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Effect Of An Inorganic Compound On Geopolymer Concrete And Ordinary Portland Cement Concrete

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Abstract
The main problems with durable concrete constructions are attacks by sulphates and chlorides on concrete. Thus, the impact of concrete strength characteristics is based on the addition of fly ash exposed to the environment used as sulphate and chloride solution as the primary goal of this research work. In this research work, geopolymer concrete (GPC) is used instead of ordinary Portland cement (OPC). The concrete composition is prepared with geopolymer varies. Samples are demolded and then submerged in water for a full 28 days to cure. Following this, the samples are placed in different solutions of 10% sodium chloride (NaCl) and 10% sodium sulphate (Na_2SO_4) for hardening times at 28, 56, and 90 days respectively. A degree of damage, variation in compressive strength, and weight change were used to assess the impacts of sulphate and chloride on the concretes. After 90 days, the exposure of fly ash to concrete significantly improved its compressive strength at 33.11% as compared to the strength of 10% NaCl solution, water and OPC, respectively. In contrast to the OPC, the 10% NaCl solution decreased the compressive strength of fly ash-containing GPC after 90 days of exposure. In comparison to other models, the maximum ultrasonic pulse velocity of GPC-7 was attained at 4430 m/s. The minimal charge cleared in the GPC-7 fast chloride permeability test is 1045 coulombs. According to this study, adding fly ash to concrete as an additional cementitious material may help lessen the harmful impacts of sulphate and chloride salts. The study's findings suggest that adding ground fly ash to concrete as an additional cementitious element strengthens the material's durability to harsh environments.
Keywords: Geopolymer Concrete; Curing; Compressive Strength; Sodium sulphate and chloride; Ordinary Portland cement.

1. Introduction

The formation of concrete composite materials is consisting of cement, sand as a fine aggregate, crushed stone as a coarse aggregate, and water. It may be readily worked into a variety of shapes because to its workability. Concrete also offers excellent fire resistance and compressive strength [1, 2]. The concrete is classified into two categories, the lighter, less dense type weighs less than 19,200 kg/m^3, and the more typical dense type weighs 24,000 kg/m^3. The cement is a major component of concrete. Tricalcium silicate ($3CaOS1O_2$), dicalcium silicate ($2CaCOS1O_2$), tricalcium aluminate ($3CaOAlO_3$), and tetra calcium alumino ferrite ($4CaOAl_2O_3$ Fe_2O_3) are main chemical components of Portland cement. Concrete materials are subjected to elements known as contaminants or impurities, which can impact the plain and reinforced concrete strength. The environmental pollutants are acids, chlorides, sulphates, organic debris, etc. [3]. This study focuses on the highly concerning effect of chloride. When mixed with the ingredients of concrete, sodium chloride (NaCl) can cause harm, according to Helmenstine [4] and Robertson [5], but it can also speed up the pigments in the wet concrete's surface right away. Carter [6] found in his studies conducted between 1993 and 2005 that sodium chloride corrodes concrete more than other substances, but Lee et al., [7] assert that the solution as NaCl affect the concrete.

Concrete may suffer negative effects from industrial effluents' chemical contaminants. This raises serious questions about the characteristics of finished concrete and the mixing of water during cement hydration. Two sources of water are often used in the making of concrete: the moisture in the particles and the water that is added. The majority of water quality criteria focus more on the amount of water added than the fine and coarse aggregate moisture content. Most of the time, people overlook the quality of the water because they assume that adding drinkable water will neutralize any contaminants. Geographically varying quantities of dissolved inorganic compounds are predicted in groundwater, which mostly originates from minerals. Salts of calcium, magnesium, potassium, sodium, and other elements may be found in water.

Concrete's resistance to chloride attack is compromised. Previous studies [8-13] that looked at how concrete affected reinforced concrete concluded that precautions against chloride attack are especially crucial because corrosion is the major reason for reinforcement, which accounts are more than 40% of structural failures.

However, the current investigation focuses on how mass concrete is affected by water contaminated with chloride. The goals are to ascertain the strengths of concrete produced using water containing varied percentages of chloride contamination, to investigate the structural failure pattern that may result from this contamination, and to formulate results. In this research study focused on mechanical qualities, specifically compressive strength, and the ability of geopolymer concrete to withstand sulphate assault.

2. Related Works

Research is required to determine how chemically contaminated water affects the strength and longevity of hardened concrete. Results of a study on the effects of different deicing agents and exposure times on concrete materials showed that different deicing agents saw varying rates of penetration into a particular paste, which led to varying degrees of damage to the concrete [13]. provided an evaluation of the chemical resistance of eight distinct polymeric mortar formulations [14]. Reported on how environmental variables affected the durability and addition of epoxy-bonded concrete prisms characteristics [15]. An investigation results of mortars resistance to attack of magnesium sulphate revealed a notable alteration in their compressive and flexural characteristics [16]. investigated the effects of strong alkaline materials are bicarbonate and sodium carbonate in water mixtures of the concrete mix and characteristics of concrete strength. Therefore, it is necessary to evaluate how different concentrations of magnesium chloride in water affect the cement's setting times and concrete's strengths [17].

Sodium chloride, sometimes known as rock salt, has a strong taste and is very soluble in water, making it a useful deicing agent for melting ice at temperatures below 20 ºF [18]. When compared to other salts, it is comparatively safe for concrete [19]. Equal amounts of sodium as positively charged and chloride ions as negatively charged make up the ionic composition of sodium chloride [20]. Early research [21] on the effects of sodium chloride in mixing water is obtained an improvement of compressive strength at a concentration of 25 g/kg of solution and mild steel significantly decreased corrosion to transfer of water vapor. NaCl has been observed to have unpredictable effects on concrete, accelerating set in certain cement and delaying it in others [22].

Research on NaCl-containing deicers shows that NaCl significantly reduces concrete's compressive strength [23]. The concrete is affected by the corrosion in the zone of chloride salt solution obtained at a corrosion rate is 1.74 mm/year when sea water has a NaCl level of roughly 3.5% [24], 5% of NaCl solutions are utilized to research work the properties of durability at RHA-containing concrete in a laboratory setting [25]. The recognized qualities of concrete may be improved by adding Rice Husk Ash (RHA) [26-28]. At 28 days, the addition of RHA at 10% to reduced chloride ion penetration in concrete compared to cubes. A pozzolana called RHA is utilized all around the world to create high-performance concrete constructions. The primary component of increased concrete performance is dense calcium silicate hydrates (CSH), which are created when reactive amorphous silica in the concrete matrix combines with the release of cement hydration by calcium hydroxide [29, 30]. According to the results, Ca^{2+} and OH^- ions combine in the RHA of silica amorphous silica to generate less portlandite and more CSH gel, which increases the concrete strength of RHA and non-RHA-containing concrete [31].

For both financial and safety considerations, the primary issue with concrete constructions is their long-term endurance. Aggressive chemicals seeping into the concrete is typically the cause of concrete structure degradation [32]. Many concrete constructions, including power plants, waste disposal facilities, decks, piers, floating offshore platforms, and harbors, are frequently exposed to hostile environments. Carbon (IV) oxide, sulphates, chlorides, and moisture are a few examples of these aggressive agents [33]. The most serious issue impacting the longevity of concrete structures, particularly in salty settings, the reinforcing steel bars is corrosion of reinforced concrete (RC) due to the entry of chloride ions. Pitting corrosion will happen when there is growth of chloride on the implanted steel rebar surface [34]. Worldwide, RC corrosion is an issue that requires large sums of money for restoration and repair. Numerous studies have been conducted to determine the correlation among the concentration of chloride ions and the commencement of corrosion [35-39].

The concrete pore solution-free penetrates are not affected by all chloride ions, as shown by Haque and Kayyali [40]. When some of the ions are chemically bonded by the hydration products, chloroaluminate hydrate is produced. The RC structures are broken down by the portion of the chloride ions that remain free. According to Sague´s [41], the control of depassivation in steel rebar concrete is used as the ions of chloride and hydroxide. However, they have recommended that while corrosion will happen at a reduced rate when internal chlorides are present, a ratio of less than 3 does not significantly contribute to corrosion when external chlorides are present [42]. Sulfurate assault is a term used to describe the detrimental effects of exposing materials of cement-based construction of an environment that contains sulphate ions. This is considered to be a major problem [43]. Researchers have investigated the construction-based aggressive ions. They have collected the sources from different zones such as deicing salts, ocean, groundwater, infectious activity, unwanted water from companies, usage of chemical contaminated mixed water [44–47].

3. Materials and Methods

3.1 Materials

OPC was utilized to this investigation. Materials for geopolymer concrete (GPC), including coarse aggregate, sand, fly ash, calcined clay, sodium hydroxide (SH), sodium silicate (SS), water, and super plasticizer (SP), are used in the current study project. Micro silica is also added to geopolymer concrete. For instance, A35 is a geopolymer concrete mixture in which 35% of the total binder is alkaline activator solution (A). Table 1 displays the several binder combinations for the SS and SH, ranging from 1.5 to 2.5.

***Table 1:** Binder Ratio of SS and SH*

Mixture	**GPC – 1**	**GPC – 2**	**GPC – 3**	**GPC – 4**	**GPC – 5**	**GPC – 6**	**GPC – 7**	**GPC – 8**	**GPC – 9**	**OPC**
Label	A35	A35	A35	A35	A35	A35	A35	A35	A35	OPC
	R2.5	R2.5	R2.5	R2	R2	R2	R1.5	R1.5	R1.5	
Aggregate as Coarse	1222	1222	1216	1222	1222	1222	1222	1216	1216	1054
Sand	658	658	655	658	658	658	658	655	655	740
Fly Ash	400	-	-	400	-	-	400	-	-	-
GGBFS	-	400	-	-	400	-	-	400	-	-
Calcined Clay	-	-	400	-	-	400	-	-	400	-
Cement	-	-	-	-	-	-	-	-	-	376
SH	40	40	40	47	47	47	56	56	56	-
SS	100	100	100	94	94	94	84	84	84	-
Water	8	8	8	8	8	8	8	8	8	151

SP	6	6	6	6	6	6	6	6	6	4.2

Based on the results of Table 2's maximum compressive strength (48.9 MPa) and the above binder composition, we have determined the optimal binder composition (2.5), which is then used to determine the fraction of the geopolymer concrete mixture.

Table 2: *Compressive strength of binder ratio*

Mix ID	**Label**	**Compressive Strength (MPa)**	
		28 days	**90days**
GPC – 1 (F)	A35 R2.5	42.3	43.4
GPC – 2 (G)	**A35 R2.5**	**44.8**	**48.9**
GPC – 3 (CC)	A35 R2.5	39.8	40.8
GPC – 4 (F)	A35 R2	40.5	41.4
GPC – 5 (G)	A35 R2	43.1	43.9
GPC – 6(CC)	A35 R2	38.6	39.7
GPC – 7 (F)	A35 R1.5	39.2	40.1
GPC – 8 (G)	A35 R1.5	41.9	43.1
GPC – 9 (CC)	A35 R1.5	37.8	38.7
OPC	OPC	38.9	41.5

3.2 Mixture Proportion

The concrete mixes are in two categories: initially with fly ash, GGBFS, and micro silica added, and another is pure 100% OPC. GGBFS and fly ash for various geopolymer blends. Superplasticizer and water were added to the mixes to make them more workable. Table 3 displays the mixture proportions of the ten blends that were examined. Combining solutions of SH and SS served as an alkaline activator. About half an hour before the concrete was actually mixed, the SS and SH solutions were combined used as alkaline activator. First, the aggregates and fly ash were combined in a pan mixer. To create fresh geopolymer concrete, the activator solutions were added to dry ingredients and mixed for an additional three to five minutes. A consistent ratio of SS/SH was used in creation of mixtures GPC1–10. A 35% alkaline activator was employed in each batch. Standard Portland Cement Concrete was designed using ACI 211.1 as a guide.

Table 3: *Mixture Proportion (Kg/m^3) of the concrete*

Mixture	**GPC – 1**	**GPC – 2**	**GPC – 3**	**GPC – 4**	**GPC – 5**	**GPC – 6**	**GPC – 7**	**GPC – 8**	**GPC – 9**	**GPC – 10**	**OPC**
Label	A35	A35	A35	A35	A35	A35	A35	A35	A35	A35	OPC
	R2.5	R2.5	R2.5	R2.5	R2.5	R2.5	R2.5	R2.5	R2.5	R2.5	
Coarse Aggregate	1222	1222	1216	1222	1222	1222	1222	1216	1216	1216	1054
Sand	658	658	655	658	658	658	658	655	655	655	740
Fly Ash	40	80	200	-	-	-	40	40	-	-	-
GGBFS	360	320	200	360	320	200	320	340	320	340	-
Calcined Clay	-	-	-	40	80	200	-	-	40	40	-

Micro Silica	-	-	-	-	-	-	40	20	40	20	-
Cement	-	-	-	-	-	-	-	-	-	-	376
SH	40	40	40	40	40	40	40	40	40	40	-
SS	100	100	100	100	100	100	100	100	100	100	-
Water	8	8	8	8	8	8	8	8	8	8	151
SP	6	6	6	6	6	6	6	6	6	6	4.2

3.3 Casting and curing

100 mm-sized concrete cubes were made in order to measure compressive strength. A total of 297 specimens were created using various geopolymer concrete compositions. After a 24-hour casting period, concrete cubes were demolding, and samples were submerged in water for 28 days to achieve the intended strength. Following this, 90 GPC 1–10 specimens and 90 GPC 1–10 specimens were moved into each of the 10% Na_2SO_4 and 10% NaCl solutions. The residual samples were then left in water for subsequent hardening at 28, 56, and 90 days. Three distinct exposure conditions were applied to the specimens: 10% Na_2SO_4 solution, 10% NaCl solution, and water. Table 4 has a detailed list of the specimens.

Table 4: *Details of Samples*

Samples Details	**Curing Time (Days)**	**Absorbed under**		
		Water	**10% Na_2SO_4**	**10% NaCl**
GPC-1-10 (For each composition 3 sample each)	28	30	30	30
	56	30	30	30
	90	30	30	30
OPC	28	3	3	3
	56	3	3	3
	90	3	3	3
Sub Total		99	99	99
Total number of Specimens		297		

3.4 Testing of concrete specimens

Cast geopolymer concrete specimens of diameter and height is 100 mm and 200 mm were allowed to cure naturally at temperature 15-20 ^{o}C and 70±10% of relative humidity. For testing of compressive strength and mass change, cylinder specimens with diameter and height are 100 and 200 mm respectively. The weight change testing, the prism samples were submerged in 10% NaCl and 10% Na_2SO_4. The cylinder samples were submerged in the same chemical ratio to determine changes in compressive strength and mass.

4. Results and Discussion

4.1 Mechanical Properties

The compressive strength of concrete results are with and without reinforcement of fly ash shown graphically in Figures 1-3. The performance of GPC-7 (53.8 MPa) under water curing was found to be higher than that of OPC (38.9 MPa) at the 28-day mark. However, at later ages, GPC-7's compressive strength is 2.5% and 5.76% higher, respectively, than OPC's at 56 and 90 days. It was noted that fly ash and micro silica were added after 56 days and that this process grew steadily as the concrete aged. In addition, Figure 2 indicates that the performance of concrete containing GPC and OPC was determined to be equal under the 10% sodium sulphate (Na_2SO_4) exposure condition at 28 days, 56 days, and 90 days respectively. For short-term exposure conditions, it was found that the sodium sulfate solution had no discernible effect on the concrete, either with or without fly ash. Similar outcomes were seen by investigated OPC over a maximum 360-day exposure time in a Na_2SO_4 solution [48]. They have used fly and bottom ash, and furnace slag in place of some cement. They found that the mechanical property of blended cement was reached 2% higher than OPC following a 360-day exposure to Na_2SO_4.

It was also reported that, even after 300 days, a reduced concentration of Na_2SO_4 did not significantly alter the qualities of the mortar. Furthermore, the mechanism underlying the Na_2SO_4 reaction was previously understood to be that sulfate ions penetrate within concrete pores, and that a chemical interaction might occur between sulfate ions and cement hydration. Na_2SO_4 then reacts with CaO to produce mono-sulfate, which in turn forms gypsum and ettringite within the pores of the concrete [49]. Even though ettringite development is not ideal over the long run, it can be inhibited by adding fly ash since it causes the pores in the concrete to shrink. Furthermore, the improvement of GPC strength was observed very slowly when exposed to 10% NaCl compared to OPC. Nonetheless, the pore sizes circulation is crucial at hardened concrete and is impacted by the occurrence of chloride ions. Decalcifications that are obvious at later ages cause degradation and the production of chloro-aluminate in chloride solutions. The effects of Na_2SO_4 on concrete include decalcification, the creation of porous CaSO4, and calcium hydroxide leaching.

The leaching of calcium hydroxide (CaO) is a significant phenomenon in concrete; however, the influence of fly ash, which contains amorphous silica, reacts with Na_2SO_4 that is generated when cement hydrates, lowering the amount of $CaSO_4$ that is present in the concrete overall. Thus, the physical appearance of concrete is ultimately impacted by the presence of chlorides, which also alter pore diameters and disrupt the hydration process. Given the information regarding the impact of chloride on concrete, the experimental results showed that OPC in a 10% NaCl solution gradually increased strength at 56 days and decreased strength later 90 days of contact. Though it was discovered that geopolymer concrete performed better than OPC, it was a noticeable material strength has been increased with time. Therefore, it was previously recognized that while the sulphate attack product, ettringite, was difficult to generate, the consumed calcium oxide made the concrete denser. Fly ash, on the other hand, contains less calcium oxide, which may lessen the sulphate attack. Therefore, it was discovered through experimentation that fly ash-containing concrete has an appropriate compressive strength and remains unaffected by Na_2SO_4 solution. However, its chemical reaction slows down and takes longer to recover below 10% NaCl.

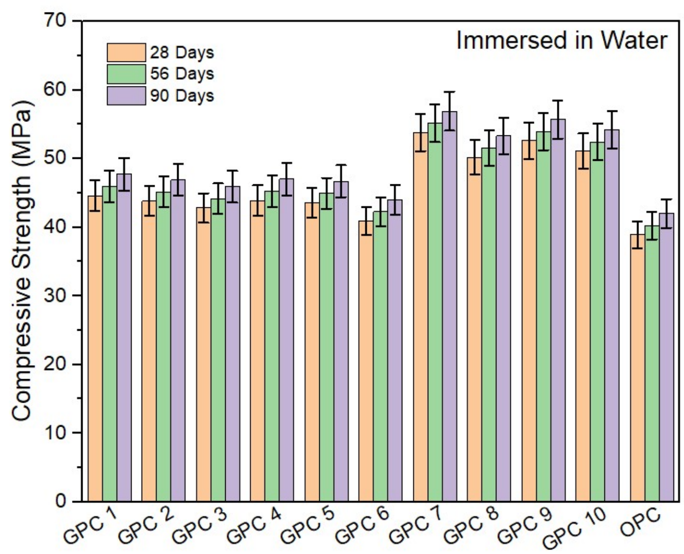

Figure 1. *Schematic representation strength of OPC and GPC for immersed in water.*

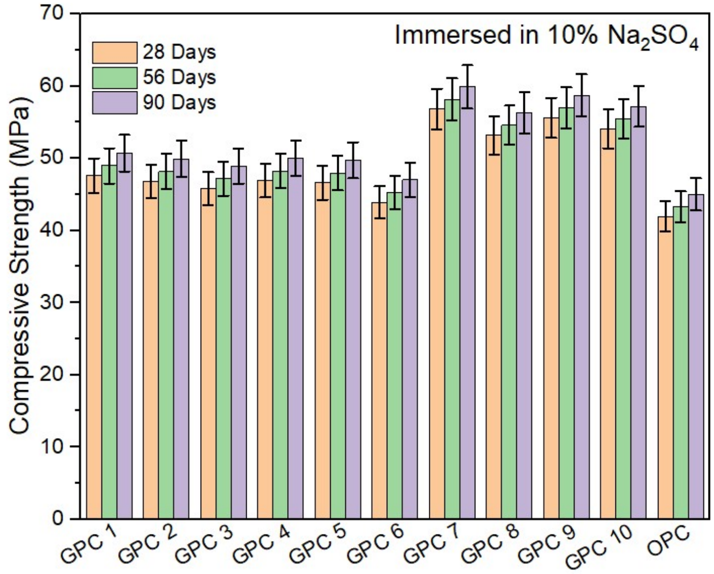

Figure 2. *Schematic representation strength of OPC and GPC for immersed in Na_2SO_4.*

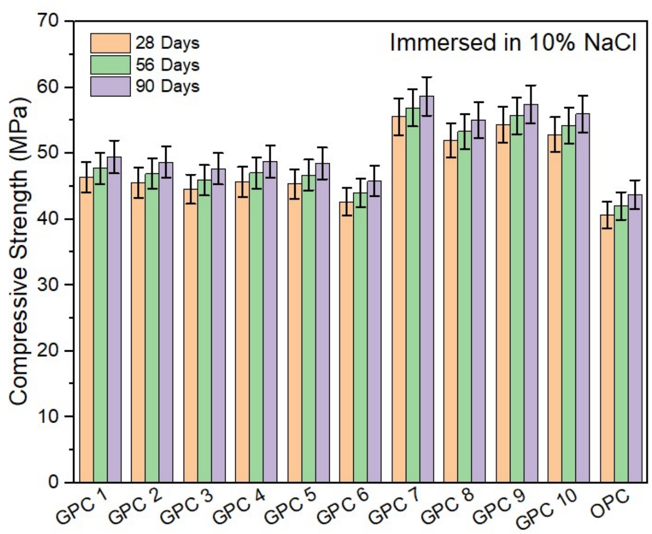

Figure 3. *Schematic representation strength of OPC and GPC for immersed in NaCl.*

4.2 Compressive Strength Variation

By comparing compressive strength of GPC to regular Portland concrete under various exposure of 28, 56, and 90 days respectively. The study is able to determine the strength of compressive variance in different sources. The concrete compressive strength containing fly ash was shown unchanged at 28 days, but to significantly increase at the ages of 56 and 90 days with solutions. Under Na_2SO_4 solution, fly ash-containing concrete performed compressive strength is better than others. After 90 days, it had reached a strength that was nearly 33.11% more than the other control mix exposure circumstances. Then, under a 10% NaCl solution, the concrete with fly ash depicted less compressive strength variance. Figure 4 depicts that the results of an examination of variation (%) in concrete compressive strength with fly ash and micro silica exposed to Na_2SO_4 and NaCl at varying curing days.

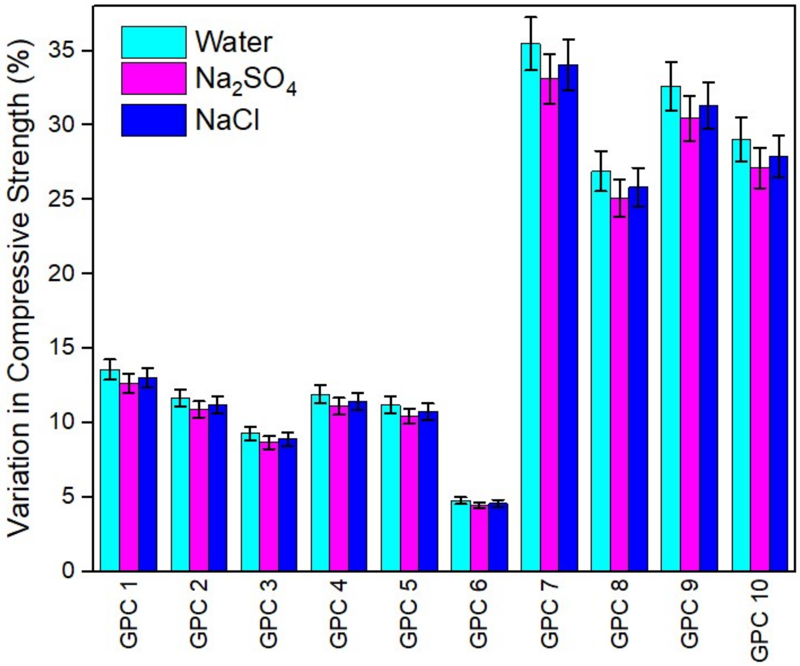

Figure 4. *Variation of strength in OPC and GPC for immersed in water, sulphate and chloride solution.*

4.3 Revolution in Weight

The concrete samples are weighing under water, Na_2SO_4, and NaCl was done both before and after exposure. Figure 5 shows the weight change of 10% fly ash-containing geopolymer concrete after 28, 56, and 90 days of curing. It was noted that after typical water curing, the weight of all types of concrete remained same. But there was a noticeable shift in weight in all combinations when it was exposed the solution at 10% Na_2SO_4 and NaCl. Under Na_2SO_4 at 56 and 90 days, the geopolymer concrete (GPC-7) showed the least weight gain; in the same conditions, other geopolymer concretes and OPC also showed greater weight gain.

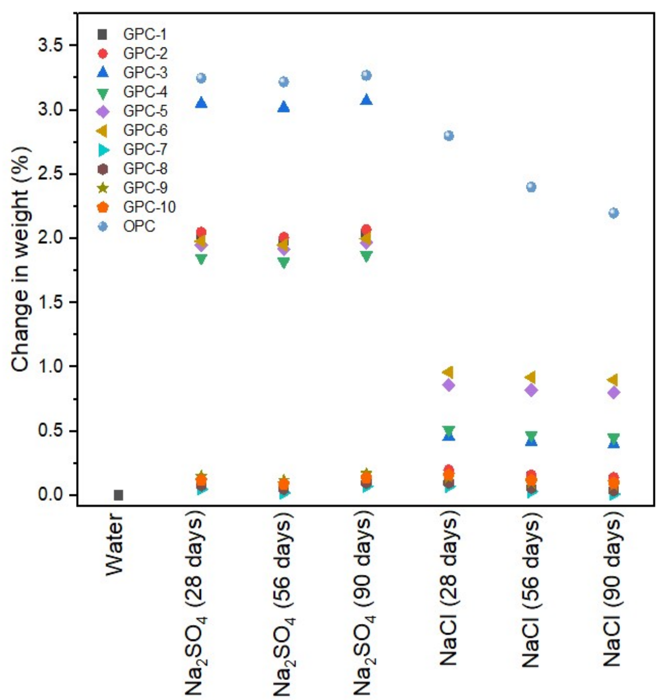

Figure 5. *The concrete weight change under sulphate and chloride exposure.*

It demonstrates how the penetrability of salts is decreased in concrete that contains fly ash and micro silica, with lower values observed compared to others. Less weight growth was seen in geopolymer concrete as a result of the findings that decreased fly ash and micro silica in the concrete might slow down process of hydration and lessen absorptivity of salts in concrete (GPC-7). It guaranteed that adding more cement to concrete would lessen the permeability of strong salt solutions, which corrode reinforcing and ultimately lead to structural collapse. Therefore, under 10% Na_2SO_4 and 10% NaCl circumstances, the overall performance of concrete decreased with fly ash and micro silica was shown satisfactory.

4.4 Degree of damage

According to the concept of damage degree, which is the indication of concrete deterioration, the damage degree was computed using the following equation, which Niu, [50], had previously determined.

$$D_i = 1 - \frac{\sigma_i}{\sigma_o} \quad (1)$$

On the other hand, D_i represents the extent of damage following a specific immersion time, σ_i represents the concrete's compressive strength following specific immersion duration, and σ_o represents the concrete's original compressive strength. The mechanical properties value of OPC and GPC at 28 days of age, prior to being transferred into sulfate and chloride solutions, is represented by the σ_o value in this study. The aforesaid Eq. (1) was used to assess the degree of damage for concrete with and without fly ash exposed to Na_2SO_4 and NaCl. The results are shown graphically in Figure 6. The findings showed that OPC experienced damage to a greater extent in all circumstances. In addition, compared to OPC and other geopolymer concrete, geopolymer concrete incorporating fly ash with micro silica (GPC-7) has reduced degree of damage. Additionally, Ming et al. [51] concurred that as damage increases, the capability of construction decreased. Eventually, when crack reaches are particular threshold, the structure concrete completely collapse. On the other hand, OPC -0.52, -0.57, and -0.54 in water, Na_2SO_4, and NaCl, respectively, showed greater results. Lower values were then found in geopolymer concrete under water, Na_2SO_4, and NaCl, respectively, measuring -0.57, -0.62, and -0.59. Therefore, it is stated here that the stronger and more durable the concrete, the lesser the degree of damage.

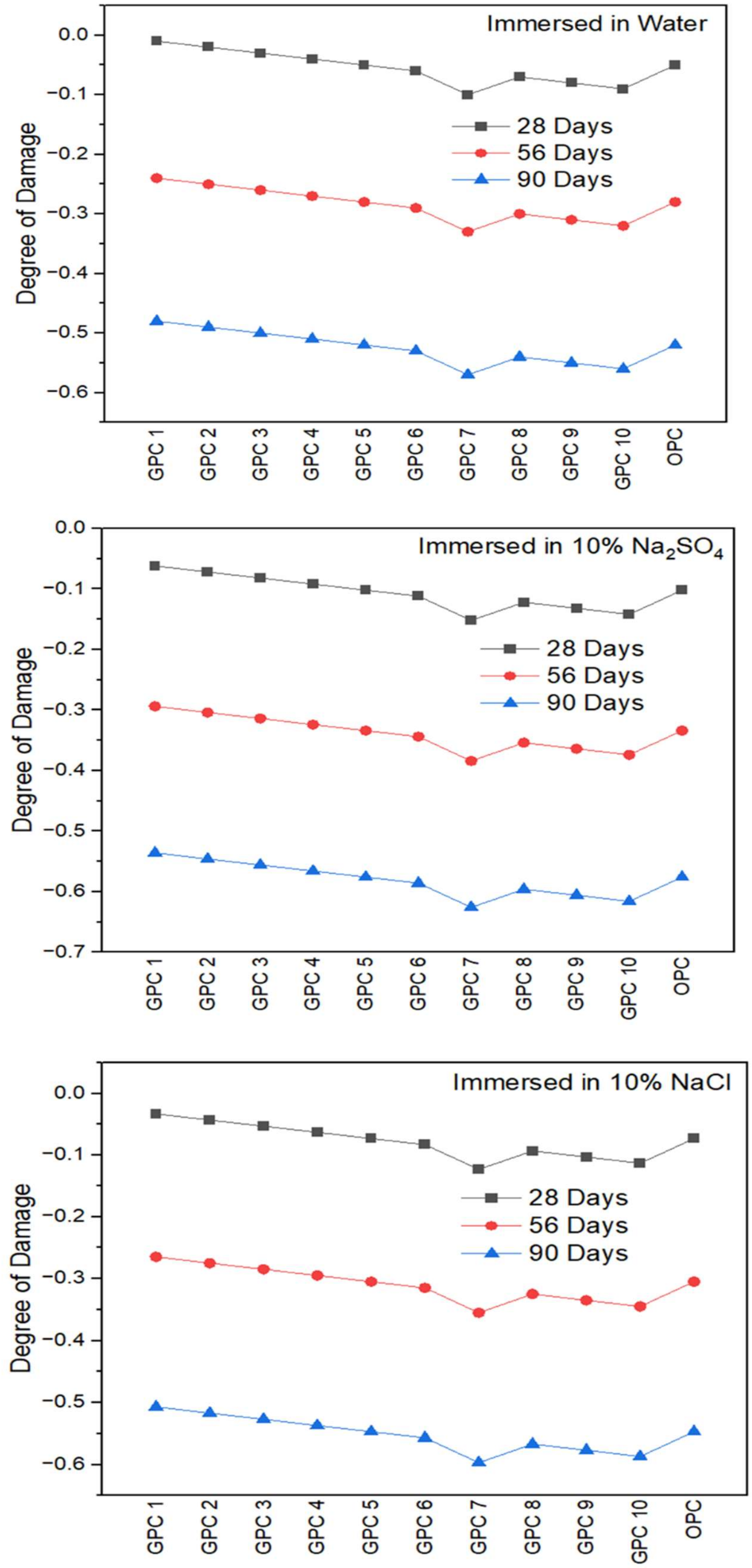

Figure 6. *Damage of OPC and GPC under sulphate and chloride exposure at hardening time.*

4.5 Ultrasonic Pulse Velocity (IPV)

Figure 7 depicts that the UPV of geopolymer concrete and regular Portland concrete varies with different days of curing for the concentration of alkali solutions. For one sample, UPV as the curing period increased (GPC-7). Nonetheless, in the samples at varying stages of maturation, there are differences in the velocity enhancement's magnitude and rate of growth. The sample containing GPC-7 reached the greatest velocity, followed by GPC-9 and GPC-8, in that order. The strength of GPC prepared with 10% fly ash is superior to that of other alkali concentrations, as evidenced by the rise in velocity for the latter. This study selected 90-day-old hardened concrete as the reference topic for examination in order to streamline the analysis process.

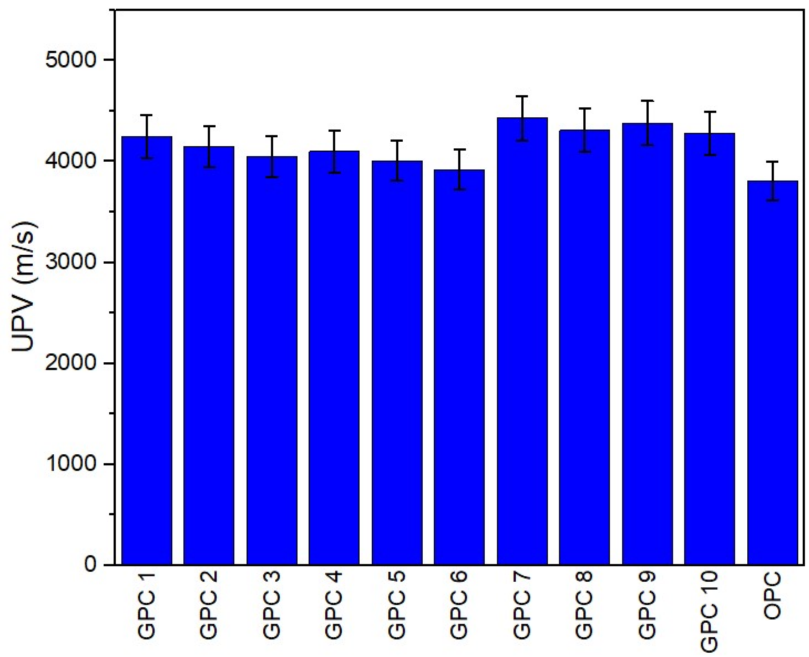

Figure 7. *Progress of UPV at 90 days curing of GPC synthesized by different concentration of alkali activator.*

For geopolymer concrete, 90-day velocity trend was high. For GPC-7 and OPC, the maximum and lowest velocities have been noted, respectively. When accounting for the minimum and greatest parameters of standard deviation, which are comparable to mechanical properties that has been predictable at various curing periods, it is nearly constant after 90 days of maturity. The experimental results show that a higher alkali content led to a stronger initial polymerization. When concrete ages and the concentration of alkali activator is high, the discharges of additional humidity from the framework of geopolymer precursor. The structure becomes porous and fragile due to this moisture loss, which slows down the polycondensation reaction portion.

4.6 Rapid chloride permeability test (RCPT)

During experiment, the conductance of electrical on GPC was recorded for approximately six hours through charge passing. The amount of charge passed through test samples was calculated using Eq. (2), which was derived using the trapezoidal law and data collected every 30 minutes.

$$Q = 900\,(I_0 + 2I_{30} + 2I_{60} + \cdots + 2I_{330} + I_{360}) \quad (2)$$

Where, Q = Charge passed (Coulombs)

I_0, I_{30}, I_{60}...I_{330}, I_{360} – Current at 0, 30, 60…330, 360 minutes

According to ASTM C 1202 [53], the outcome of chloride ion dispersion relies on the charge transmitted. The chloride ion permeability of OPC and GPC mixtures is depicted in Table 5.

Table 5: *RCPT outcome of OPC and GPC*

Samples	Composition	Average Current (coulombs)
GPC-1	F10+G90	1230
GPC-2	F20+G80	1310
GPC-3	F50+G50	1790
GPC-4	G90+C10	1480
GPC-5	G80+C20	1860
GPC-6	G50+C50	2230
GPC-7	**F10+G80+S10**	**1045**
GPC-8	F10+G85+S5	1160
GPC-9	G80+C10+S10	1150
GPC-10	G85+C10+S5	1215
OPC	OPC	2380

It shows that the best way to resist Cl^- permeability in fly ash-GGBFS and micro silica-based GPC was increasing the percentage of composition. The charge applied to other geopolymer concrete and OPC is also decreased. The minimal permeability of the GPC-7 sample can be primarily ascribed to an increased incorporation of GPC. On the other hand, the concrete mix (GPC-6) is classified as high chloride ion permeability. Nevertheless, compared to all other mixes, the mix GPC-7 which consists of 80% GGBFS, 10% fly ash, and 10% S showed reduced chloride ion permeability. Additionally, the same composition has demonstrated increased compressive strength. This was credited to a skilful modification of the pore structure of geopolymer concrete.

4.7 Scanning Electron Microscopy (SEM)

Figure 7 depicts that the pictures from study of SEM with fly ash-containing sample that was exposed to 10% Na_2SO_4 and 10% NaCl over at the days of 56.

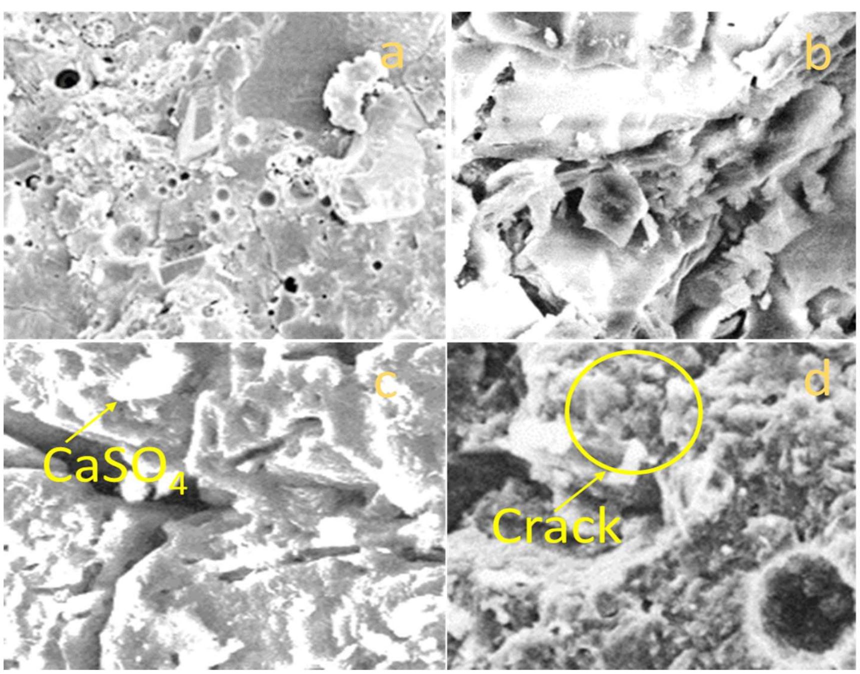

Figure 7. *SEM Images of a) GPC; b) GPC with water; c) GPC with sulphate solution and d) GPC with chloride solution.*

It is evident that the calcium sulphate reaction starts at 56 days of age, and a well-formed reaction between calcium oxide was seen. The concrete that contained fly ash also showed signs of calcium sulphate production. A small quantity of ettringite was fashioned in concrete while it was exposed to a solution of Na_2SO_4, which capacity partially fills in the voids and promotes the improvement of strength [52]. Similarly, the synthesis of calcium sulphate was observed in GPC when exposed to a Na_2SO_4 solution. But in this case, a notable illustration of a reduction in compressive strength was seen as a symptom of crack propagation.

5. Conclusions

From the outcome of the experimental results for OPC and GPC assumptions are the following;

i. The outcome of this research work suggested that fly ash and micro-silica might substitute some of the OPC in both benign and harsh environments.

ii. It was noted that during typical water curing, fly ash-infused concrete does alter in weight. However, a noticeable shift in weight was seen in all combinations are subjected to solution of 10% Na_2SO_4 and NaCl. In OPC, the weight gain was increased. The minimum gain of weight was seen in geopolymer concrete, though, because fly ash may slow down the process of hydration and lessen salts' capacity to material penetrate.

iii. GPC-7 has a stronger performance than OPC, which was cured in water at the days of 28. GPC has a compressive strength that is 2.5% and 5.76% developed than OPC at 56 and 90 days, respectively.

iv. It was discovered that, up to ninety days, the presentation of fly ash-containing concrete, GPC, and OPC exposed to 10% sodium sulphate (Na_2SO_4) was equivalent. For brief exposure, the Na_2SO_4 solution has no discernible effect on concrete.

v. Ordinary Portland concrete gradually gains strength at 56 days and gradually loses strength over 90-day exposure period when placed in a 10% sodium chloride (NaCl) solution. Nonetheless, it was discovered that geopolymer concrete performed better than OPC, but there was a noticeable increase in strength over time (GPC-7).

vi. The strength performance of the concrete is not negatively impacted by the partial replacement of cement with fly ash mixed with micro silica. Nonetheless, it performs well enough in typical water conditions and when exposed to sulphate and chloride.

vii. There are technical and environmental advantages to using fly ash and micro silica in place of regular cement, which are crucial in the current context of sustainable development. Therefore, it is suggested that fly ash coupled with micro silica be used as a concrete material. It is also recommended that more research be conducted to ascertain the material's long-term strength and durability in the presence of seawater and the combined effects of sulphate and chloride.

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