



## Durability Study of Low Calcium Flyash Based Geopolymer Concrete

### KEYWORDS

Geopolymer, Durability, Strength

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**ABSTRACT** Geopolymer concrete technology has the potential to reduce globally the carbon emission and lead to a sustainable development and growth of the concrete industry. The influence of alkaline activators on the strength and durability properties has been studied. Fly ash used in this study was procured from a local thermal power station. Specimens were manufactured from low calcium fly ash by activation with a mixture of Sodium Hydroxide and Sodium Silicate solution. The concrete was prepared with a fly ash ratio of 0.4. Geopolymer specimens were casted using two different mix proportions with 10Molar and 12 Molar of sodium hydroxide solution. The specimens were tested Compression test, Split tensile test, Flexure test. The results indicate that the combination of the above constituents at 60 C has a positive impact on the strength and durability properties of geopolymer concrete. Since it utilizes the industrial wastes such as fly ash for producing the binding system in concrete, it can be considered as eco-friendly materials.

### 1 INTRODUCTION

Concrete is one of the most widely used construction materials; it is usually associated with Portland cement as the main component for making concrete. On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern during the last decade. The global warming is caused by the emission of greenhouse gases, such as CO<sub>2</sub>, to the atmosphere by human activities. Among the greenhouse gases, CO<sub>2</sub> contributes about 65% of global warming. The cement industry is responsible for about 6% of all CO<sub>2</sub> emissions, because the production of one ton of Portland cement emits approximately one ton of CO<sub>2</sub> into the atmosphere.

Although the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made to reduce the use of Portland cement in concrete. One of the ways to produce environmentally friendly concrete is to reduce the use of Ordinary Portland Cement by replacing cement with by-product materials such as fly ash.

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as 'the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system'

In this respect, Davidovits [1] coined the term Geopolymer in 1978 to describe the alkali-activated material from geological origin or by-product materials such as fly ash and rice husk ash. This geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the geopolymer technology could reduce the CO<sub>2</sub> emission to the atmosphere caused by cement and aggregates industries by about 80%.

### 2. PAST RESEARCH ON GEOPOLYMER MATERIAL

In geopolymers, the polymerisation process involves a chemical reaction under highly alkaline conditions on Al-Si minerals, yielding polymeric Si-O-Al-O bonds, as described by Davidovits [2]. The chemical composition of geopolymers is similar to zeolites, but shows an amorphous microstructure [7]. The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly ash, slag etc., yield higher compressive strength when compared to

those synthesised from non-calcined materials, such as kaolin clay. The source material used for geopolymerisation can be a single material or a combination of several types of materials [8]. A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator [3][4][5][7] with the activator liquid-to-source material ratio by mass in the range of 0.25-0.30 [3][4].

Walloh and Rangan [6] reported that geopolymer concrete specimens exhibit extremely small changes in length and also shows very little increase in mass after one year of exposure in sulphate solution. In another study by Bakharev [1] the author used various concentrations of sulphate solution to immerse the geopolymer materials prepared using different types of activating solutions. The geopolymer material can be used in various applications, such as fire and heat resistant fiber composites, sealants, concretes, ceramics, etc., depending on the chemical composition of the source materials and the activators. Davidovits [2] suggested that the atomic ratio of Si-to-Al of about 2 for making cement and concrete. Geopolymer can also be used as waste encapsulation to immobilise toxic metals [5].

### 3. MATERIALS

#### 3.1 LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE

In this work, low-calcium (ASTM Class F) fly ash-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures.

As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in geopolymer concrete. The silicon and the aluminium in the low-calcium (ASTM Class F) fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials. In this research low calcium Class F (American Society for Testing and Materials) dry fly ash obtained from the silos of Ennore Power Station, Tamil Nadu, was used as the base material. The chemical composition of the ASTM class F Fly ash is given below in Table 1.

Oxides	Silica	Alumina	Lime	Iron	Sulphur	Magnesia	Alkalines	LOI	Specific Gravity
% by Mass	52.8	22.3	Trace	9.2	0.7	0.5	0.2	3.7	2.30

**Table 1 Chemical Compositions of Fly Ash**

LOI - Loss on Ignition

### 3.2 ALKALINE LIQUID

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions. The sodium hydroxide solids were either a technical grade flakes form (3 mm) or a commercial grade in pellets form with 97% purity. The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in water.

### 3.3 AGGREGATE

Aggregates from local sources were obtained. The coarse aggregate is a mixture of aggregates ranging from 6mm to 12mm sized aggregates. Fine aggregate is also obtained from local sources and used as such. Both the aggregates are kept in Saturated – Surface Dry condition (SSD) prior to use in the concrete.

## 4. Manufacture of geopolymer concrete

### 4.1 Mix proportioning

A trial mix ratio of 1:1.6:2.6 with ratio of activator solution to fly ash as 0.45 was chosen. The sodium silicate to sodium hydroxide ratio was fixed as 2.5 and the concentration of NaOH was taken as 10M and 12M. There are two different mixes used in this study. In mixture 1 (M1) the concentration of Sodium Hydroxide solution was 10 Molars and in mixture 2 (M2) the concentration of Sodium Hydroxide solution was 12 Molars and these mixtures contain no extra added water. These two mixture proportions were selected to yield two different concrete compressive strengths. The details of mix proportions are shown in table 2.

**Table 2 Details of Mix proportions**

Mix	Ratio	Molarity of NaOH
M1	1:1.1:2.6	10M
M2	1:1.1:2.6	12M

### 4.2 Mixing, Casting, Compaction and Curing of Geopolymer Concrete

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The activator solutions were prepared one day before use. After the dry mix is made, the prepared alkaline solution is mixed thoroughly with the dry mix for another 5 minutes to make the fresh Geopolymer Concrete. In preparation of NaOH solution, NaOH pellets were dissolved in one liter of water in a volumetric flask for concentration of NaOH (12M) and (10M). Alkaline activator with the combination of NaOH and Na<sub>2</sub>SiO<sub>3</sub> was prepared just before the mixing with fly ash. The alkaline liquid (Na<sub>2</sub>SiO<sub>3</sub> / NaOH) used in the current study was 2.5 for all the mixes. The fly ash and alkaline activator were mixed together in the mixer until homogeneous paste was obtained. This mixing process can be handled within 5 minutes for each mixture with different molarity of NaOH. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept accordingly to the various curing conditions namely ambient room temperature and hot air oven curing both maintained at 60°C for 24 hours. The workability of the concrete was assessed using slump test and the slump value was in between the range 90 mm to 120 mm.

### 4.3 Test Specimens

**Table 3 Total number of specimens**

S.No	Particulars	Total specimens
1	Cubes 150X150X150mm	20
2	Cylinders 100x120mm	20
3	Beams 100x100x500mm	5
TOTAL		45

### 4.4 TESTS CONDUCTED:

- Compression test.
- Split tensile test.
- Flexure test

#### A. Compressive strength

The compressive strength of hardened fly ash-based geopolymer concrete was performed on a 1000KN capacity compression testing machine as per IS 516. The cube specimens of size 150mm x 150mm x150mm were tested for cube compression testing at 7 days and 28 days. Geopolymer cubes of 12M and 10M were cast. The specimens were wrapped by plastic sheet to prevent loss of moisture and placed in an oven. They were then left at open air (room temperature 25°C) in the laboratory until testing.

#### B. Split Tensile Test

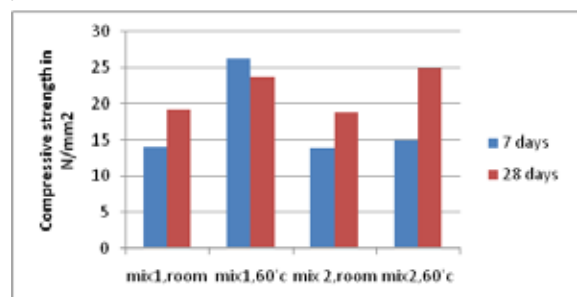
Split tensile test was carried out as per ASTM C496-90. Concrete cylinders of size 100 mm diameter and 150 mm height were cast. The test is performed on a 1000KN capacity compression testing machine. The Geopolymer specimens were wrapped by plastic sheet to prevent the loss of moisture and placed for curing at 60°C. The average split tensile strength values were recorded.

#### C. Flexure Test

Beams are subjected to four point bending test. It is conducted in laboratory using universal testing machine. Specimens of size 100x100x500mm were casted. During moulding, the beams were mechanically vibrated. After 24 hours the specimen were removed from the mould and subjected to water curing for 7 and 28 days. The average flexural strength value was recorded.

## 5. OBSERVATIONS AND TEST RESULTS

The graphs of all the tests performed are given below. From the graph, it can be seen that the geopolymer concrete cured at 60°C gives the best results. The compressive strength of the GPC specimens is synthesized at two different regimes of curing. The condensation polymerization that takes place is endothermic in nature therefore supply of heat need to be consistently present. Ambient and heat curing compressive strength results are compared by plotting graphs as shown in Figure 1. From the graphs it is clear that hot air oven resulted in maximum strength. The 7 and 28 days average compressive strength of hot air oven specimens were higher than that of ambient cured specimens respectively, which indicates that heat curing is necessary for achieving strength for geopolymer concrete.



**Fig 1 Compressive strength value**

The split tensile strength of geopolymer concrete is only a fraction of compressive strength, as in case of Ordinary Portland cement concrete. The variation of results is presented in Fig.2. From the graphs it is clear that hot air oven resulted in maximum strength. The 7 and 28 days average split tensile strength of hot air oven specimens was higher than that of ambient cured specimens respectively.

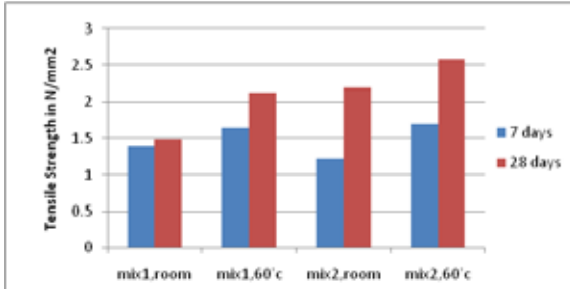


Fig 2 Split tensile strength value

The flexural strength of different mixes at 7 days and 28 days are shown in figure3. From the graph it is clear that the flexural strength is high for 28 day strength.

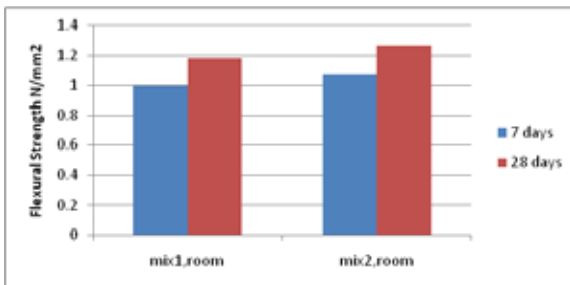


Fig 3 Flexural Strength Value

## 6. CONCLUSION

Low calcium fly ash based geopolymer concrete has excellent compressive strength and is suitable for structural application. The average compressive strength of heat cured specimens was higher than that of ambient air curing respectively. The average split tensile strength of heat cured specimens was also higher than that of ambient air curing respectively. Geopolymer concrete is more environmental friendly and has the potential to replace ordinary Portland cement concrete. The better performance of geopolymeric materials than that of Portland cement attributed to the lower calcium content of the source material as a main possible factor since geopolymer concrete does not rely on lime like Portland cement concrete. It can thus be concluded that geopolymer concrete possesses excellent durability as a construction material. Geopolymer concrete is eco friendly as the usage of ordinary Portland cement is completely avoided and therefore emission of CO<sub>2</sub> can be controlled there by reducing pollution. Based on the results of this research, a mixture design process for low calcium fly ash-based geopolymer concrete is proposed.

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