# Study of Mechanical Properties and Durability Performance of Fly Ash-based Alkali-Activated Process-Modified Geopolymer Concrete

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**Abstract -** *Most recent research has focused on the mechanical strength and durability of geopolymer concrete with heat activation (at different temperatures) and has indicated a limitation for its application in precast industries only. This limitation can be overcome by changing when the ingredients for geopolymer concrete are mixed so that curing can be made at ambient temperature. With this process modification (heat activation of fly ash and alkaline fluid), the modified geopolymer concrete shows a significant enhancement in mechanical strength (compressive, split tensile, flexural, and bond strength) and durability (water absorption, acid attack resistance, and rapid chloride permeability test) compared with conventional geopolymer concrete (heat activation after casting) and the control concrete.*

***Key Words***: geopolymer concrete, heat activation, alkaline solution, fly ash, durability

## 1.INTRODUCTION

There is an increasing demand for construction and construction materials worldwide, and concrete is the most extensively used material in construction. However, a huge amount of carbon dioxide and other greenhouse gases are released into the atmosphere during the production of ordinary Portland cement. On the other hand, the production of coal-based fly ash has speedily increased in the past few decades, which is annually estimated to be around 780 million worldwide. Presently, about 35% of fly ash is utilized in landfills, embankments, and in the production of blended cement, and the remaining is industrial waste. Hence, the development of green concrete using fly ash such as alkali-activated inorganic polymer concrete (geopolymer concrete) has become an important research area.

### 1.1 Materials

The most commonly used fly ash for the geopolymer concrete is low-calcium fly ash (class F). Generally, a high-strength geopolymer concrete can be obtained from using fly ash with heat activation. It is noted that the strength and durability of the geopolymer concrete is highly influenced by the heat activation process of alkali from the past research. In this study, the fly ash from NLC, Tamil Nadu, India has been used.

Sodium hydroxide is a white solid ionic compound consisting of sodium cations $Na^+$ and hydroxide anions $OH^-$. It is highly soluble in water and readily absorbs moisture and carbon dioxide from air. The locally available sodium hydroxide pellets are used.

Concrete treated with a sodium silicate solution helps to reduce porosity in most masonry products such as concrete, stucco, and plasters. This effect aids in reducing water penetration, but has no known effect on reducing water vapor transmission and emission. A chemical reaction occurs with the excess $Ca(OH)_2$ (portlandite) present in the concrete that permanently binds the silicates with the surface, making them far more durable and water repellent. The liquid sodium silicate solution with 45% solid content is used.

The alkali activator fluid is made with sodium hydroxide, sodium silicate and water. The portable water is used.

The natural river sand of 2.36mm sieved size is utilized as fine aggregate and coarse aggregates of maximum 12.5mm size are used for all the trial mixes of the concrete while fly ash based Portland Pozzolana cement is used only for the conventional concrete.

### 1.2 Methodology

The materials used in casting the geopolymer concrete are studied for their properties and tested. The mix design for the conventional concrete and the geopolymer concrete is done. The casting of concretes are made.

For the process-modified geopolymer concrete i.e, trial mix GPC-1, heat activation of the fly ash and the activator fluid is done for 45 minutes at 60°C first, and to this hot mixture, the fine and coarse aggregates are added. After 12 hours of casting, the specimens are demolded and cured at room temperature.

For the conventional heat cured geopolymer concrete i.e, trial mix GPC-2, fly ash, activator fluid, fine and coarse aggregates are mixed together and made into the molds. The specimens are demolded after 48 hours of casting and heat activated inside a hot air oven for 48 hours.

For the conventional concrete i.e, trial mix CC, cement, fine and coarse aggregates are mixed with appropriate water and cured for 28 days. Finally, the mechanical and durability properties are studied and tested.

## 2. MATERIAL TESTING AND MIX PROPORTIONS

The initial setting time of the cement was 30 minutes. The standard consistency of the cement was found to be 30% while performing using Vicat apparatus. The specific gravity of the cement was measured as 3.39. The fineness modulus of fine aggregate was found to be 2.46 while for coarse aggregate, it was 5.13. The specific gravity of fine aggregate was found using a pycnometer which was 2.6, while for the coarse aggregate it was 2.7.

There is no specific code for the mix design of the geopolymer concrete. So, the design is made based on density or unit weight of concrete (2400kg/m$^3$). The alkaline to binder ratio was found to be 0.45. For the conventional concrete, the design mix for M25 is proportioned. The mix proportions are detailed in Table -1.

**Table -1:** Mix proportions for GPC-1,GPC-2 and CC.

| Materials | GPC-1 & GPC-2 (kg/m$^3$) | CC (kg/m$^3$) |
|---|---|---|
| Fly Ash | 414 | 445 |
| Sand | 630 | 753 |
| 12.5mm aggregate | 585 | 532 |
| 20mm aggregate | 585 | 532 |
| Sodium Hydroxide | 53.20 | - |
| Sodium Silicate | 133.01 | - |

## 3. TESTING PROCEDURE AND RESULTS

The mechanical and durability properties of the trial mixes are studied. The testing procedures and the corresponding results are as follows.

### 3.1 Compressive Strength

The test procedure is followed as per IS (519: 1959). The cube specimen of size 150 cubic-mm is used and they are placed in compressive strength testing machine. The load is applied to the specimen until the specimen failure or crack in the cube is found and the compressive strength for all the mix proportion with different mix id where tested for 3, 7 and 28 days. The compressive strength results are tabulated in Table -2 and the corresponding chart is shown in Chart -1.

**Table -2:** Variation in compression strength

| Compressive strength | GPC-1 (N/mm$^2$) | GPC-2 ((N/mm$^2$) | CC (N/mm$^2$) |
|---|---|---|---|
| 3 days | 25 | 19 | 13 |
| 7 days | 32 | 26 | 19 |
| 28 days | 39 | 33 | 27 |

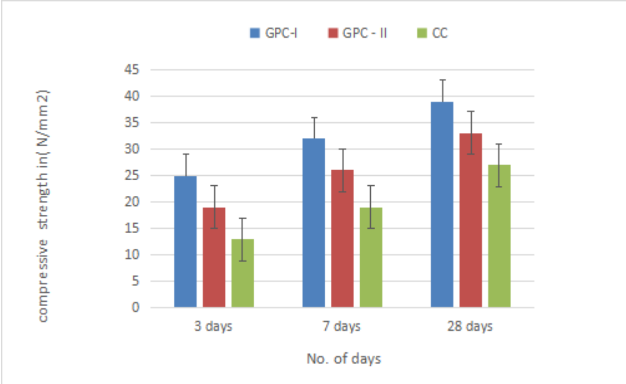


**Chart -1**: Variation in compression strength

### 3.2 Split Tensile Strength

The Split tensile strength test is followed as per IS (5816: 1999). The tensile strength of concrete is that which they show the concrete ability to withstand the tensile force applied to the cylinder. The tensile strength of geopolymer concrete for all mix proportion is done for 7 and 28 days and their results are tabulated in Table -3 and the corresponding chart is shown in Chart -2.

**Table -3:** Variation in tensile strength

| Tensile strength | GPC-1 (N/mm$^2$) | GPC-2 ((N/mm$^2$) | CC (N/mm$^2$) |
|---|---|---|---|
| 3 days | 1.9 | 1.6 | 1.25 |
| 7 days | 2.7 | 2.4 | 1.9 |
| 28 days | 3.2 | 2.7 | 2.5 |

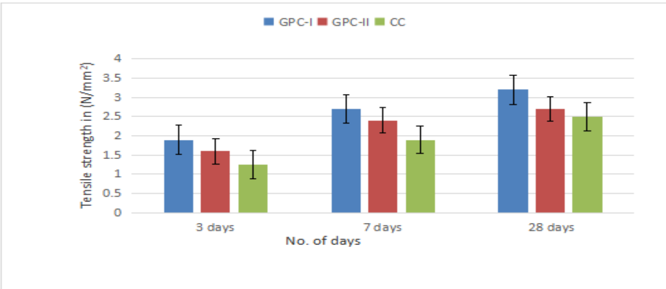


**Chart -2**: Variation in tensile strength

### 3.3 Flexural Strength

The beam specimens were 150mm wide and 150mm deep in cross-section with 700mm length. Four beams were casted and three-point bend method beam test is done to determine the flexural strength properties of geopolymer concrete mixes.

HYSD steel bars of 10mm diameter were used as longitudinal reinforcement. Two legged stirrups of 8mm diameter at 90mm centre to centre spacing were used as shear reinforcement.

The results are tabulated in Table -4.

**Table -4:** Results of flexural strength test

| Mix | First crack load (KN) | Ultimate load (KN) | Max. displacement (mm) | Max. stress (N/mm²) | Max. Strain (%) |
|---|---|---|---|---|---|
| GPC-1 | 20.0 | 70.63 | 7.89 | 17.26 | 2.348 |
| GPC-2 | 18.0 | 68.49 | 8.51 | 16.74 | 2.532 |
| CC | 18.5 | 69 | 8.21 | 17.40 | 2.445 |

The force displacement curves for GPC-1, GPC-2 & CC are shown in Fig -1, Fig -2 & Fig -3 respectively.

### 3.4 Salt Water Resistance

Salt water resistance is most important for the concrete because the salt water consist of chloride and the chloride when enters in to the concrete they corrode the reinforcement and degrade the strength of concrete. In this salt water resistance test the concrete specimen of size, 150 cubic.mm is placed in the 5% sodium chloride solution and the pH is maintained constant throughout the period. The concrete specimen is checked for their compressive strength and weight for 28 days. Thus, the initial compressive strength is compared and their percentage of change is calculated for all mix proportion as given in Table-5. The compressive strength is shown in Chart -3.

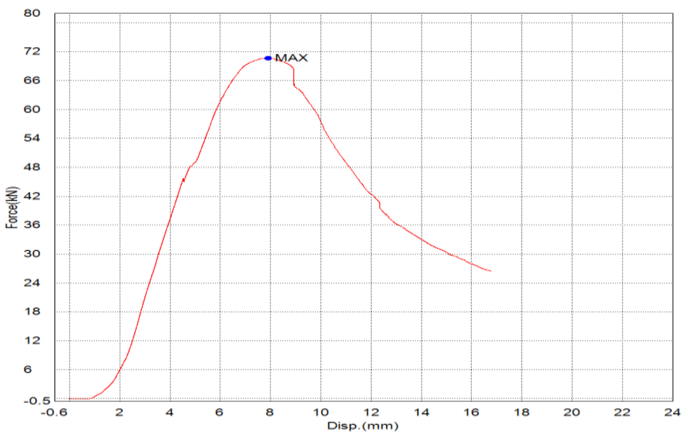


**Fig -1:** Force – Displacement curve for GPC-1

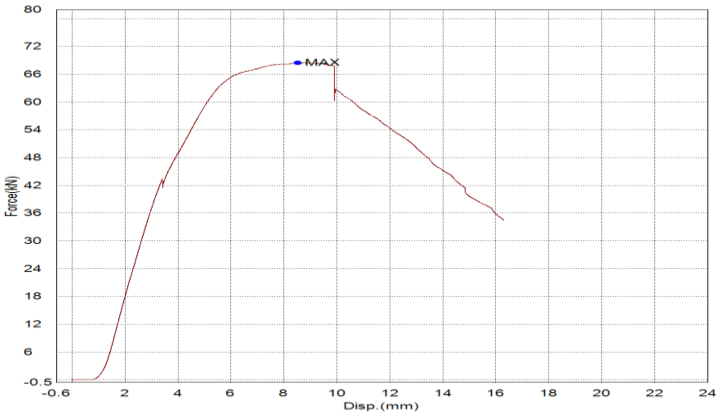


**Fig -2:** Force – Displacement curve for GPC-2

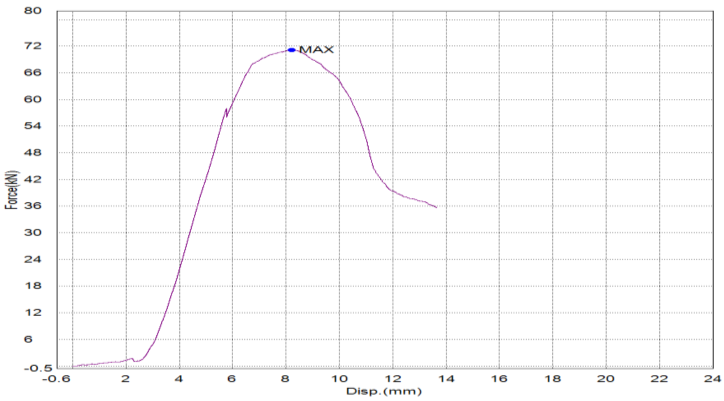


**Fig -3:** Force – Displacement curve for CC

**Table -5:** Variation of Compressive strength in salt water

| | GPC-1 (N/mm²) | GPC-2 (N/mm²) | CC (N/mm²) |
|---|---|---|---|
| Initial Strength | 39 | 33 | 31 |
| 28 days | 37 | 30 | 25 |

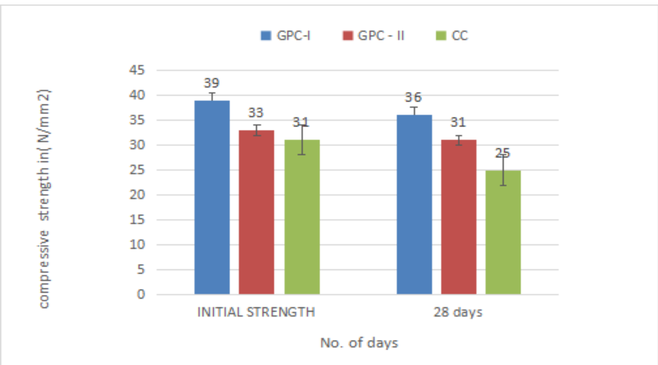


**Chart -3**: Variation in compression strength in salt water

### 3.5 Acid Attack

The test procedure is followed as per ASTM C-267. In this the specimen are placed in 5% sulfuric acid solution and the pH is maintained constant throughout the durability study. The concrete specimen is tested for 28 days for their compressive strength and the initial compressive strength is compared with the acid attacked specimen to calculate the percentage of change in compressive strength and the loss of weight in specimen is also calculated for all mix proportion and given in Table -6. The variation of Compressive strength in acid attack is shown in Chart -4.

**Table -6** Variation of Compressive strength in acid attack

| | **GPC-1 (N/mm²)** | **GPC-2 (N/mm²)** | **CC (N/mm²)** |
|---|---|---|---|
| Initial strength | 39 | 33 | 31 |
| 28 days | 32 | 27 | 25 |

### 3.6 Sulphate Attack

This sulphate attack test is carried out as per the standards of ASTM C 1012-10. In this the casted cubes are kept inside the 5% of sodium sulphate solution and their pH value is maintained constant throughout the process. They are tested for compressive strength after the sulphate attack for 28, 56 and 90 days.

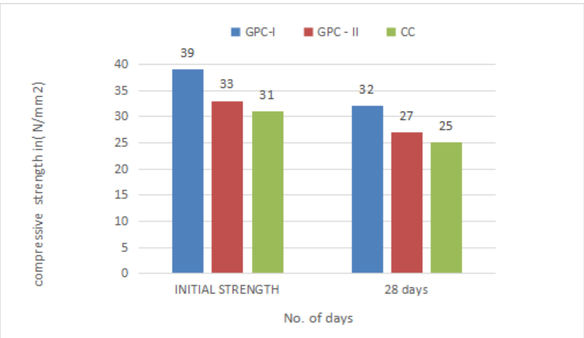


**Chart -4**: Variation in compression strength in acid attack

The variation of Compressive strength in sulphate attack is shown in Table -7 & Chart -5.

**Table -7:** Variation of Compressive strength in sulphate attack

| | **GPC-1 (N/mm²)** | **GPC-2 (N/mm²)** | **CC (N/mm²)** |
|---|---|---|---|
| Initial Strength | 39 | 33 | 31 |
| 28 days | 37 | 32 | 28 |

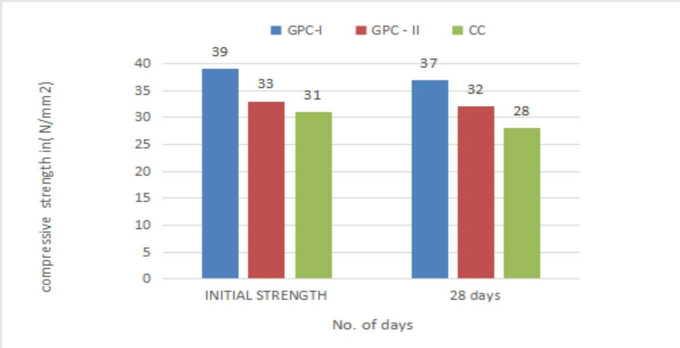


**Chart -5**: Variation in compression strength in sulphate attack

### 3.7 Rapid Chloride Attack

This test is followed as per ASTM C 1202. In this the concrete specimen of 50mm thick and 100mm diameter is cut and they are vacuum saturated. Then the 60V potential is passed through the setup which consists of the specimen disc coated with epoxy resin and they are placed inside the cell with one side is connected to the 3% Sodium chloride solution and the other side is connected to 0.3 N of sodium hydroxide. The coulombs charges passed through the specimen is calculated by measuring the current and temperature for every 15 minutes for about 6 hours and the readings is substituted in the formula. The formula used is

$I = 900 * [ I_0 + 2* (\text{Sum of current passed for every 15minutes})]$

Where, $I_0$ = Initial reading in mA.

I = Total charges passed

The chloride permeability of concrete specimen based on the coulomb passed is listed in Table -8 and the results are tabulated in Table -9.

**Table -8:** Quality of concrete based on charges passed

| Charges passed (Coulomb) | Chloride permeability |
|---|---|
| >4000 | High |
| 2000 – 4000 | Moderate |
| 1000 - 2000 | Low |
| 100 – 1000 | Very low |
| <100 | Negligible |

**Table -9:** Rapid Chloride penetration test result

| Total charges passed (coulombs) | | | |
|---|---|---|---|
| No of days | GPC-1 | GPC-2 | CC |
| 28 | 950 | 1200 | 1485 |

### 3.8 Sorptivity

This test procedure is carried out as per ASTM C158-13. The concrete consists of fewer voids so that the pores will be less and the water absorption is less and the strength of the concrete will be good and the concrete will be more durable. In this test the concrete specimen is kept in the 5% of calcium hydroxide solution. The specimen is placed in the solution which they are coated with epoxy resin in all side except the bottom which is placed above the stick in that they are not fully immersed in the solution. The equation used for calculating the sorptivity value is

**M (t) =c* t^1/2**

Where,

M = mass of change in grams

C = Sorptivity value

t = time in minutes

The sorptivity test results are tabulated in Table -10.

**Table -10:** Sorptivity test result

| Sorptivity S (*10^-4) mm/min $^{(1/2)}$ | | | |
|---|---|---|---|
| No of days | GPC-1 | GPC-2 | CC |
| 28 | 4.32 | 5.07 | 4.96 |

## 4. CONCLUSIONS

Based on the results obtained from the experiments the subsequent conclusions can be derived regarding the performance of the concrete

- The low-calcium fly ash–based process-modified geopolymer concrete (GPC-1) cured at ambient room temperature after casting shows improved mechanical strength and durability than conventional heat–cured geopolymer concrete (GPC-2) and OPC concrete.
- The uniform and smooth polymerization reaction of fly ash have been accelerated by the early age heat activation in the GPC I mix, thereby increasing the Si/Al ratio and enhancing the alteration of the amorphous phase of fly ash to crystalline phases in the geopolymer matrices.
- The energy saving is also an important criterion for use of the process-modified geopolymer concrete (GPC I) mix in practical applications.

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