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# Durability Testing Of Geopolymer Concrete Against Acidic And Sulphuric Environments Using Ultrasonic Pulse Wave Velocity Test

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Geopolymer Concrete (GPC) is an innovative construction material that has gained attention for its sustainability and superior performance in specific applications. The potential applications of GPC are extensive, ranging from infrastructure projects to precast concrete elements, positioning it as a promising alternative in the construction industry. In this context, non-destructive testing (NDT) methods, such as Ultrasonic Pulse Wave Velocity (UPV), offer valuable insights into the material's long-term performance and durability. The current research focuses on assessing the capacity of geopolymeric concrete against acid and sulphuric attacks using ultrasonic pulse wave velocity, a nondestructively testing method over 90 days where GPC is cured under two different conditions, accelerated curing method and room temperature curing. GPC specimens were subjected to acid attack and sulfur resistance tests, and UPV measurements were taken at 30-day intervals for up to 90 days. The results of these tests revealed distinct patterns in the degradation of concrete quality over the 90 days, with Portland cement concrete showing the highest total weight reduction over the same period. A comparative analysis of three concrete samples revealed varying levels of degradation in structural integrity. The accelerated treatment enhances the concrete's resistance to environmental stressors, improving its durability and maintaining structural integrity under challenging environments. Performing NDT is essential and reliable for this purpose, as it allows continuous assessment of material integrity without causing damage.

**Keywords:** Geopolymer Concrete, Durability, Acid Attack, Sulphur Attack, Ultrasonic Pulse Velocity, Non-destructive Testing.

## 1. Introduction

Geopolymer Concrete (GPC) is an innovative construction material that has gained attention for its sustainability and superior performance in specific applications. First coined by Joseph Davidovits[1] in the 1970s, the concept of geopolymers involves using aluminosilicate materials such as fly ash, slag, or metakaolin, which are activated with alkaline solutions to form a hardened binder. Unlike traditional Portland cement concrete, which relies heavily on limestone and contributes significantly to global $CO_2$ emissions, GPC uses industrial by-products, reducing its carbon footprint. Additionally, the polycondensation of silica and alumina in GPC forms a three-dimensional aluminosilicate network, imparting enhanced mechanical properties, including higher early strength, better fire resistance, and lower shrinkage[2]. The potential applications of GPC are extensive, ranging from infrastructure projects to precast concrete elements, positioning it as a promising alternative in the construction industry. However, the durability of GPC under harsh environmental conditions, such as acidic and sulphuric environments, is crucial[3].[4]. These conditions are prevalent in industrial waste zones, sewage systems, marine environments, and chemical plants. Acidic environments can aggressively attack the calcium-containing components of concrete, leading to severe deterioration by forming byproducts that weaken the concrete's core[5]. Sulphates, on the other hand, react with the hydration products in the concrete matrix, causing expansive reactions and cracking, compromising the material's integrity.

Although GPC is generally recognized for its resistance to chemical attacks compared to traditional Portland cement concrete, the extent of its durability under prolonged exposure to harsh conditions is not yet fully understood. To ensure the safe and sustainable application of GPC in such environments, it is critical to evaluate its long-term resistance to aggressive agents[6]. Traditional destructive testing methods, which involve physically damaging the concrete samples to assess their performance, are not ideal for ongoing durability assessments[7]. These methods are labor-intensive, costly, and may not accurately reflect the material's behavior in real-life conditions. In this context, non-destructive testing (NDT) methods, particularly Ultrasonic Pulse Velocity (UPV) testing, offer valuable insights. UPV measures the velocity of ultrasonic waves passing through the concrete, providing information about its internal structure, homogeneity, and potential degradation[8]. By correlating UPV readings with the degree of damage caused by acid and sulphate attacks, researchers can evaluate the resilience of GPC without the need for invasive procedures. This approach preserves the integrity of the test samples and allows for continuous monitoring of concrete durability over time. The application of UPV in evaluating GPC's durability against acid and sulphuric attacks is critical, as it can help in understanding the material's long-term performance, thereby ensuring its broader and more confident application in challenging environments[9]. GPC represents a significant advancement in sustainable construction materials, offering numerous environmental and mechanical advantages. While research has demonstrated that GPC exhibits excellent resistance to chemical attacks, further investigation is needed to fully understand its long-term durability, particularly under harsh environmental conditions. The integration of NDT methods like UPV in durability assessments is essential for advancing GPC's application in the construction industry[10]. The durability of concrete when exposed to acidic and sulphuric conditions is a critical consideration in ensuring the longevity and safety of structures in aggressive environments. The acid attack typically involves the neutralization of the alkaline components of concrete, particularly calcium hydroxide, leading to the leaching of calcium ions and the formation of expansive and soluble compounds that weaken the material[11]. Sulphuric acid, in particular, is highly destructive as it not only lowers the pH of the concrete but also forms gypsum and ettringite, which can cause severe expansion and cracking. Sulphate attack, on the other hand, involves the reaction between sulphate ions and the hydration products in concrete, particularly calcium aluminate hydrates, to form expansive products such as ettringite[12], [13]. This expansion can result in internal stresses, cracking, and ultimately, the disintegration of the concrete matrix Research on the performance of GPC under these harsh conditions has shown promising results. GPC's resistance to acid and sulphate attacks is attributed to its lack of calcium-based compounds, which are the primary reactants in these degradation processes. Studies have reported that GPC exhibits significantly lower mass loss and surface damage when exposed to sulphuric acid compared to Portland cement concrete. Furthermore, the formation of less porous and more chemically stable structures in GPC contributes to its enhanced durability in sulphate-rich environments. However, it is important to note that the performance of GPC can vary depending on factors such as the type of aluminosilicate material used, the molarity of the alkaline activator, and the curing conditions[14]. The current research focuses on assessing the capacity of GPC against harsh environment like sulphur and acid using ultrasonic pulse wave velocity (UPV), a non-destructive testing method over 90 days where GPC is cured under two different conditions, accelerated curing method and room temperature curing.

## 2. Material and Methods

All materials used for this study were sourced from the local market, except for fly ash, which was obtained from the Raichur Thermal Power Plant. Specific gravity and fineness tests were conducted on all materials required for the mix design by IS 10262:2019[15]. The properties of all the ingredients used are detailed in Table 1.

Table 1: Basic Material Tests on Components

| Material | Property | Results | Test Conducted |
|---|---|---|---|
| Fly Ash | Fineness% | 16 | Wet Sieve test in 45 μ |
| | Specific Gravity | 2 | Density Bottle test |
| GGBS | Fineness% | 9 | Wet Sieve test in 45 μ |
| | Specific Gravity | 2.85 | Provided by JSW Cements |
| Coarse Aggregates | Fineness% | 7.1 | Sieve Analysis |
| | Specific Gravity | 2.61 | Wire Bucket Test |
| Recycled Aggregates | Fineness% | 6.4 | Sieve Analysis |
| | Specific Gravity | 2.1 | Wire Bucket Test |
| M-Sand | Fineness% | 2.64 | Sieve Analysis |
| | Specific Gravity | 2.61 | Pycnometers Test |
| NaOH | Specific Gravity | 1.47 | Provided by distributor |
| $Na_2SiO_3$ | Specific Gravity | 1.6 | Compared with water weight |

XRD and EDX tests were also conducted on the fly ash, and the results are presented in Figure A. These tests confirm that the fly ash is classified as low-calcium fly ash, as per IS 3812-part

1[16]. The mineral composition of both fly ash and GGBS is detailed in Table 2, with the mineral composition of GGBS provided by the supplier, JSW Cements.

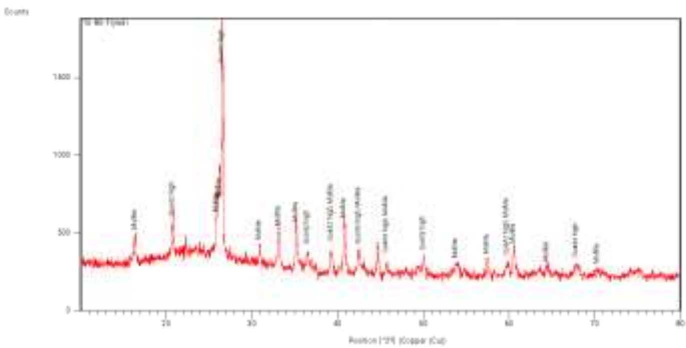

Figure A: XRD test Result Graph of Fly Ash

Table 2: Mineral Composition of GGBS and Fly Ash

| | GGBS | Fly Ash |
|---|---|---|
| Density | 2.85 | 2 |
| $Na_2O$ | -- | 1.30 |
| MgO | 7.96 | 2.81 |
| $Al_2O_3$ | 13.6 | 23.83 |
| $SiO_2$ | 35.1 | 60.23 |
| $SO_3$ | 0.16 | 3.49 |
| $K_2O$ | -- | 1.81 |
| CaO | 35.05 | 5.16 |
| $Fe_2O_3$ | 0.61 | 1.38 |
| Cl | 0.004 | -- |

### 2.1 Alkali Activators

The geopolymerization process is driven by alkali activators that promote the formation of aluminosilicate chains. These activators are composed of a blend of NaOH and $Na_2SiO_3$ in a 1:2.5 ratio, which is highly effective[17]. Sodium hydroxide (NaOH) is procured in crystalline form, and to prepare solutions of specific molarities, the crystals are dissolved in carefully measured amounts of water. For instance, to prepare a 12M NaOH solution, 480 grams of NaOH crystals are dissolved in water. Due to the corrosive nature of NaOH and the exothermic reaction that occurs, generating substantial heat, extreme caution is required during preparation. The NaOH solution is typically prepared 24 hours before the casting process to ensure it is fully dissolved and ready for use. Sodium silicate ($Na_2SiO_3$) is directly obtained from a supplier and consists of 48% solids and 52% water. Its gel-like consistency makes manual mixing difficult, so $Na_2SiO_3$ and NaOH solutions are mixed using a mechanical mixer approximately one hour before casting. This careful preparation highlights the importance of safety measures and precise timing when handling these chemicals to ensure successful geopolymerization.

## 2.2 Mix Design

Due to the lack of standardized mix designs for fly ash-based geopolymer concrete, mix proportions are determined by fixing the binder quantity and setting the alkali activator-to-binder (AA/B) ratio. Volumetric calculations are then performed based on the specific gravities of the materials, following the guidelines outlined in IS 10262:2019[18]. Extensive research by Anuradha et al. has shown that the optimal AA/B ratio and the percentage of Ground Granulated Blast Furnace Slag (GGBS) significantly influence the properties of geopolymer concrete, leading to the use of optimal material percentages[17]. In the chosen concrete mix, binders consist of 70% fly ash and 30% GGBS. Coarse aggregates are made up of 70% conventional material and 30% recycled aggregate, with proportions determined by the material properties of each type. M-sand is used as the fine aggregate[19]. The alkaline-to-binder ratio is set at 0.45, and the alkaline solution consists of NaOH and $Na_2SiO_3$ in a 1:2.5 ratio, with the NaOH solution having a molarity of 12M. To achieve the desired workability, a naphthalene-based superplasticizer is used at 1.5% of the binder's weight. Curing methods include ambient temperature, accelerated curing, and oven curing. Table 3 presents the material quality by volume for the geopolymer concrete.

For a comprehensive comparison between geopolymer concrete and traditional cement concrete, specimens of cement concrete were also prepared using the same water-to-binder ratio and aggregate proportions as those used in the geopolymer mix. This approach ensures that any observed differences in performance can be attributed to the binder type rather than variations in mix design. The cement concrete mix was formulated using Ordinary Portland Cement (OPC) as the binder, with the water-to-cement ratio matching the water-to-alkaline solution ratio of the geopolymer concrete. Similarly, the proportions of fine and coarse aggregates were kept consistent across both mixes to maintain uniform test conditions

Table 3: Table Quantity of Materials for Concrete

| Materials | Quantity kg/m3 |
|---|---|
| Fly Ash (70%) | 280 |
| GGBS (30%) | 120 |
| Na2SiO3 | 128.5 |
| NaOH | 51.4 |
| M-Sand | 680 |
| Coarse Aggregate (70%) | 690.9 |
| Recycled Aggregate (30%) | 296.1 |
| Superplasticizer | 1.5% of binder |

## 2.3 Preparation

The specified quantities in Table 3 were thoroughly mixed in dry form for approximately 5 minutes to ensure uniform distribution of all components. After the initial dry mixing, the alkaline solution was gradually added while the mixture was blended using a hand trowel. Due to the low water content in the mix, a superplasticizer, accounting for 1.5% of the binder weight, was introduced to enhance workability. However, it is important to note that excessive use of superplasticizer can negatively affect the strength of geopolymer concrete[20]. To mitigate this effect, additional water was added to achieve a workable consistency. The workability of the mixture was evaluated using the Slump Test, which revealed that geopolymer concrete tends to settle at a slower rate than traditional cement concrete. This behaviour is attributed to the gel-like nature of the activator solution. To further assess the workability of the concrete mix, the Slump Cone Method was employed after preparation. Given the gel-like consistency of geopolymer concrete, it is necessary to add additional water to achieve the desired workability, even with the use of a superplasticizer. Specifically, 101 litres of extra water per cubic meter of concrete were required to attain a slump value of 100 mm. This process involved iterative testing with incremental additions of water to fine-tune the consistency. The concrete achieved satisfactory workability with a 100 mm slump during the filling of all specimens. Figure B illustrates the mixing procedure and materials used. Cubic specimens (100 mm x 100 mm x 100 mm) were cast for compressive strength tests as per IS 516:1959. After casting, the cement concrete specimens were cured using standard water curing methods, where they were immersed in water at ambient temperature for specified periods before testing.

Preparing and testing both geopolymer and cement concrete specimens under identical conditions enabled a direct comparison of their mechanical properties, such as compressive strength, tensile strength, and flexural strength. This approach offered valuable insights into the potential advantages of geopolymer concrete over traditional cement concrete, particularly regarding early strength gain and overall performance.

## 2.4 Curing

In this study, two different curing regimes Accelerated Curing, and Room Temperature Curing—were employed to examine their effects on acid attack and sulfur resistance on GPC. The same set of geopolymer concrete mixes, with consistent design and proportions, was used for all tests to ensure uniformity and reliable comparison of results.

### 2.4.1 Accelerated Curing

As per the guidelines outlined in IS code IS: 9013:1978[21], a method employed to accelerate the attainment of initial strength involves the use of boiling water. Following the initial 24 hours of casting, specimens are immersed in boiling water for approximately 3.5 hours at a temperature of 80°C. Subsequently, the specimens are left in a curing tank for about 20 hours. Following this accelerated curing process, the specimens are further cured at room temperature. Figure C shows the indicative setup of the accelerated curing tank.

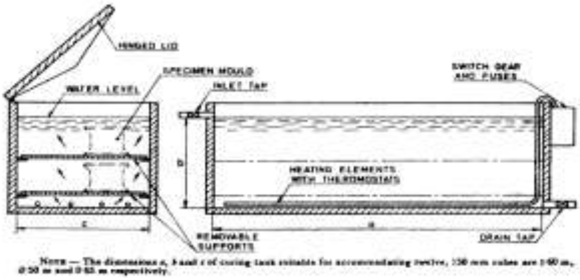


Figure B: Accelerated Curing tank (IS: 9013:1978)

### 2.4.2 Open Air Curing

After arranging the specimens, they were positioned in a sufficiently ventilated room and enveloped with polythene. To mitigate moisture loss from the surfaces, water was sprinkled on the cubes every other day.

## 2.5 Testing

To prepare for chemical exposure, cube specimens were first immersed in water for 24 hours to achieve water saturation, and their initial saturated weights were recorded. After this, the specimens were subjected to two different chemical solutions: a 5% sodium sulphate ($Na_2SO_4$) solution for the sulfate resistance test and a 3% sulfuric acid ($H_2SO_4$) solution for the acid attack test on concrete. Ultrasonic Pulse Velocity (UPV) tests were performed on the specimens to evaluate their strength, with measurements taken at 30-day intervals for up to 90 days[22]. Throughout the testing period, the corresponding weights of the specimens were also measured to monitor changes in mass as a result of the chemical exposures.

### 2.5.1 UPV Testing

Ultrasonic Pulse Velocity (UPV) testing is a non-destructive technique based on the principle that ultrasonic waves travel faster through denser and more homogeneous materials. When these waves encounter flaws such as cracks, voids, or deteriorated areas, their velocity decreases, providing insights into the material's integrity. The procedure for UPV testing involves several steps. First, the concrete surface must be prepared by cleaning and smoothing to ensure good contact between the transducers and the material. A coupling agent, like grease or gel, is typically applied to the surface to enhance the transmission of ultrasonic waves. The UPV apparatus includes two transducers (a transmitter and a receiver), a pulse generator, and a timer. Depending on the testing configuration—direct, semi-direct, or indirect—the transducers are positioned either on opposite sides of the material or along the same side, the schematic diagram is as shown in the figure C and F. During measurement, a pulse is transmitted through the material, and the receiving transducer captures it. The time taken for the pulse to travel through the material is recorded, and the UPV is calculated by dividing the distance between the transducers by the travel time. The interpretation of concrete quality concerning velocity is mentioned in Table 4, as per IS 13311(part 1): 1992[23], and the same values are used as a reference for analysis.

Table 4: Velocity Criteria for Concrete Quality grading according to IS 13311 (Part 1): 1992

| **Sl.No.** | **Pulse Velocity m/s by Cross Probing in m/s** | **Concrete Quality Grading** |
|---|---|---|
| 1 | Above 4500 | Excellent |
| 2 | 3500 to 4500 | Good |
| 3 | 3000 to 3500 | Medium |
| 4 | Below 3000 | Doubtful |

Interpreting the results involves analysing the pulse velocity as per IS 13311(Part 1): 1992 a high pulse velocity (typically above 4,000 m/s) suggests that the concrete is of good quality, dense, and well-cured, with minimal voids or cracks. A medium pulse velocity (3,000 to 4,000 m/s) may indicate minor defects or potential areas of concern, while a low pulse velocity (below 3,000 m/s) points to poor-quality concrete with significant cracks, voids, or other flaws.

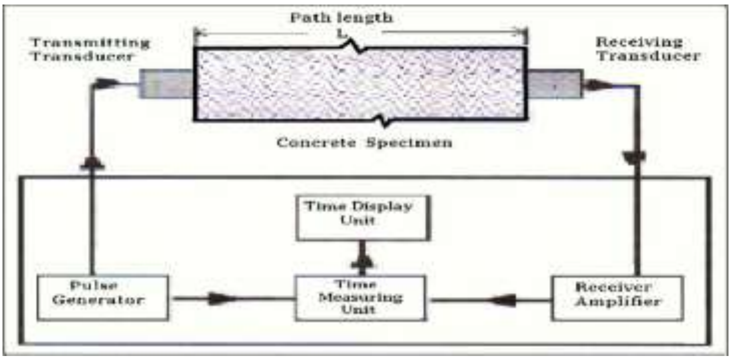


Figure C: Schematic Diagram of Ultrasonic Pulse Velocity Test

Acid Resistance of Quaternary Blended Recycled Aggregate Concrete - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Schematic-Diagram-of-Ultrasonic-Pulse-Velocity-Test_fig2_324074386 [accessed 27 Aug 2024]

Figure F: Cross Probing Method of UPV Testing

## 3. Results and discussion

Acid and sulphate attack tests were conducted in the laboratory, with periodic evaluations carried out every 30 days for up to 90 days following an initial 28-day curing period. The results of these tests were assessed using the Ultrasonic Pulse Velocity (UPV) method.

### 3.1 Acid Attack

The cubes were exposed to an acid environment and the pH of the solution was maintained throughout. At every 30 days interval cubes were tested in the direct method and average values are given in table 5.

Table 5: UPV values for Acid attack specimen

| | | GPCR | GPCA | CC |
|---|---|---|---|---|
| Weight before Exposure | | 2340 | 2310 | 2530 |
| Velocity before exposure | | 3860 | 3960 | 3970 |
| 30 DAYS | Weight | 2116 | 2104 | 2298 |
| | Velocity (m/s) | 3506 | 3670 | 3780 |
| 60 DAYS | Weight | 2094.3 | 2066 | 2277 |
| | Velocity (m/s) | 3205 | 3300 | 3290 |
| 90 DAYS | Weight | 2073.2 | 2056 | 2224 |
| | Velocity (m/s) | 3106 | 3204 | 3012 |
| GPCR – Geopolymer concrete Cured at Room Temperature<br>GPCA – Geopolymer Concrete Cured at Accelerated Curing Technique | | | | |

| CC – Portland Cement Concrete |
|---|

Table 5 provides the ultrasonic pulse wave velocities (UPV) and corresponding weights of concrete specimens at 30, 60, and 90 days of exposure, illustrating the effect of acid attack on geopolymer concrete (GPC) and conventional concrete (CC). A comparative analysis of the UPV test results for the concrete samples—GPCR, GPCA, and CC—over 90 days reveals distinct patterns in the degradation of concrete quality. Initially, all samples demonstrated high ultrasonic pulse velocities, indicating good quality concrete, with GPCR at 3860 m/s, GPCA at 3960 m/s, and CC at 3970 m/s. As time progressed, a decline in pulse velocity was observed across all samples. By 30 days, the velocities had decreased to 3506 m/s, 3670 m/s, and 3780 m/s for GPCR, GPCA, and CC, respectively, representing reductions of approximately 9.2%, 7.3%, and 4.8%. This decline continued at 60 days, with velocities dropping further to 3205 m/s for GPCR, 3300 m/s for GPCA, and 3290 m/s for CC, amounting to total reductions of about 16.9%, 16.7%, and 17.1% from their initial values. By 90 days, the velocities had decreased to 3106 m/s for GPCR, 3204 m/s for GPCA, and 3012 m/s for CC, reflecting total reductions of 19.5%, 19.1%, and 24.2%, respectively. Among the samples, CC showed the most significant reduction in pulse velocity, indicating a higher susceptibility to environmental degradation. In contrast, GPCA maintained relatively higher velocities over time compared to GPCR, demonstrating better resistance to quality degradation. Figure D shows the variation of velocities at different stages and this comparative analysis underscores the differing long-term durability of the concrete mixtures, with GPCA exhibiting superior performance in maintaining concrete integrity over the 90-day period. GPCA has remained with minor defects, even though at initial stages room temperature cured and accelerated cured concrete indicated almost the same ultrasonic pulse wave velocity, this shows that initial curing is important to accelerate the geopolymerization in concrete.

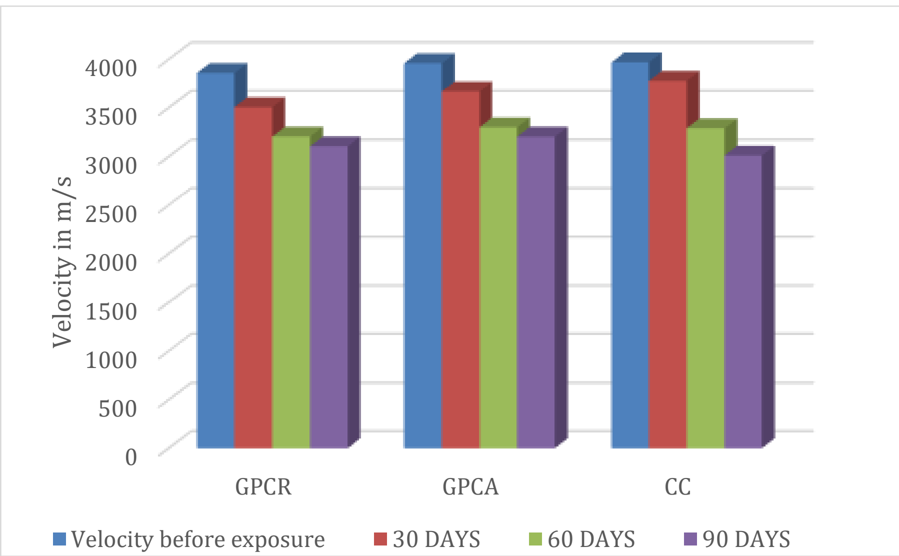

Figure D: Ultrasonic pulse velocity for various samples at various intervals under acid exposure

The weight loss of concrete specimens subjected to acidic environments over time was recorded for different mixtures. For the GPCR mix, the initial weight was 2340 grams. After 30 days, the weight reduced to 2116 grams, reflecting a loss of 224 grams. At 60 days, the weight further decreased to 2094.3 grams, showing a total weight loss of 245.7 grams from the initial measurement. By 90 days, the weight had decreased to 2073.2 grams, resulting in a total reduction of 266.8 grams from the initial weight. For the GPCA mix, the initial weight was 2310 grams. After 30 days, the weight decreased to 2104 grams, indicating a reduction of 206 grams. At 60 days, the weight further reduced to 2066 grams, marking a total loss of 244 grams from the initial weight. By the 90th day, the weight dropped to 2056 grams, showing a total reduction of 254 grams. In comparison, the conventional concrete (CC) specimen started with an initial weight of 2530 grams. After 30 days, the weight decreased to 2298 grams, a loss of 232 grams. At 60 days, the weight further dropped to 2277 grams, indicating a total reduction of 253 grams. By the end of 90 days, the weight was 2224 grams, reflecting a total loss of 306 grams from the initial weight. These results indicate that all concrete mixes experienced weight loss due to acidic exposure, with Portland cement concrete showing the highest total weight reduction over 90 days. Figure shows the trend of weight loss and it shows that weight loss in considerably higher in room temperature cured concrete.

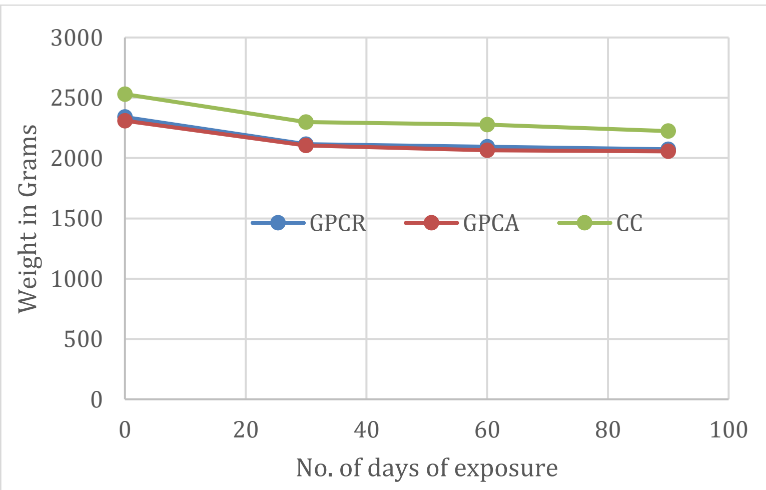


Figure F: Variation of Weight with respect to various intervals of acid exposures

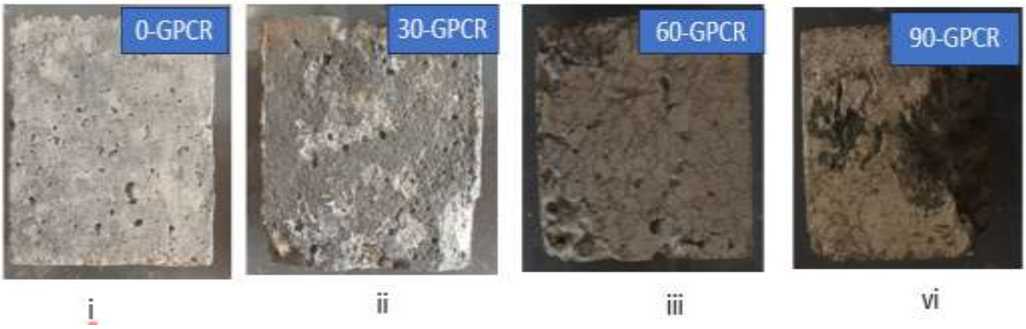


Figure G : GPCR before exposure, ii. GPCR at 30 days of exposure to acid , iii. GPCR 60 days of exposure to acid iv. GPCR at 90 days of exposure to acid


Figure H:  GPCA before exposure, ii. GPCA at 30 days of exposure to acid , iii.GPCA 60 days of exposure to acid iv. GPCA at 90 days of exposure to acid

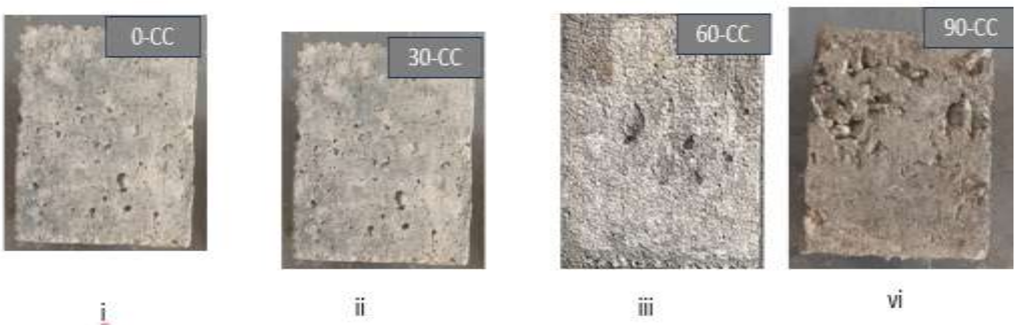


Figure I:  CC before exposure, ii.CC at 30 days of exposure to acid, iii.CC 60 days of exposure to acid iv.CC at 90 days of exposure to acid

Figures G, H, and figure I, show the samples at various stages and it is visible that on 90$^{th}$ day GPCR has lower integrity than GPCA and has just surface erosion but remains intact. Accelerated cured samples have sustained the acid attack by maintaining the integrity of concrete without undergoing any leeching or bulging.

### 3.2 Sulphate Attack

Cubes cured under various conditions were exposed to sulphur attack, and tested periodically at 30 days after curing of 28 days. Results of ultrasonic pulse wave velocity have been presented in Table 6.

Table 6: UPV results of samples under sulphur attack with weight at different intervals**.**

| | | **GPCR** | **GPCA** | **CC** |
|---|---|---|---|---|
| Weight before Exposure | | 2340 | 2310 | 2530 |
| Velocity before exposure | | 3860 | 3960 | 3970 |
| 30 DAYS | Weight | 2106 | 2110 | 2293 |
| | Velocity (m/s) | 3491 | 3666 | 3773 |
| 60 DAYS | Weight | 2003.1 | 2085 | 2282 |
| | Velocity (m/s) | 3195 | 3300 | 3297 |
| 90 DAYS | Weight | 1926 | 2079 | 2252 |
| | Velocity (m/s) | 2990 | 3210 | 3204 |

Over 90 days, a comparative analysis of three concrete samples—GPCR, GPCS, and CC—revealed varying levels of degradation in structural integrity. The GPCR sample exhibited the most significant degradation, with its initial velocity of 3860 m/s dropping by 9.6% to 3491 m/s after 30 days, indicating early signs of deterioration. This downward trend continued, with a velocity of 3195 m/s recorded at 60 days (a 17.2% reduction) and 2990 m/s at 90 days, reflecting a substantial total decrease of 22.6%. In contrast, the GPCS sample began with a slightly higher initial velocity of 3960 m/s. After 30 days, its velocity reduced by 7.4% to 3666 m/s, suggesting less severe degradation than GPCR. The velocity continued to decline, reaching 3300 m/s at 60 days (a 16.7% reduction) and 3210 m/s at 90 days, resulting in a total decrease of 18.9%. This data indicates that while GPCS did experience degradation, it maintained better structural integrity over time than GPCR. The CC sample demonstrated the smallest initial decrease among the three, with its velocity reducing from 3970 m/s to 3773 m/s after 30 days, a 4.9% decrease. However, by 60 days, its velocity had declined to 3297 m/s, representing a 17% reduction from the initial value, showing noticeable degradation. By the end of 90 days, the velocity further decreased to 3204 m/s, a total reduction of 19.3%. Although the CC sample displayed substantial degradation, its overall reduction was slightly less than that of GPCR. In summary, all samples showed varying degrees of degradation over the 90 days. GPCS maintained the highest structural integrity, followed by CC, while GPCR exhibited the most significant degradation, indicating a comparative analysis of their durability and resilience figure indicates the variation concerning different exposure times figure J indicates the variation of velocities with respect to time under different curing conditions.

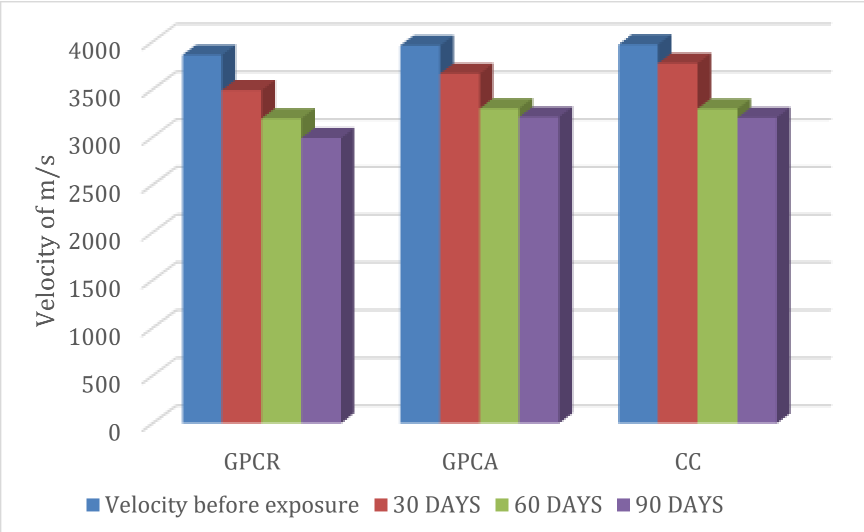


Figure J : Ultrasonic pulse velocity for various samples at various intervals under sulphur exposure

Over 90 days, a comparative analysis of three concrete samples—GPCR, GPCA, and CC—revealed different levels of weight loss and figure indicates the trend of weight loss for all samples, reflecting varying degrees of degradation. The GPCR sample exhibited the most significant weight reduction, starting with an initial weight of 2340 grams. After 30 days, its weight decreased by 234 grams to 2106 grams, indicating substantial early degradation. The weight decreased to 2003.1 grams by 60 days, resulting in a cumulative loss of 336.9 grams. By the end of 90 days, the final weight recorded was 1926 grams, marking a total weight reduction of 414 grams. This significant decline suggests a high level of material loss over the 90-day period. In comparison, the GPCA sample showed a more moderate weight loss. It started with an initial weight of 2310 grams, which dropped by 200 grams to 2110 grams after 30 days. The weight further decreased to 2085 grams at 60 days, representing a cumulative loss of 225 grams. By 90 days, the weight was recorded at 2079 grams, with a total reduction of 231 grams. Although there was a continuous weight decrease, the GPCA sample experienced less overall material loss compared to GPCR, indicating better resistance to degradation. The CC sample, which had the highest initial weight of 2530 grams, also showed a significant reduction but to a lesser extent than 0.45GP10MR. After 30 days, the weight reduced by 237 grams to 2293 grams. The weight further decreased slightly to 2282 grams by 60 days, a cumulative loss of 248 grams. By 90 days, the final weight was 2252 grams, totalling a reduction of 278 grams. While the CC sample exhibited substantial degradation, the overall weight loss was lower than that of GPCR. Overall, while all samples experienced weight loss over time, the GPCR sample had the most significant degradation, followed by the CC sample. The GPCA sample maintained the best integrity, with the least weight loss, demonstrating greater resistance to degradation over the 90 days.

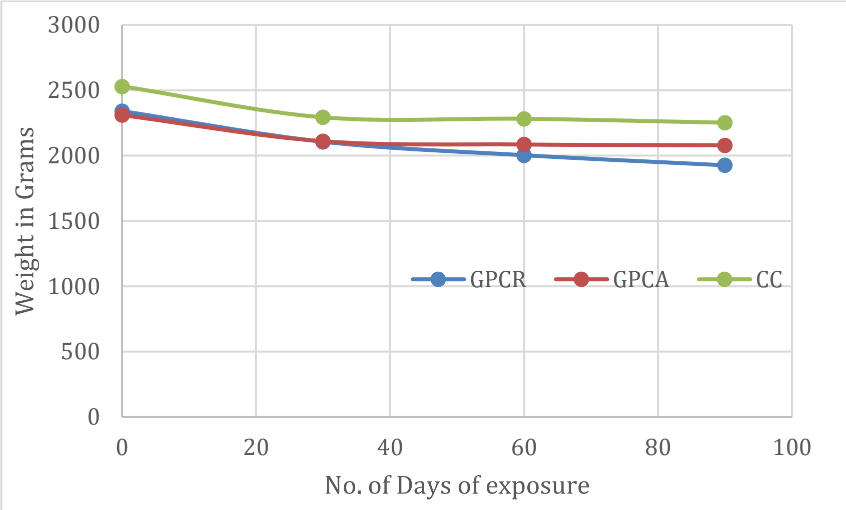


Figure K : Variation of Weight with respect to various intervals of acid exposures

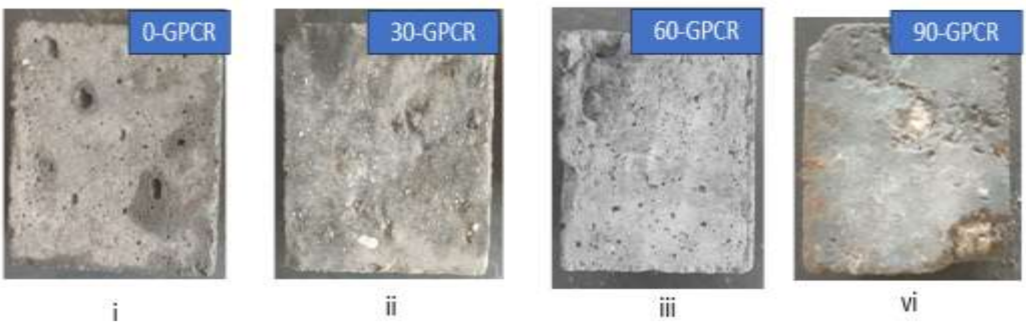


Figure L : GPCR before exposure, ii.GPCR at 30 days of exposure to sulphate, iii.GPCR 60 days of exposure to sulphate iv. GPCR at 90 days of exposure to sulphate

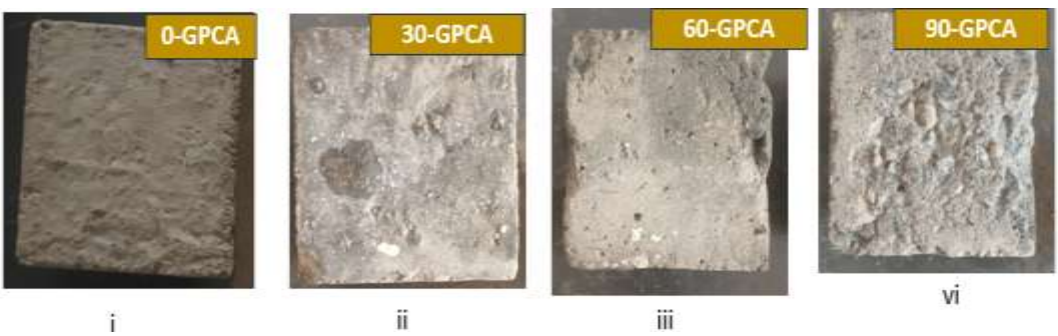


Figure M : i.GPCA before exposure, ii.GPCA at 30 days of exposure to sulphate, iii.GPCA 60 days of exposure to sulphate iv. GPCA at 90 days of exposure to sulphate

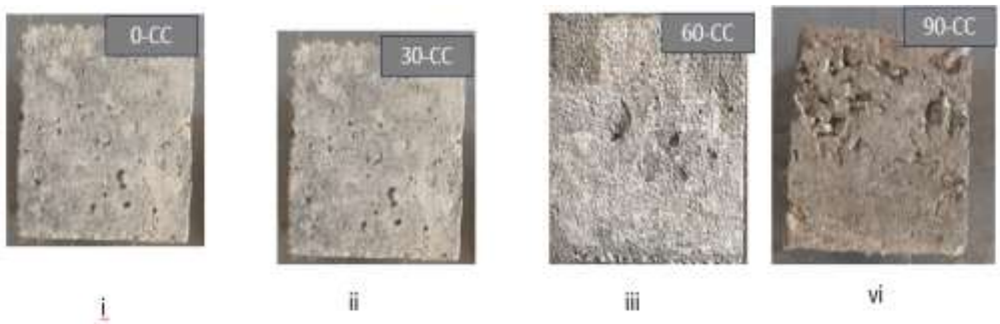


Figure N : i. CC before exposure, ii.CC at 30 days of exposure to sulphate , iii.CC 60 days of exposure to sulphate iv.CC at 90 days of exposure to sulphate

Figure L, M and figure N show samples exposed to sulfur attack at different stages: before exposure, at 30 days, 60 days, and 90 days. Sample GPCR is more affected, displaying exposed aggregates on its surface, while sample GPCA shows signs of surface erosion. This suggests that specimens subjected to initial accelerated curing demonstrate better performance in extreme environments.

## 4. Conclusions

- Conducting tests under extreme environmental conditions is crucial to assess the durability and suitability of concrete for real-world applications. These tests help identify potential weaknesses and ensure that the concrete can withstand harsh conditions, such as chemical exposure, thereby enhancing its reliability and longevity in actual construction projects.
- Concrete cured under accelerated conditions shows superior performance when exposed to acid attacks, exhibiting minimal defects. This improved durability suggests enhanced geopolymerization and stronger binding between particles compared to concrete cured at room temperature. The accelerated curing process promotes a denser microstructure, making the concrete more resilient in harsh chemical environments.
- Accelerated cured concrete experiences less weight loss compared to concrete cured at room temperature when exposed to harsh conditions. This reduced weight loss indicates a better resistance to environmental degradation. The accelerated curing process enhances the material's durability by improving the concrete's density and overall structural integrity, making it more robust against environmental attacks.
- Concrete remains highly usable even when incorporating recycled aggregates, provided it undergoes accelerated curing. This curing method enhances the concrete's strength and durability, compensating for the potential weaknesses of recycled materials. The process ensures that the recycled aggregate concrete can maintain structural integrity and perform effectively in demanding conditions.
- In samples subjected to accelerated curing, only surface erosion was observed, indicating minimal degradation. In contrast, concrete cured at room temperature showed significantly more deterioration. This suggests that accelerated curing

enhances the concrete's resistance to environmental stressors, improving its durability and maintaining structural integrity under challenging conditions.

- Monitoring the same sample at different stages is crucial to understanding the effects of environmental exposure on concrete. Performing non-destructive testing (NDT) is essential and reliable for this purpose, as it allows continuous assessment of material integrity without causing damage, providing valuable insights into long-term performance and durability

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