# Study on the Mechanical Properties of Flyash-GGBS Based Geopolymer Concrete

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***Abstract:*** The aim of the study is to develop a mix of geopolymer concrete with different binder ratios, and to find an optimum mix by comparing the compressive strength, and then the optimum mix is compared with conventional concrete. Geopolymer concrete are representing the most promising and eco-friendly alternative to Ordinary Portland Cement (OPC). It is the result of the reaction of materials containing alumino silicates with concentrated alkaline solution to produce inorganic polymer binder. The geopolymer concrete used in this study consists of fly ash, ground granulated blast furnace slag, alkaline liquid, fine aggregate and coarse aggregate. For alkaline liquid combination ratio of sodium silicate to sodium hydroxide was fixed as 2.5. Geopolymer concrete shows brittle failure during compressive strength test, hence steel fibers are added to improve ductility. Flexural strength test and split tensile strength test are conducted in order to study the ductile behaviour of fiber added geopolymer concrete.

***Index Terms*: Geopolymer concrete, GGBS, Fly ash, Alkaline liquid.**

## I. INTRODUCTION

Geopolymer is an inorganic polymer. Geopolymer Concrete (GPC) is gaining importance world over as the carbon emission and consequent global warming has become the major concern of the entire countries world over. One tone of cement production results in the emission of one tone of carbon dioxide. Many countries are promoting the use of fly ash as building material by granting carbon credit, which will not only reduces the production of cement and emission of carbon dioxide but also promotes the consumption of the waste materials such as fly ash and GGBS which poses a major problem for disposal world over. In India almost all the states have thermal power plants and abundant availability of fly ash and GGBS.

The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. The alkaline solution sodium hydroxide and sodium silicates are cheap and locally available. This paper is devoted to heat-cured low-calcium fly ash-GGBS based geopolymer concrete.

## II. OBJECTIVES

a) To develop a design mix for GGBS-Fly ash based geopolymer concrete and conventional concrete of same grade.
b) To study and compare the fresh and mechanical properties of geopolymer and conventional concrete.
c) To select a suitable fiber for reducing the brittleness and improving the ductility of GPC.

## III. MATERIALS USED

### 3.1. Fly ash

Low calcium Class F type fly ash obtained from Uduppi thermal power station and it was analysed as per IS:3812-1981, having specific gravity of 2.15 were used. Table 1 gives its chemical property.

Table 1. Properties of Class F fly ash

| Property | Requirements%(ASTM C618) |
|---|---|
| $SiO_2 + Al_2O_3 + Fe_2O_3$ (min) | 70 |
| $SO_3$ (max) | 5 |
| Moisture content (max) | 3 |
| Loss On Ignition (max) | 6 |

### 3.2. Ground granulated blast furnace slag

Ground Granulated Blast Furnace Slag (GGBS) is obtained from Bellary JSW unit. Specific gravity of GGBS used is 2.9

Table 2 Chemical composition of GGBS as per ACI 233-R

| Compound | Percentage |
|---|---|
| CaO | 32-45 |
| SiO2 | 32-42 |
| Al2O3 | 7-16 |
| Fe2O3 | 0.1-1.5 |
| MgO | 5-15 |
| MnO | 0.2-1 |

### 3.3. Aggregates

The coarse aggregate is chosen by shape as per IS 2386 (Part I) 1963, surface texture characteristics of aggregate is classified as in IS 383 – 1970[11]. Coarse aggregates comprising of different sizes 20mm, 12mm, 6mm having specific gravity of 2.74 were used. The sand is used as fine aggregate and it is collected from nearby area. The sand has been sieved in 4.75 mm sieve having specific gravity of 2.82 and fineness of 3.865 was used.

### 3.4. Alkaline solution

The alkaline liquid used was a combination of sodium silicate and sodium hydroxide solution. The molarity used for mixing of NaOH is 14M. The NaOH solution and sodium silicate solution were prepared separately and mixed together 24hours before casting.

### 3.5. Super plasticizer

Polycarboxilate based super plasticizer-Glenium ace was used in all of the geopolymer mixes, which is having a specific gravity of 1.145.

### 3.6. Cement

The cement used for this study is Ordinary Portland Cement is conforming to Indian Standard IS 12269 – 1987[12] of grade 53 having specific gravity of 3.125 were used.

### 3.7. Steel fibers

Steel fibre having geometry of cylindrical shape with crimped property was used. The length and diameter of fibres are 30mm and 0.5mm respectively. The aspect ratio (l/d) of the steel fibre is 60. Fig 1.shows the steel fiber used.

Fig.1. Steel Fibers

## IV. METHODOLOGY

### 4.1. Mix Design

The mix design of geopolymer concrete was adopted from B. Vijaya Rangan, Curtin University of Technology. Mix proportions for geopolymer concrete and mix proportion of conventional concrete (M40) are described in Table 3. From table 3, Mix 1and 2 have binder ratio 0.35, binder is completely flyash, but super plasticizer varies from 1.4, 2%. In Mix 3 and 4, binder ratio is again 0.35, binder is equal amount of flyash and GGBS with 1.4, 2% super plasticizer. From Mix 5-8 binder is equal amount of flyash and GGBS, super plasticizer 2%, binder ratio of 0.4, 0.5, 0.55 and 0.6 respectively.

Table 3 Mix proportions

| Materials | | Quantity (kg/m$^3$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Mix 1** | **Mix 2** | **Mix 3** | **Mix 4** | **Mix 5** | **Mix 6** | **Mix 7** | **Mix 8** | **M40** |
| **Binder ratio** | | 0.35 | 0.35 | 0.35 | 0.35 | 0.4 | 0.5 | 0.55 | 0.6 | - |
| **Fly ash (low calcium ASTM Class F)** | | 408 | 408 | 204 | 204 | 197 | 184 | 178 | 171 | - |
| **GGBS** | | - | - | 204 | 204 | 197 | 184 | 178 | 171 | - |
| **Cement** | | - | - | - | - | - | - | - | - | 450 |
| **Coarse aggregate** | **20mm** | 277 | 277 | 277 | 277 | 277 | 277 | 277 | 277 | 1084.9 |
| | **12mm** | 370 | 370 | 370 | 370 | 370 | 370 | 370 | 370 | |
| | **6mm** | 647 | 647 | 647 | 647 | 647 | 647 | 647 | 647 | |
| **Fine aggregate** | | 554 | 554 | 554 | 554 | 554 | 554 | 554 | 554 | 623.63 |
| **Sodium hydroxide solution** | | 144 | 144 | 144 | 144 | 158 | 183 | 196 | 210 | - |
| **Super plasticizer** | | 6 | 8 | 6 | 8 | 8 | 8 | 8 | 8 | - |
| **Extra water** | | 22.5 | 22.5 | 22.5 | - | - | - | - | - | 180 |

### 4.2. Mixing of geopolymer concrete

The solid constituents of geopolymer concrete mix i.e. fly ash, GGBS, fine and coarse aggregates were dry mixed in pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done for 3-4 minutes. Finally extra water along with superplasticizer was added to achieve workable GPC mix. Steel fibre was added to the wet mix in different proportions such as 0.25%, 0.5%, 0.75%, and 1.0% by the volume of the concrete. Prior to casting, the inner walls of moulds were coated with lubricating oil to prevent adhesion with the concrete specimens. All specimens were cast horizontally in three layers. Each layer was compacted using a tamping rod. The specimens considered in this study consisted of 150mm ×150mm×150mm size cubes, 150 mm diameter and 300 mm long cylinders, 100mm x100mm x500mm size prisms.

### 4.3. Curing of geopolymer concrete

Setting time of geopolymer concrete depend on many factors such as composition of alkaline solution and ratio of alkaline liquid to fly ash by mass. During curing process, geopolymer concrete experiences polymerization process. Here the test specimens were then left in the laboratory ambient conditions until the day of testing.

## V. RESULTS

### 5.1. Workability

Workability of both geopolymer (with and without steel fibers) as well as conventional concrete (M40) specimens were tested using standard slump test cone Fig 2(a) and 2(b) shows the slump test conducted on GPC and M40 respectively. The obtained results are tabulated in table 4 and 5 below. Fig 3 show the graphical variation corresponding to table 4 and Fig 4 shows the graphical variation corresponding to table 5.

(a)

(b)

Fig.2 Slump Test (a) GPC, (b) M40

Table 4. Slump of geopolymer without steel fibers and conventional mix

| Mix ID | Slump (mm) |
|---|---|
| Mix 1 | 100 |
| Mix 2 | 105 |
| Mix 3 | 108 |
| Mix 4 | 110 |
| Mix 5 | 115 |
| Mix 6 | 118 |
| Mix 7 | 120 |
| Mix 8 | 116 |
| M40 | 135 |

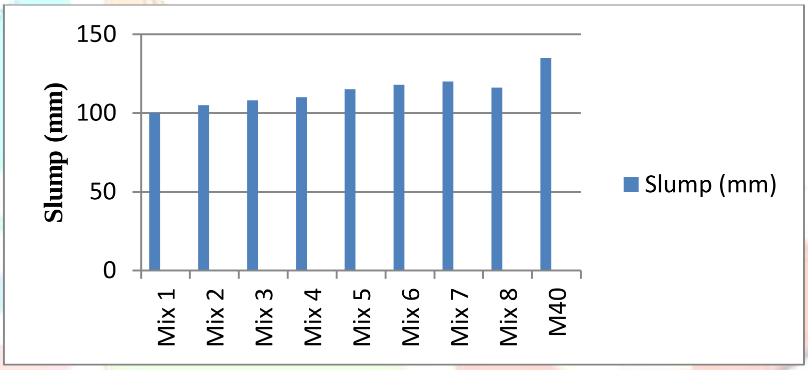


Fig.3 Graphical variation of slump test

Table 5 Slump values of geopolymer with steel fibers

| Mix ID | Steel Fibers (%) | Slump (mm) |
|---|---|---|
| G00 | 0 | 120 |
| G025 | 0.25 | 95 |
| G050 | 0.50 | 80 |
| G075 | 0.75 | 78 |
| G100 | 1 | 75 |

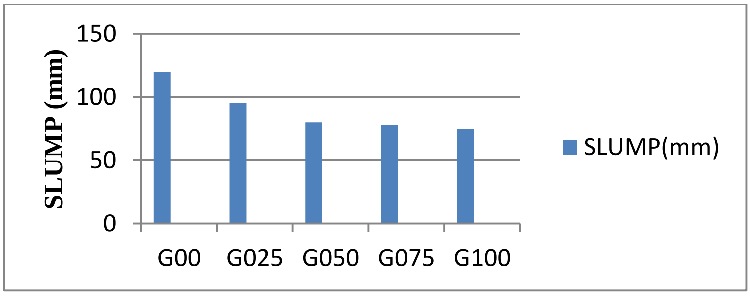


Fig.4 Graphical variation of slump of fibre added GPC

### 5.2. Compressive strength

The average compressive strength of geopolymer concrete (with and without steel fibers) for ambient curing of 28 days and conventional concrete are shown in Table 6 and 7. The specimens, GPC and M40, under compression testing machine are shown in fig 5(a) and 5(b) respectively. Compressive strength of GPC and CC (control specimen) specimens were compared by plotting graphs as shown in Figure 6 and 7


(a) (b)

Fig.5 (a) GPC, (b) M40

Table 6 Compressive Strength Test Results of GPC without steel fibers and conventional concrete

| Mix ID | Compressive strength (N/mm$^2$) | |
|---|---|---|
| | 7 days | 28 days |
| Mix 1 | 4.63 | 6.62 |
| Mix 2 | 10.61 | 14.14 |
| Mix 3 | 28.39 | 37.85 |
| Mix 4 | 31.32 | 39.64 |
| Mix 5 | 34.992 | 43.2 |
| Mix 6 | 40.51 | 49.71 |
| Mix 7 | 43.99 | 53 |
| Mix 8 | 36.84 | 46.05 |
| M40 | 31 | 47.7 |

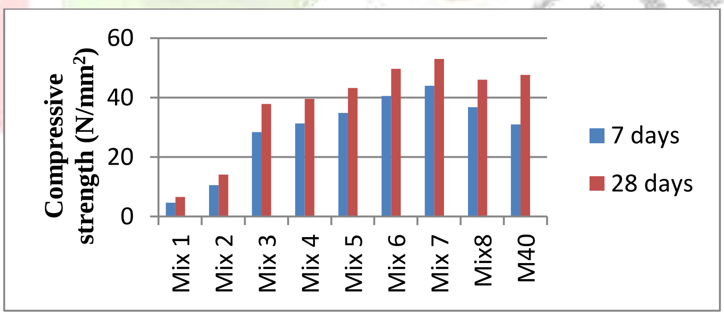


Fig.6 Graphical variation of compressive strength of GPC and M40

Table 7 Compressive Strength Test Results of GPC with steel fibers

| Mix ID | Steel Fibers % | Compressive strength (N/mm$^2$) | |
|---|---|---|---|
| | | 7 days | 28 days |
| G00 | 0 | 43.99 | 53 |
| G025 | 0.25 | 47.2 | 55.53 |
| G050 | 0.50 | 49.81 | 58.6 |
| G075 | 0.75 | 59.74 | 69.47 |
| G100 | 1 | 52.49 | 63.25 |

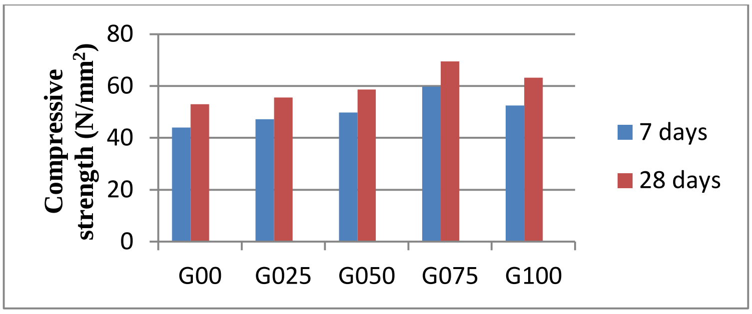


Fig.7 Graphical variation of compressive strength of GPC with steel fibers

**5.3. Flexural Strength**

Flexural strength of geopolymer concrete with Mix ID-7 without steel fibers and G075 with steel fibers were tested on flexural testing machine having capacity of 100kN. Results of flexural strength after 28 days curing are as given as follows. Table 8 shows the results of flexural strength test. Fig 8 and 9 shows the tested specimens with and without steel fibers. Fig 10 shows the graphical variation of the results.


Fig.8 Specimen after testing without steel fibers


Fig.9 Specimen after testing with steel fibers

Table 8 Flexural Strength Test Results

| Description | Load (kN) | Flexural strength ($N/mm^2$) 28 days |
|---|---|---|
| Mix 7 | 16 | 6.4 |
| G075 | 19.5 | 7.8 |

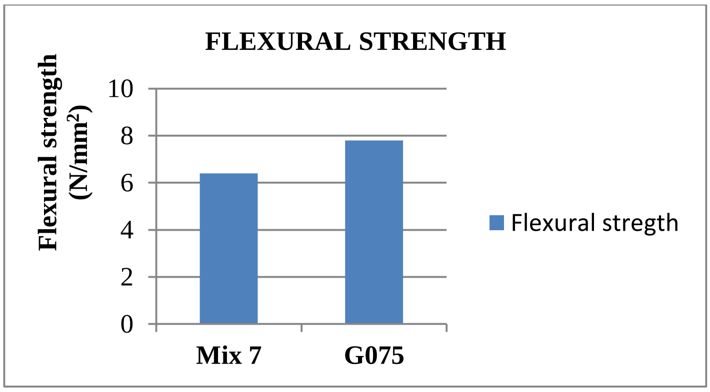


Fig.10 Graphical variation of flexural strength of GPC with and without steel fibers

**5.4. Split Tensile Strength**

Split tensile strength of geopolymer concrete with Mix ID-7 without steel fibers and G075 with steel fibers were tested on universal testing machine to study its tensile behavior and corresponding crack propagation. Results of split tensile strength after 28 days curing are as given in Table 9, Fig11 and 12 shows the tested specimen. Fig 13 shows the graphical variation of the results.

Fig.11. Specimen without steel fibers for split tensile strength test

Fig.12 Specimen with steel fibers for Split tensile strength test

Table 9 Split Tensile Strength Test Results

| **Description** | **Load (kN)** | **Split Tensile Strength ($N/mm^2$)** |
|---|---|---|
| Mix 7 | 366 | 5.2 |
| G075 | 512 | 7.24 |

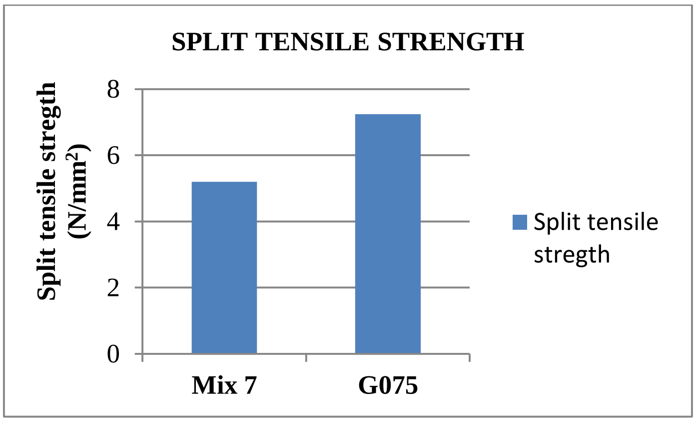


Fig.13 Graphical variation of split tensile strength of GPC with and without steel fibers

## VI. CONCLUSIONS

1. Workability of geopolymer concrete is less than that of conventional concrete.
2. From the different mix proportion designed for GPC, the mix with ID 7, having 0.55 % binder ratio, 14M alkaline liquid along with 2% superplasticizer and equal amount of fly ash and GGBS was selected as the optimum mix.
3. Based on the results of compressive strength for GPC and M40, GPC – Mix 7 gives the highest value of 53N/mm$^2$ compared to 47.7N/mm$^2$ of conventional concrete.
4. During compressive strength test of different specimens, they showed a brittle failure; hence addition of steel fibers becomes important.
5. Fiber added GPC showed higher compressive strength than GPC without steel fibers.
6. Flexural strength test conducted on beam specimens with steel fibers showed higher value than GPC without steel fibers, also the failure is more ductile. No cracks are observed on the compression side of the specimen.
7. In the case of split tensile strength test, fibre added GPC showed better results. Also the cylinder specimen does not show any crack on its sides and bottom of cylindrical specimen.

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