# Strength Properties of Geo-Polymer Concrete using Flyash, GGBS and Mill Rejected Coal

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*Abstract*— The second most consumed product in the world is Cement. It contributes nearly 7% of the global carbon dioxide emission. Geo-polymer concrete (GPC) is a special type of concrete that is manufactured using industrial waste like fly ash, GGBS which are considered as a more eco-friendly alternative to Ordinary Portland Cement (OPC) based concrete. By using this type of industrial by-products in concrete industry as a replacement for cement we can reduce the usage of cement which results in minimizing the emission of greenhouses gases into the atmosphere and also savings in cost. This project mainly aims at the study of effect of fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geo polymer concrete (GPC) when they were replaced for cement at different replacement levels (FA50-GGBS50, FA75-GGBS25, FA100-GGBS0) using Sodium silicate ($Na_2SiO_3$) and sodium hydroxide (NaOH) solutions as alkaline activators , sand as fine aggregate and mill rejected coal (up to 30%) as coarse aggregate, crushed stone of size 10mm, 20mm as coarse aggregate (up to 70%) . Specimens were casted and cured for different curing periods like 7, 14, 28, 56 and 112 days at ambient room temperature to determine the mechanical properties of geo-polymer concrete. Test results shows that as the percentage of GGBS in the mix is increasing, mechanical properties such as compressive strength, split tensile strength and flexural strength were increasing.

***Key words:*** Geopolymer Concrete, GGBS, Fly Ash, Sodium Silicate, Sodium Hydroxide, Compressive Strength, Split Tensile Strength, Flexure Strength

## I. INTRODUCTION

Concrete is the most widely used construction material in the world and Ordinary Portland Cement (OPC) is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide (CO2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of CO2 is released into the atmosphere for every ton of OPC produced[1]. In view of this, there is a need to develop sustainable alternatives to conventional cement utilizing the cementitious properties of industrial by-products such as fly ash and ground granulated blast furnace slag[2-4]. On the other side, the abundance and availability of fly ash and GGBS worldwide create opportunity to utilize these by-products, as partial replacement or as performance enhancer for OPC. In 1978, Davidovits developed a binder called geo-polymer to describe an alternative cementitious material which has ceramic-like properties. Geo-polymer technology is one of the new technologies attempted to reduce the use of Portland cement in concrete. Geopolymer are environmental friendly materials that do not emit greenhouse gases during polymerization process. Geopolymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions[5]. Geopolymers are made from source materials with silicon (Si) and Aluminium (Al) content and thus cement can be completely replaced by marginal materials such as fly ash and ground granulated blast furnace slag which is rich in silica and alumina[6-7]. Fly ash and GGBS reacts with alkaline solutions to form a cementitious material which does not emit carbon dioxide into the atmosphere and enhances the mechanical properties of the geo-polymer concrete. Davidovits (1978) proposed that binders could also be produced by polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials or by-product materials such as fly ash and rice husk ash. Portland cement is still the main binder in concrete construction prompting a search for more eco-friendly materials. Furthermore, it has been reported that the durability of ordinary Portland cement concrete is under examination, as many concrete structures especially those built in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life.

## II. EXPERIMENTAL STUDY

### A. Experimental Program

Our objective was to determine the effect of GGBS and Fly-ash on the mechanical properties of geo polymer concrete. In this respect, GGBS and Fly-ash were used as binders, Sodium hydroxide and Sodium silicate were used as alkaline activators, Crushed granite stones of size 20 mm and 10 mm of coarse aggregate are used, river sand is used as fine aggregate.

### B. Material Properties

#### 1) Binders

Fly ash and GGBS were used as binders in geo polymer concrete and their physical and chemical properties of the Ground Granulated Blast Furnace Slag were tabulated below

| Particulars | Class “F” fly ash | GGBS |
|---|---|---|
| Chemical composition | | |
| % Silica($SiO_2$) | 65.6 | 30.61 |
| % Alumina($Al_2O_3$) | 28.0 | 16.24 |
| % Iron Oxide($Fe_2O_3$) | 3.0 | 0.584 |
| % Lime(CaO) | 1.0 | 34.48 |
| % Magnesia(MgO) | 1.0 | 6.79 |
| % Titanium Oxide ($TiO_2$) | 0.5 | - |
| % Sulphur Trioxide ($SO_3$) | 0.2 | 1.85 |
| Loss on Ignition | 0.29 | 2.1 |
| Physical properties | | |
| Specific gravity | 2.24 | 2.86 |
| Fineness ($m^2$/Kg) | 360 | 400 |

Table 1: Chemical and Physical Properties of Class F Fly Ash and GGBS

 

*2) Alkaline liquids*

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution ($Na_2O$= 13.7%, $SiO_2$=29.4%, and water=55.9% by mass) was purchased from a local supplier. The sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity was also purchased from a local supplier. The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in required quantity of water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molarity, M. For instance, NaOH solution with a concentration of 10M consisted of 10x40 = 400 grams of NaOH solids (in flake or pellet form) per litre of the solution, where, 40 is the molecular weight of sodium hydroxide (NaOH) pellets or flakes.

*3) Coarse Aggregate*

Crushed granite stones of size 20 mm and 10 mm of coarse aggregate are used. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm and 10mm as per IS code were 2.58 and 0.3% respectively.

*4) Fine Aggregate*

The sand used throughout the experimental work was obtained from the river Swarnamukhi near chandragiri in chittoor district. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS code were 2.62 and 1% respectivel.

*5) Mill Rejected Coal*

Mill rejected coal of size 20 mm and 10mm were used as partial replacement of 20 mm and 10 mm coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse mill rejected as per IS code were 2.06and 0.48% respectively.

### C. *Mix Proportions*

Table 2 shows the mix proportions of the specimens used in studying the strength properties

| Materials | | Mass (kg/m$^3$) | | |
|---|---|---|---|---|
| | | FA50-GGBS50 | FA75-GGBS25 | FA100-GGBS0 |
| Mill rejected coal | 20 mm | 232.8 | 232.8 | 232.8 |
| | 10 mm | 154.8 | 154.8 | 154.8 |
| Coarse aggregate | 20 mm | 541.8 | 541.8 | 541.8 |
| | 10 mm | 361.2 | 361.2 | 361.2 |
| Fine aggregate | Slag | 549 | 549 | 549 |
| Fly ash (Class F) | | 204.5 | 306.75 | 409 |
| GGBS | | 204.5 | 102.25 | 0 |
| Sodium silicate solution | | 102 | 102 | 102 |
| Sodium hydroxide solution | | 41 (10M) | 41 (10M) | 41 (10M) |
| Extra water | | 55 | 55 | 55 |
| Alkaline solution/ (FA+GGBS) (by weight) | | 0.35 | 0.35 | 0.35 |
| Water/ geopolymer solids (by weight) | | 0.29 | 0.29 | 0.29 |

Table 2: GPC Mix Proportions

## III. RESULTS AND DISCUSSIONS

### A. *Compressive Strength*

Table 3 shows the compressive strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA75-GGBS25; FA100-GGBS 0) at different curing periods.

| Mechanical property | Age (days) | Mix type | | |
|---|---|---|---|---|
| | | FA50-GGBS50 | FA75-GGBS25 | FA100-GGBS0 |
| Compressive strength, $f'_c$ (MPa) | 7 | 41.16 | 22.5 | 11.28 |
| | 14 | 47.65 | 31.6 | 19.8 |
| | 28 | 54.62 | 36.4 | 25.8 |
| | 56 | 64.12 | 50.12 | 39.6 |
| | 112 | 65.9 | 53.1 | 42.5 |

Table 3: Compressive strength of GPC

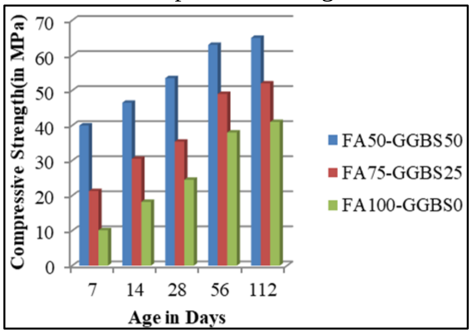


Fig. 1: Compressive strength versus Age

It was observed that there was a significant decrease in compressive strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 1. It can be concluded that the increase in Fly ash replacement level has significant decrease strength in geopolymers but still exhibits good normal strength. The GPC with 100% Fly ash sample exhibited compressive strength values of 11.28 MPa, 19.8 MPa, 25.8 MPa, 39.6 MPa and 42.5 MPa after 7, 14, 28, 56 and 112 days of curing respectively at ambient room temperature.

### B. *Split Tensile Strength*

Table 4 shows the split tensile strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA75-GGBS25; FA100-GGBS0) at different curing periods.

| Mechanical property | Age (days) | Mix type | | |
|---|---|---|---|---|
| | | FA50-GGBS50 | FA75-GGBS25 | FA100-GGBS0 |
| Split tensile strength, $f_{ct}$ (MPa) | 28 | 3.55 | 3.24 | 2.92 |
| | 56 | 3.68 | 3.36 | 3.08 |
| | 112 | 3.82 | 3.53 | 3.22 |

Table 4: Split tensile strength of GPC

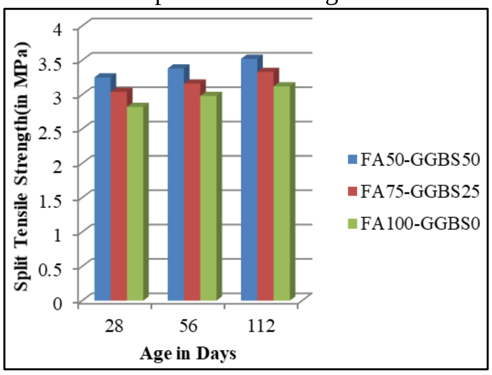


Fig. 2: Split tensile strength of mixes

 

It was observed that there was a significant decrease in splitting tensile strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 2. It can be concluded that the increase in Fly ash replacement level weakens the microstructure of GPC thus leads to detriment of splitting tensile strength of GPC but the decrement is less. The GPC with 100% Fly ash sample exhibited splitting tensile strength values of 2.92 MPa, 3.08 MPa and 3.22 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature.

### C. *Flexural Strength*

Table 5 shows the flexural strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA75-GGBS25; FA100-GGBS0) at different curing periods.

| Mechanical property | Age (days) | Mix type | | |
|---|---|---|---|---|
| | | FA50-GGBS50 | FA75-GGBS25 | FA 100-GGBS0 |
| Flexural strength, $f_{cr}$ (MPa) | 28 | 5.55 | 5.16 | 5.1 |
| | 56 | 6.12 | 5.26 | 5.25 |
| | 112 | 6.59 | 6.04 | 5.64 |

Table 5: Flexural strength of GPC

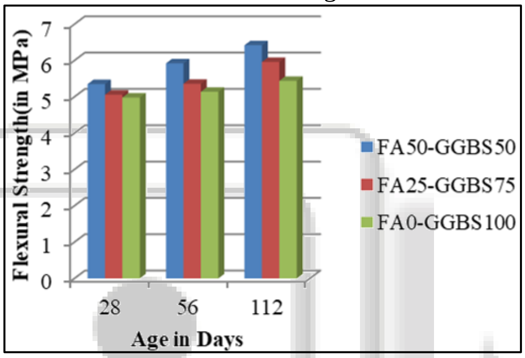


Fig. 3: Flexural strength of mixes

It was observed that there was a significant decrease in flexural strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 3. It can be concluded that the decrease in GGBS replacement level reduce the Silica content of GPC thus lessens the flexural strength of GPC but maintains its strength. The GPC with 100% Fly ash sample exhibited Flexural strength values of 5.1 MPa, 5.25 MPa and 5.64 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature.

## IV. Conclusions

Based on the test results, the following conclusions are drawn:

- GGBS blended FA based GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes.
- Fly ash based GPC mixes have attained comparable values of mechanical properties at ambient room temperature curing at all ages to normal Strength.
- Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended as an innovative construction material at low cost for the use of constructions.

Though 100% Fly ash exhibited decrease in strength, it maintains the strength. The cost is also low compared to the 50% GGBS& 50% Fly ash

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