# FLEXURAL BEHAVIOUR OF LOW CALCIUM FLYASH BASED GEOPOLYMER CONCRETE BEAMS

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**Abstract**

*The ecosystem is polluted by the emission of green house gas $CO_2$ due to the production of ordinary Portland cement (OPC). An alternate material is substituted with low calcium i.e. Fly ash. Fly ash which is a by-product of coal industry is introduced to replace OPC in the concrete. Fly ash is rich in silicate gel with alkaline solution, to produce a good concrete. Increase in fly ash fitness increases the compressive strength and reduces the porosity. This study is presented on the flexural behaviour of geopolymer concrete (GPC) beams and control cement concrete beams. The beams are cast over an effective span of 3000mm and tested up to failure under static loads. The load displacement response of the geopolymer concrete beams and control beams are obtained to compare with the theoretical results. The result implies that there is an increase in flexural strength, service load, and peak load of geopolymer concrete beams.*

**Keywords:** flexural behaviour, reinforced concrete, geopolymer concrete, beams, cubes.

## 1. Introduction

The global use of concrete is second only to water. As the demand for concrete result in increase of construction materials, so also the demand for Portland cement. It is estimated that the production of cement will increase from about 1.5 billion tons in 1995 to 2.2 billion tons in 2010 [1]. On the other hand, the climate change due to global warming has become a major concern. Many efforts are being made in order to reduce Portland cement in concrete by means of finding alternative cementing materials such as fly ash, silica fume, ground granulated blast furnace slag, rise husk ash and metakaolin. Davidovits proposed an alkaline liquid that could be used to react with the silicon (Si) and aluminium (Al) to produce binders [2]. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that results in a three-dimensional polymeric chain and ring structure consisting of **Si-O-Al-O** bonds [3]. The geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement [4].

## 2. Geopolymer concrete

The low - calcium fly ash-based geopolymer concrete (ASTM Class F) is preferred as a source material. The main constituents of geopolymers are the source materials and the

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alkaline liquids, alumino-silicate should be rich in silicon and aluminium. Alternatively the by product materials such as fly ash, silica fume, slag, rice husk ash, red mud, etc. The presence of calcium in high amounts may interfere with the polymerization process and alter the microstructure. Low-calcium fly ash has been successfully used to manufacture geopolymer concrete when the silicon and aluminium oxides constituted about 80% by mass, with the Si-to-Al ratio of about 2. The alkaline liquids are formed soluble alkali metals like sodium based. The combination of sodium hydroxide with sodium silicate is used as the ratio of 2.5.

## 3. Preparation of geopolymer concrete

### 3.1 Materials

**3.1.1** Fly ash

Low-calcium (ASTM Class F) fly ash obtained from the Mettur Thermal Power Station, (Tamilnadu) is used for this experimental study [1].

**3.1.2** Aggregates

Coarse and fine aggregates are used by the concrete industry are suitable to manufacture geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of geopolymer concrete [5-8]. The properties of aggregate are specific gravity of fine and coarse aggregate - 2.66 and 2.73 (20mm), 2.70 (10mm). The fineness modulus of fine and coarse aggregate - 2.73 and 7.12 (20mm), 6.71(10mm).

**3.1.3** Alkaline liquid

It is recommended that the alkaline liquid is prepared by mixing sodium silicate and sodium hydroxide solutions together. The alkaline liquid is allowed thorough mixing and reaction for at least 24hours before it is used. The sodium silicate solution is commercially available in different grades. The sodium silicate solution ($Na_2SiO_3$) with Sodium Hydroxide (NaOH) ratio by mass of 2.5 is used. The sodium hydroxide with 97-98% purity in pellet form is commercially available. The solids dissolved in water to make a solution with the required concentration. The 12 Molar (12 M) solution is used. Since the molecular weight of Sodium Hydroxide is 40, and in order to prepare 12 molar solution 480 gms of Sodium Hydroxide was dissolved in 1000ml of water.

**Table 1** Constituents of Geopolymer Concrete

| DESCRIPTION | QUANTITY |
|---|---|
| Flyash | 410 kg / $m^3$ |
| $Na_2SiO_3$ / NaOH | 2.5 |
| ($Na_2SiO_3$+NaOH)/ Flyash | 0.45 |
| NaOH Solid | 25.30 kg / $m^3$ |
| Water ( dilute of NaOH) | 27.40 kg / $m^3$ |
| $Na_2SiO_3$ Solution | 131.50 kg / $m^3$ |
| Fine aggregate | 676 kg / $m^3$ |
| Coarse aggregate<br><20mm<br>>10mm | (1230 kg / $m^3$)<br>863kg/$m^3$<br>367kg/$m^3$ |
| 24 Hours Curing (Hot air) | 60° C |

The mass of NaOH solids in a solution varies depending on the concentration of the solution. The materials required for making geopolymer concrete is shown in Figure1. The strength of concrete is M 30 grade as per I.S: 10262 – 2009 mix design code calculate the ratio 1:1.65:3.0 is used. The following ratio is tried in this study. The same ratio of mix is tried in the geopolymer concrete also. The constituents of geopolymer concrete of 12 Molarity Sodium Hydroxide for M 30 grade concrete (1:1.65: 3.0) is shown in Table 1.

### 3.2 Mixing, Casting and Curing

The geopolymer concrete is manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. The fly ash and fine aggregate are mixed dry together in 50-litre capacity Pan mixer for three minutes. The saturated surface dry (SSD) coarse aggregate is added and mixed with the fly ash and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch. The chemical solution is added and the entire batch is mixed for four minutes. The fresh concrete is cast and compacted by the usual methods used in the case of Portland cement concrete. The workability of fresh concrete is measured by means of the conventional slump test. The slump measured is 120 mm Figure 2. The prepared concrete is kept in moulds of specimen size 100 x 100 x100mm cubes.

After casting the specimens, they are kept in rest period in room temperature for 1 days. The term ‘Rest Period’ is coined to indicate the time taken from the completion of casting of test specimen to the start of curing at an elevated temperature. The geopolymer concrete was de-moulded and then placed in an autoclave for hot air curing for 24 hours at a temperature of 60$^{o}$C. The compressive strength of geopolymer concrete cubes increases with the increase in age. The density of geopolymer concrete is around 2350 kg/m$^3$, which is less to that of conventional concrete. A boiler is used to generate the steam at a specified temperature of 60$^{o}$C Figure 3. The curing at 60$^{o}$C is done in the hot air curing chamber for 24 hours Figure 4

**Figure 1**: Materials for Geopolymer Concrete

**Figure2**: Slump Test

**Figure 3**: Curing Chamber

**Figure 4:** Casting of Beams

## 4. Experimental investigation

The test program consists of casting and testing of four beams of size of 125 X 250 X 3200 mm length, out of which two are control cement concrete beams and there are geopolymer concrete beams and the beams designed as under reinforced section. It is reinforced with 3-12 # at bottom, 2–10 # at top using 6mm diameter stirrups @ 150 mm c/c. The control cement concrete beams cast using M 30 grade (1: 1.65: 3.0) with water cement ratio of 0.40, Used in to improve the workability of the fresh concrete, a naphthalene sulphonate super plasticiser, and Fe415 grade steel. Ordinary Portland cement, natural river sand and the crushed granite of maximum size 20mm and 10mm in the ratio 70:30 are mix used for control concrete [9]. High yield strength deformed (HYSD) bars of 12 and 10 mm diameter with mean strength of 523 $N/mm^2$ is used. The elastic modulus of the concrete is found as 2.30 $x10^4$ $N/mm^2$ and the Poison ratio found as 0.14. The control beams and geopolymer concrete beams are designated as RCC-I, RCC-II and GPC-I, GPC-II respectively. The companion cubes (100x100x100 mm size) and cylinders (100mm diameter x 200mm height) are also cast along with the beams and tested.

## 5. Test setup

The test setup for the flexural test is shown in Figure 5. The test specimen is mounted in a beam testing frame of 500kN capacity. The beams are simply supported over a span of 3000mm, and subjected to two concentrated loads placed symmetrically on the span. The distance between the loads is 1000mm.The load is applied on two points each 500mm away from centre of the beam towards the support. Dial gauges of 0.001 mm least count are used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings are recorded at different loads. The strain in concrete is measured using a demec gauge. An automatic data acquisition unit is used to collect the data during the test. Linear Variable Data Transformers (LVDTs) are placed at mid span and under the load points of the beam. The load is applied at intervals of 2.5 kN. The first crack loads are obtained by visual examination. The crack patterns of the control beam (RCC-I) is shown in Figure 6.

**Figure 5**: Test Setup

**Figure 6**: Crack Pattern Control Beam

**Table 2** Summary of Test Results

| Sl. No | Beam Code | Ist Crack Load (kN) | Service Load (kN) | Yield Load (kN) | Ultimate load(kN) | | Max. Deflection(mm) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Experimental | Numarical (ANSYS) | Experimenal | Numarical (ANSYS) |
| 1 | RCC – I | 15.00 | 34.00 | 47.00 | 50.00 | 48.00 | 73.00 | 70.00 |
| 2 | RCC – II | 12.50 | 32.66 | 46.00 | 49.00 | 48.00 | 70.00 | 70.00 |
| 3 | GPC – I | 17.50 | 33.34 | 45.50 | 51.50 | 50.00 | 75.00 | 72.00 |
| 4 | GPC – II | 20.00 | 36.00 | 48.00 | 54.00 | 50.00 | 76.00 | 72.00 |

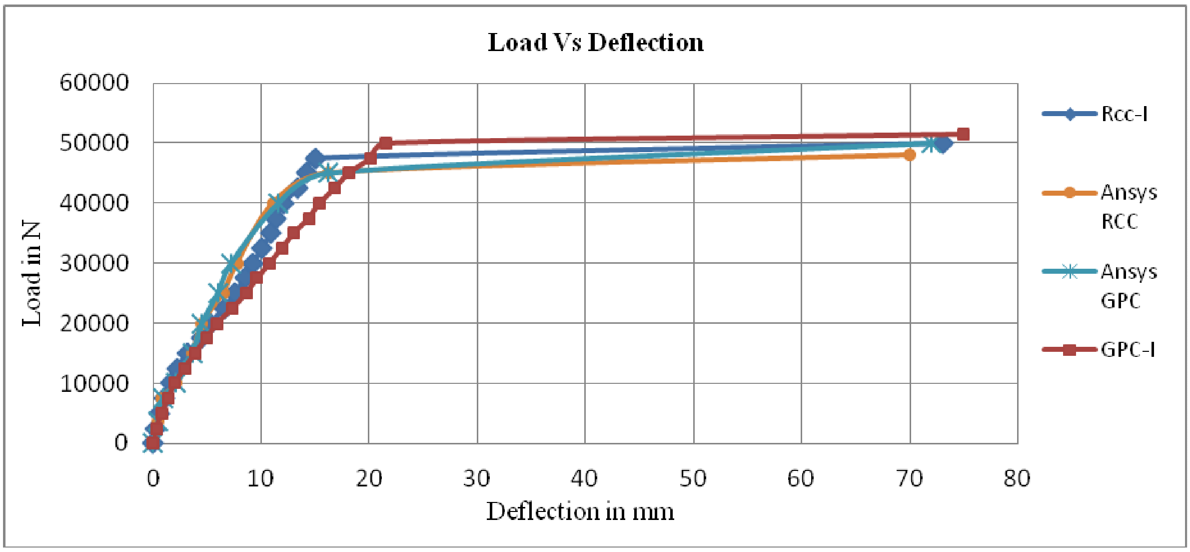


**Figure 7:** Load – Deflection Relationships for Control and Geopolymer Beam


**Figure 8:** Crack Pattern of RCC and GPC Beams

## 6. Numerical analysis

Use of FEA software ANSYS is adopted for predicting the load displacement response of the control Beams and Geopolymer Concrete beams numerically. The mesh model defined 675 nodes and 37 elements. The programme offers solid65 for beam element (Figure 9 ), link8 for steel element (Figure 10 ). The generated model for beams are RCC I, RCC II and GPC I, GPC II. A typical deflected shape at ultimate stage of GPC I is shown in (Figure 11). The experimental and numerical (ANSYS) load deflection curves are compared for both control beam RCC I, RCC II and GPC I, GPC II are shown in (Figure 7). It can be seen that the predicted deflections are in close agreement with the experimental results. Comparisons of ultimate loads for experimental and numerical (ANSYS) results are shown in Table 2

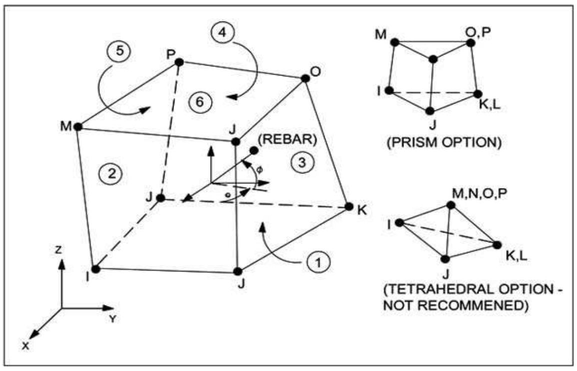


**Figure 9:** Solid65 Geometry

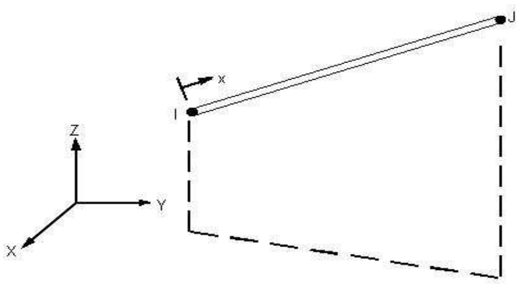


**Figure 10:** Link 8 Geometry

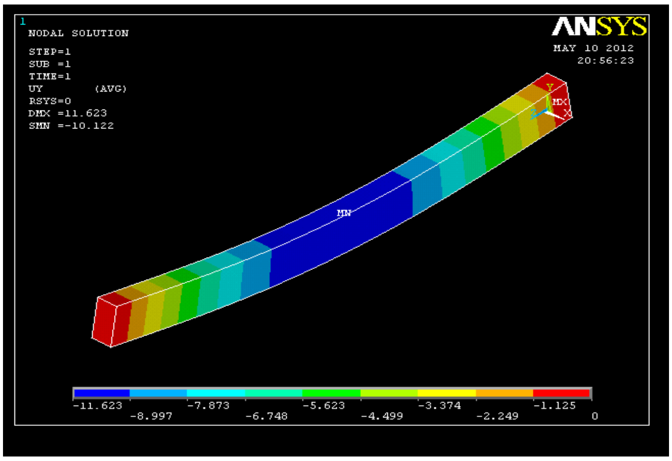


**Figure11:** A Typical Deflected Shape

## 7. Results and disscussions

The average compressive strength of cement concrete cubes and geopolymer cubes are obtained as 34.5 N/mm$^2$ and 38.5 N/mm$^2$ respectively. The test results on strength and deformation properties of control beams and geopolymer beams are reported in Table 2. The load-deflection relationships are obtained using deflection measurements from LVDTs and strain data collected from demec gauges for control beams and geopolymer concrete beams under static monotonic loading and are presented in Figure 10. From the load deflection it is clear that the geopolymer beams exhibit similar behaviour with respect to control beams. The crack pattern of all the beams are shown in Figure 8.

## 8. Conclusions

The experimental investigations carried out to study the flexural behaviour of the reinforced geopolymer concrete beams and conventional Portland cement concrete beams and concluded the following:

a. The compressive strength of cement concrete and geopolymer concrete cubes are obtained as 34.5 N/mm$^2$and 38.5 N/mm$^2$. The slump of geopolymer concrete is obtained as 120mm even without any addition of water.
b. The load deflection characteristics obtained for the RCC beams and GPC beams are almost similar curvature. The first cracking and service loads (20kN) of GPC beams shows slightly higher when compared to RCC beams (15kN).
c. The ultimate load capacity of GPC beams is 13.87% higher when compared to RCC beams.
d. The crack patterns and failure modes observed for GPC beams are found to be similar to the RCC beams. The beams failed initially by yielding of the tensile steel followed by the crushing of concrete in the compression face.

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