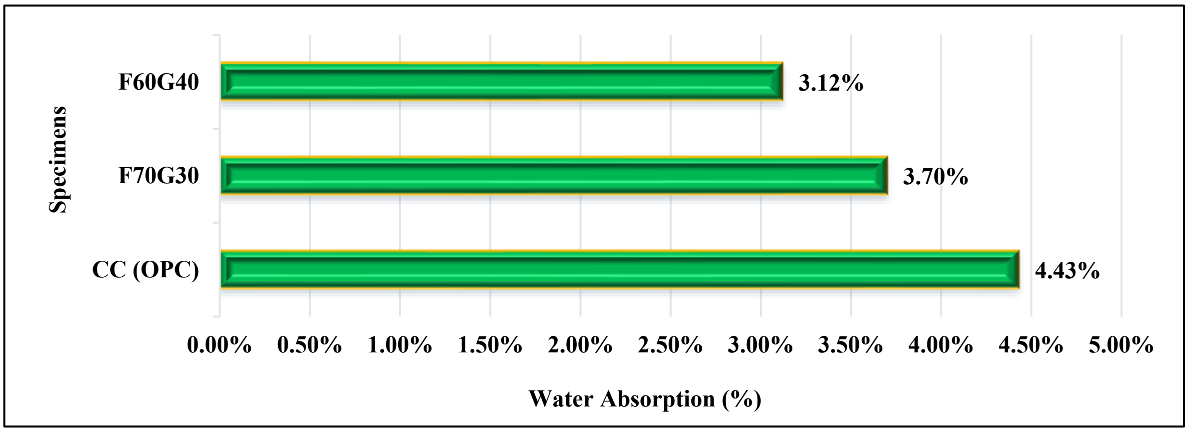

Figure 17. Water Absorption Behaviour

6.6 Acid Resistance Properties

The resistance of GPC mixtures to acidic exposure is illustrated in Figure 18. The control sample demonstrated a weight loss of 8.75% and a strength reduction of 33.80% following acid exposure, whereas the GPC-1A and GPC-1B mixtures exhibited lower weight losses of 7.23% and 5.81%, respectively, along with diminished strength losses of 26.36% and 24.12%. This specifies an augmentation in acid resistance of nearly 22% (GPC-1A) and 29% (GPC-1B) in terms of strength when compared to the CC. The improved resistance can be attributed to the lower calcium content and the formation of aluminosilicate gel, which mitigates the risk of acid attack (Shi et al., 2012; Zhang et al., 2020; Temuujin et al., 2011).

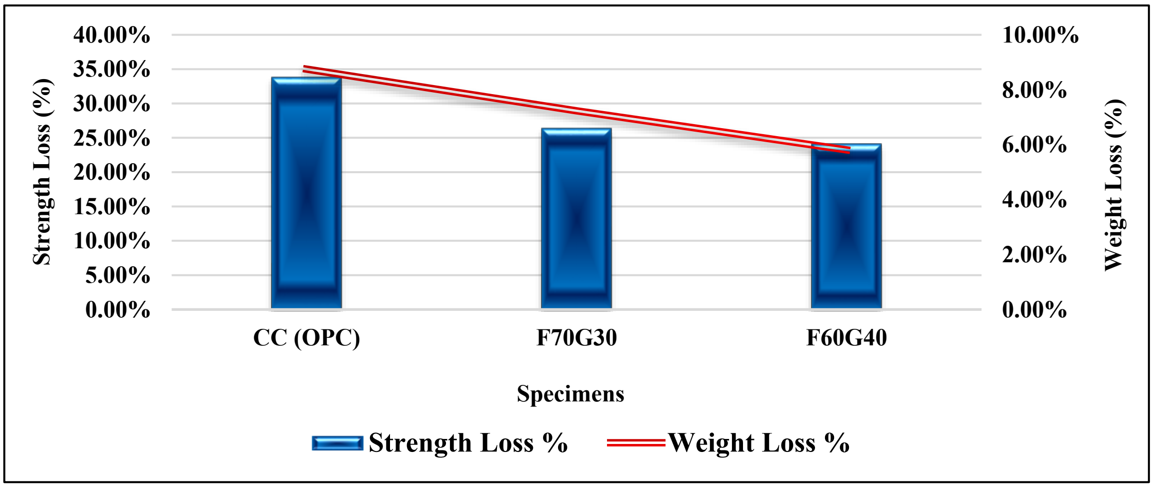

Figure 18. Acid Resistance Behaviour

6.7 Sulphate Resistance Behaviour

The sulphate resistance of the concrete specimens is illustrated in Figure 19. The CC mix experienced a weight reduction of 2.36% and a strength reduction of 12.36% following sulphate exposure. In contrast, the GPC-1A and GPC-1B mixes demonstrated lower weight losses of 1.75% and 1.67%, respectively, along with diminished strength losses of 8.15% and 8.27%. This represents an improvement of nearly 34% for GPC-1A and 33% for

GPC-1B in terms of strength retention when compared to CC. The enhanced resistance to sulphate attack can primarily be attributed to the aluminosilicate matrix and the formation of products such as gypsum and ettringite (Ismail et al., 2013; Bakharev, 2005; Sata et al., 2012).

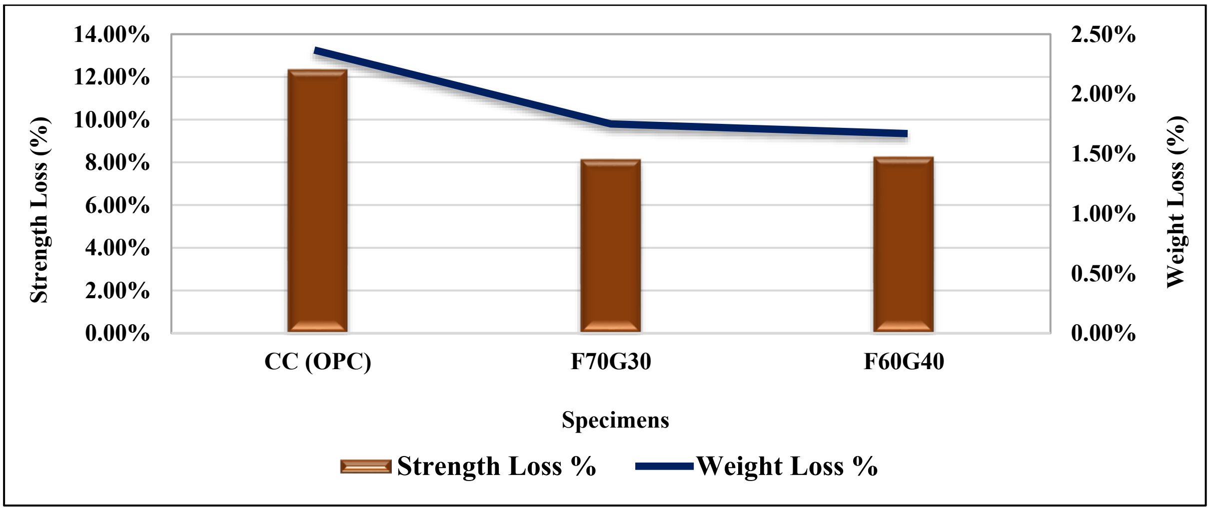

Figure 19. Sulphate Resistance Behaviour

7. CONCLUSION

The GPC mixtures demonstrated a workability that rivals conventional concrete, measuring between 70 to 72 mm, thus rendering it ideal for practical applications without any issues of consistency.

Notable enhancements in compressive strength were observed, with GPC-1A and GPC-1B achieving 43.55MPa and 45.62 MPa, respectively, reflecting increases of 46% and 53% when juxtaposed with conventional concrete.

The flexural strength saw an elevation from 3.84 MPa (CC) to 3.92 MPa (GPC-1A) and 4.32 MPa (GPC-1B), marking improvements of nearly 2% and 12.5% respectively. Likewise, elasticity improved from 2.82×10^4 MPa (CC) to 3.38×10^4 MPa (GPC-1A) and 3.54×10^4 MPa (GPC-1B), indicating enhancements of approximately 20% and 25%, which signifies increased stiffness and resistance to deformation.

The GPC mixtures also exhibited enhanced durability, with water absorption decreasing from 4.43% (CC) to 3.70% (GPC-1A) and 3.12% (GPC-1B), corresponding to reductions of nearly 16% and 30%. In terms of acid exposure, strength loss diminished from 33.80% (CC) to 26.36% (GPC-1A) and 24.12% (GPC-1B), while sulphate attack resulted in a reduced strength loss from 12.36% (CC) to 8.15% (GPC-1A) and 8.27% (GPC-1B), demonstrating the resistance afforded by a denser and more stable geopolymer matrix.

Consequently, the GPC-1B mix exhibited exceptional performance in mechanical, durability, and structural aspects, establishing it as a highly effective alternative to conventional concrete.

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