# An Experimental Investigation on Evaluation of Strength Properties of Flyash Based Geopolymer Concrete With GGBS

**Ms. Smitha[1], Mr. Anveeth Mallya[2], Mr Darshan S[3], Mr Rohith Kumar B[4], Mr Bharath Raj[5]**
[1, 2, 3, 4, 5] Department of Civil Engineering
[1, 2, 3, 4, 5] Sahyadri College of Engineering & Management, Mangalore, India

***Abstract**- Concrete is the most abundantly used material in the world. One of the main ingredients in a normal concrete mixture is Portland cement. However, the production of cement is responsible for approximately 8% of the world's $CO_2$ emissions. Geopolymer concrete is much more durable than ordinary concrete due to its resistance to corrosion. It is also much stronger than ordinary concrete. Geopolymer is a material resulting from the reaction of a source material that is rich in silica and alumina with alkaline solution. Geopolymer concrete is totally a cement free concrete. In Geopolymer concrete, flyash and GGBS act as binder and alkaline solution acts as an activator. Flyash with GGBS and alkaline activator undergo geo-polymerization process to produce alumino silicate gel. Alkaline solution of 13 M (Molar) used in this investigation is a combination of sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$). In this present study the main limitations of fly ash based geopolymer concrete are slow setting of concrete at ambient temperature and the necessity of heat curing are eliminated by addition of Ground Granulated Blast Furnace Slag (GGBS) powder which shows considerable gain in strength.*

***Keywords***- Geopolymer, fly ash, GGBS, alkaline liquid, design mix proportion.

## I. INTRODUCTION

### 1.1 General

In the present scenario the demand for concrete as a construction material has increased as the demand for infrastructure development has increased. However, the utilization of cement pollutes the environment and reduces raw materials (limestone). In addition to that large amount energy was also consumed for the cement production. Hence, it is inevitable to find an alternative material to the existing most expensive, most resource consuming Portland cement. One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials. The most common industrial by-products used as binder materials are Fly ash (FA) and ground granulated blast-furnace slag (GGBS).The Geo-polymers depend on thermally activated natural materials like Metakaoline or industrial by products like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These Silicon and Aluminum is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder.

Fly ash is a fine powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. The GGBS is a by-product from the blast furnace used to make iron. The manufacturing of Ordinary Portland Cement (OPC) requires the burning of large quantities of fuel as well as the decomposition of limestone, resulting in significant emissions of $CO_2$. For every ton of OPC manufactured, nearly one tone of $C0_2$ is produced, depending on the production process adopted. Cement plants have been reported to emit up to 1.5 billion tons of CO into the atmosphere annually. As such, Geo-polymer concrete has been introduced to reduce this problem. The Portland cement industry does not quite fit the contemporary desirable picture of a sustainable eco-friendly industry. There is an urgent need to find an alternate binder which should be similar or superior to that of Portland cement for use in concretes in respect of parameters such as processing conditions for production of concrete mixes, mechanical and durability properties, long term chemical stability of the binding system with common filler aggregate systems such as sand, crushed natural stones, etc. Towards this, a new binder material known as 'Geo-polymer' is introduced Alkali activation of alumina and silica containing blast furnace slag powder, known as GGBS and fly ash is done to obtain inorganic polymeric binding material called Geo-polymer. Fly ash particles are almost totally spherical in shape, allowing flowing and blending freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete .Eventually it is worn away completely. Class F fly ash could serve as an ideal source material for mass production of Geo-polymer. Class F fly ash is preferred over class C fly ash because of lower percentage of calcium presence in elevated levels which could hinder the polymerization reaction and leads to flash set due to formation of calcium hydrate products. The alkaline liquid comprised a combination of sodium silicate solution and sodium hydroxide solution. The silicon and the aluminium in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the Geo-polymer paste that binds the aggregates and other un-reacted materials. The choice of the alkaline solution mainly depends upon the reactivity and the cost of the alkaline solutions. Previous studies indicate that sodium silicate solution in combination with sodium hydroxide is an effective alkaline activator. Geo-polymer concrete produced without using elevated heat for curing will widen its application to the areas beyond precast members. Hence this study aimed to produce Geo-polymer concrete suitable for ambient curing condition. Ground blast furnace slag-was mixed with low calcium fly ash to study the setting time, workability and the strength properties of Geo-polymer concrete. Water is not involved in the chemical reaction of Geo-polymer concrete and instead water is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when Portland cement is mixed with water, which produce the primary hydration products calcium silicate hydrate and calcium hydroxide. This difference has a significant impact on the mechanical and chemical properties of the resulting Geo-polymer concrete. Sand collected from Aeolian deposit is expensive due to unwanted cost of transportation from natural sources. Large scale exploitation of natural sand creates environmental impact on society. River sand is most commonly used fine aggregate in concrete but due to acute shortage in many areas, availability, cost & environmental impact are the major concern.

**1.2 Necessity of GPC**

Construction is one of the fast growing fields worldwide. As per the present world statistics, every year around 2.6 to 2.8 billion tons of Cement is required. This quantity will be increased by 25% within a span of another 10 years. Since the Lime stone is the main source material for the ordinary Portland cement an acute shortage of limestone may come after 25 to 50 years. More over while producing one ton of cement, approximately one ton of carbon di oxide will be emitted to the atmosphere, which is a major threat for the environment. In addition to the above huge quantity of energy is also required for the production of cement. Hence it is most essential to find an alternative binder. The Cement production generated carbon di oxide, which pollutes the atmosphere. The Thermal Industry produces a waste called fly ash which is simply dumped on the earth, occupies larges areas. The waste water from the Chemical Industries is discharged into the ground which contaminates ground water. By producing Geopolymer Concrete all the above mentioned issues shall be solved by rearranging them. Since Geopolymer concrete doesn't use any cement, the production of cement shall be reduced and hence the pollution of atmosphere by the emission of carbon di oxide shall also be minimum.

**1.3 Objectives**

Aim of this paper is to replace total cement content by fly ash and GGBS content in Geopolymer concrete to achieve the economy and also production of environmental friendly concrete in construction.

1. To make a concrete without using cement (i.e. Geopolymer concrete).
2. To evaluate the different strength parameters of geo-polymer concrete with percentage replacement of GGBS.
3. To evaluate the optimum mix proportion of Geo-polymer concrete with fly ash and GGBS replaced in various percentages
4. To encourage use of alternate waste materials.
5. To reduce environmental pollution by lowering the $CO_2$ production.
6. Evaluation of results obtained from studies.

**1.4 Parameters Chosen For Investigation**

Based on the research on Geo-polymer paste, mortar and concrete available in the literature and experience gained during the preliminary experimental work the following parameters were selected for the investigation.

1. Total water content.
2. Percentage of Fly ash in the total binder content.
3. Percentage of GGBS in the total binder content.

**1.5 Properties of Geopolymer Concrete**

The superior properties of Geo-polymer concrete are
l. Sets at room temperature
2. Non toxic, bleed free
3. Long working life before stiffening
4. Impermeable
5. Higher resistance to heat and resist all inorganic solvents
6. Higher compressive strength

Compressive strength of Geo-polymer concrete is very high compared to the ordinary Portland cement concrete. Geo-polymer concrete also showed very high early strength. The compressive strength of Geo-polymer concrete is about 1.5 times more than that of the compressive strength with the ordinary Portland cement concrete, for the same mix. Similarly the Geo-polymer Concrete showed good workability as of the Ordinary Portland Cement Concrete.

## II. MATERIALS AND METHODOLOGY

### 2.1 Materials

**Flyash:** FA is defined as the finely divided residue that results from the combination of ground or powdered coal and that is transported by the flue gases from the combustion zone ‘to the particle removal system (AC1 Committee 232 2004). FA is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. FA particles are typically spherical, finer than Portland cement and lime, ranging from less than lμm to not more than 150μm. In this study, low calcium, grade 1 flyash was used as the base material. The physical properties of F A are given below.

Table 1 Physical properties of Fly ash

| Particulars | Properties |
|---|---|
| Residue on 90μ sieve | 23% |
| Specific gravity | 2.16 |

**GGBS:** Ground Granulated Blast -furnace Slag (GGBS) is a by-product of the steel industry. Blast furnace slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. In the production of iron, blast furnaces are loaded with iron ore, fluxing agents, and coke. The physical properties of GGBS used for this study are given in the below table.

Table 2 Physical properties of GGBS

| Properties | Values |
|---|---|
| Specific gravity | 2.62 |
| % retained on (90μ) | 27% |

**Aggregates:** In the present experimental study river sand and crushed granite aggregate 20mm down size were used as fine aggregate and coarse aggregates respectively. Aggregate were in the saturated surface dry condition. The characteristics of aggregates are presented below

Table 3 Physical characteristics of Aggregates

| Physical properties | Fine aggregate | Coarse aggregate (20mm down) |
|---|---|---|
| Specific gravity | 2.67 | 2.65 |

The fine aggregate tested conforms to Zone-II as per IS: 383.

**Alkaline Liquid:** A combination of sodium silicate solution ($Na_2Si0_3$) and sodium hydroxide (NaOH) solution can be used as the alkaline liquid. Usually the ratio of sodium silicate to sodium hydroxide is taken as 2.5. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use.

**a. Sodium silicate:** The sodium silicate solution is commercially available in different grades. The sodium silicate solution A53 with $SiO_2$-to-$Na_2O$ ratio by mass of approximately 2, i.e. and water = 50% by mass, is recommended

**b. Sodium hydroxide:** The sodium hydroxide with 97-98% purity, in flake or pellet form, is commercially available. The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in the range between 8 Molar and 16 Molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 8.Molar consists of 8x40 = 320 grams of NaOH solids per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 320 grams per kg of NaOH solution with a concentration of 8 Molar. Similarly, the mass of NaOH solids per kg of solution for other concentrations was measured as 16 Molar: 640 grams per kg of NaOH. Note that the mass of water is the major component in both the alkaline solutions. In order to improve the workability, a high range water reducer super plasticizer and extra water may be added to the mixture.

**Water:** Distilled water was used in experimental study in order to avoid any mineral interference in polymerization reaction. And water was used only for the preparation of sodium hydroxide solution.

### 2.2 Methodolgy

**Mix proportioning of Geo Polymer Concrete**

The basic assumptions made in the mix design of geo-polymer concrete

1. One of the major assumptions is that the wet density of Geo-polymer concrete which is taken as a constant of 2400kg/$m^3$.
2. Molarity of sodium hydroxide (NaOH) solution in the range of 8M and 16M has been used in literature referred which showed compressive strength in the range of l0MPa to 70MPa. However, in this study 13M solution is used throughout the study.

3. Ratio of sodium silicate solution-to-sodium hydroxide solution used is 2.5.

**1. Total water content:** The water content in case of Geo-polymer concrete is the amount of water present in the alkaline solutions which is used as the activator.
Total water content = Total water present in combined solution
= Water present in NaOH Solution + Water in $Na_2SiO_3$ Solution

No additional water was added in the present study.

**2. Total content of alkaline solution:** Strength of Geo-polymer concrete is largely influenced by the kind of activator and total content of alkaline solutions. The increase or decrease of alkaline solution decides the availability of chemicals to react with the source material. Depending upon the required strength and workability, the water content is chosen. The inherent water content in the alkali solution can be known by chemical analysis of the solution; hence the quantity of alkaline solution can be determined. Knowing the specific gravity of alkaline solution, the absolute volume can be calculated.

**3. Base materials:** Quantity of the base materials is to be decided for the desired workability and strength. Various researchers have adopted base materials @l5 to 35% by weight of total particulate content. Once the quantity of base materials is decided, knowing the specific gravity, absolute volume of FA is calculated.

**4. Quantity of Geo-polymeric binder:** The total alkaline solutions and base materials together form the Geo-polymeric binder. Once the absolute volume of alkaline solution and base materials is known, absolute volume of Geo-polymeric binder is calculated.
Then,
Volume of Geo-polymer concrete = Absolute volume of Geo-polymeric binder + Absolute volume of Aggregate.

**5. Quantity of Aggregates:** Crushed stone aggregate of 20 mm and down size and river sand are used as aggregates in the present study.

The water content in the mixes was chosen as 110 $kg/m^3$. Here the water content implies the total water content of the alkali solution (Sodium Hydroxide + Sodium Silicate solution). The Quantity of base materials was kept at a constant of 20% of the total volume Geo-polymer concrete.
The Table below gives the mix design calculation of Geo-polymer concrete per cubic meter, used for the study.

Table 4.Design Parameters used for Geo-polymer concrete

| DESIGN PARAMETERS | VALUE | UNIT |
|---|---|---|
| The wet density of Geo-polymer concrete | 2526 | $Kg/m^3$ |
| Ratio of sodium silicate to sodium hydroxide | 2.5 | Constant |
| The water content chosen for mix | 110 | Litres |
| The water content in sodium silicate | 50 | Percentage |
| Ratio of solution to base material | 0.35 | Constant |
| Coarse aggregate percentage | 67 | Percentage |
| Fine aggregate percentage | 33 | Percentage |
| Molarity considered for solution | 13 | Molar |

**Mix Calculation of Geo-polymer Concrete**

A sample mix proportioning for M30 grade of Geopolymer concrete is carried out using proposed method.

Following preliminary data is considered for the mix design:
1. Characteristic compressive strength of Geopolymer Concrete ($f_{ck}$) = 30 MPa.
2. Type of curing: Oven curing at 60 °C for 24 h and tested after 7 days
3. Workability in terms of flow: 25–50 % (Degree of workability—Medium)
4. Fly ash: Fineness in terms of specific surface: 426 $m^2/kg$
5. Alkaline activators (Na2SiO3 and NaOH)
(a) Concentration of Sodium hydroxide in terms of molarity: 13 M
(b) Concentration of Sodium silicate solution: 50.00% solid content
6. Solution-to-fly ash ratio by mass: 0.35
7. Sodium silicate-to-sodium hydroxide ratio by mass: 2.5
8. Fine aggregate
(a) Type: Natural River sand confirming to grading zone-II as per IS 383:1970:F.M. =2.80
(b) Water absorption: 3.67 %
(c) Water content: Nil
9. Coarse aggregate
(a) Type: Crushed/angular
(b) Maximum size: 20 mm
(c) Water absorption: 0.89 %
(d) Moisture content: Nil.

**DESIGN STEPS**

**1. Target mean strength**

Fck = 38.25 MPa

**2. Selection of quantity of fly ash**

The quantity of fly ash required is 405 kg/m3 for the target mean strength of 38.25 MPa at solution-to-fly ash ratio of 0.35 and for 426 $m^2$/kg fineness of fly ash.

**3. Calculation of the quantity of alkaline activators**

Calculate the quantity of alkaline activators considering:
Solution/Fly ash ratio by mass =0:35
i.e. Mass of ($Na_2SiO_3$ + NaOH)/Fly ash =0:35
Mass of Solution/405 = 0:35
Mass of ($Na_2SiO_3$ + NaOH) =141.75 kg/m3
Take the sodium silicate-to-sodium hydroxide ratio by mass of 2.5
Mass of sodium hydroxide solution (NaOH) = 40.50kg/m3
Mass of sodium silicate solution ($Na_2SiO_3$) = 101.25kg/m3

**4. Calculation of total solid content in alkaline solution**

Solid content in sodium silicate solution = (50/100)X101.25=50.625 Kg/$m^3$
Solid content in sodium hydroxide solution = (38.25/100)X40.5=15.59 Kg/$m^3$
Total Solid content in both alkaline solutions =15.59+50.625=60.22 Kg/$m^3$

**5. Selection of water content**

For medium degree of workability and fineness of fly ash of 426 $m^2$/kg, water content per cubic meter of geopolymer concrete is selected.
Water content = 110 kg/$m^3$.

**6. Adjustment in water content**

For sand conforming to grading-II, correction in water content is taken as 0.
Adjustment in water content=0%
Total quantity of water required =110-0=110 kg/$m^3$
Water content in alkaline solutions = 141.75 -66.22=75.53 kg/$m^3$

**7. Calculation of additional quantity of water**
= [Total quantity of water] − [Water present in alkaline solutions]
= 110− 75.53= 34.47kg/m3

**8. Selection of wet density of geopolymer concrete**

Wet density of geopolymer concrete is 2,526 kg/m3 for the fineness of fly ash of 426 $m^2$/kg.

**9. Selection of fine-to-total aggregate content**

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Fine-to-total aggregate content is 33% for fineness modulus of sand of sp.gravity 2.8.

**10. Calculation of fine and coarse aggregate content**

Total aggregate content= (Wet density of GPC)-(Quantity of fly ash + Quantity of both solutions +extra water; if any)
= 2526-(405 +141.75 +34.47) =1944.78 kg/$m^3$.

Sand content = (Fine to total aggregate content in %)
X (Total quantity of all-in-aggregate)
= (30/100)x1944.78=641.78 kg/m3.

Coarse aggregate content = (Total quantity of aggregate-Sand content)
=1944.78-641.78
=1303 kg/m3

**Mix Proportion = 1:1.4:3.2**

**Preparation of Test Specimens:**

The Sodium hydroxide flakes were dissolved in water to make the solution. The concentration of the NaOH solution is chosen as 13M. This consisted of 13*40=520 g of NaOH flake per litre of solution, where 40 is the molecular weight of NaOH. The sodium silicate solution was added to this solution and this mixture of alkaline liquid was prepared one day prior to the casting of the specimens as this is confirmed to have the best results as per Hardjito and Rangan.

***Mixing, casting and curing of Geo-polymer Concrete***

For mixing of concrete, manual mixing method was used. The solid constituents of the Geo-polymer concrete, i.e. the aggregates and the FA, were dry mixed in the pan for about three minutes. The liquid part of the mixture, i.e. the sodium silicate solution and Sodium hydroxide were premixed and then added to the solids. The wet mixing usually continued for another -four minutes. The fresh Geo-polymer was dark grey in colour. The mixtures were cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. Compaction of fresh concrete in the cube moulds was achieved by applying twenty five manual strokes per layer in three equal layers, followed by compaction" on a vibration Table for twenty seconds.

The Sundry curing method has adopted. The test specimens which were cast & covered with a thick Polythene sheet were kept outside the laboratory for sundry curing. This was suggested by Bakharev based on the experimental studies on Geo-polymer pastes at different curing regime and based on the report of Harish the curing which is done only in sundry regime throughout the testing period is referred as sundry curing in this study.

## III. RESULTS AND DISCUSSIONS

The Experimental results are presented and discussed below. The following tests were conducted for each of the mixes and their results have been discussed.

1. Slump test.
2. Compressive strength.
3. Split tensile strength.
4. Water absorption.

The test data presented corresponding to the mean value of three concrete samples.

In this experimental study the specimens are studied for sun-dry curing regime.

FA to GGBS has been varied in 6 batches i.e.
Flyash=100% GGBS=0% (1st batch) ,
Flyash =80% GGBS=20% (2nd batch)
Flyash =60% GGBS=40% (3rd batch)
and so on for 13M alkali solution (Sodium hydroxide) and using 110 litres of water content to arrive at optimal combination of base materials based on the workability and some basic properties have been evaluated. Strength at 7 days and 28 days is tabulated.

### 1. Slump test:

To determine the workability of the mix, the slump test is carried out. The results obtained are as follows.

Table 5: The Slump Values For Different Batches of GPC

| BATCHES | FLY ASH(%) | GGBS (%) | SLUMP (mm) |
|---|---|---|---|
| Batch 1 | 100 | 00 | 215 |
| Batch 2 | 80 | 20 | 166 |
| Batch 3 | 60 | 40 | 72 |
| Batch 4 | 40 | 60 | 39 |
| Batch 5 | 20 | 80 | 14 |
| Batch 6 | 00 | 100 | 00 |

### 2. Compressive strength

The compressive strength of Geo-polymer concrete has been measured for 7 and 28 days by sun-dry curing. The results are tabulated in Table 6. The compressive strength found to be increasing with the increase in the percentage of GGBS as tabulated in Table 6.

The maximum compressive strength achieved was 65.62MPa & 93.92MPa for 7 days and 28 days of curing respectively. It is observed that, percentage of increase in strength from 0 days to 7 days is predominating.

Table 6: The Compressive Strength Values for Different Batches of GPC

| Fly ash In % | GGBS In % | Compression test (7 days) | | | Compression test (28 days) | | |
|---|---|---|---|---|---|---|---|
| | | Load (kn) | Strength $N/mm^2$ | Avg $N/mm^2$ | Load kN | Strength $N/mm^2$ | Avg $N/mm^2$ |
| 100 | 0 | 1350 | 60 | 60.29 | 1490 | 66.22 | 66.96 |
| | | 1380 | 61.33 | | 1520 | 67.55 | |
| | | 1340 | 59.55 | | 1510 | 67.11 | |
| 80 | 20 | 1410 | 62.66 | 61.33 | 1600 | 71.11 | 70.51 |
| | | 1360 | 60.44 | | 1580 | 70.22 | |
| | | 1370 | 60.88 | | 1580 | 70.22 | |
| 60 | 40 | 1390 | 61.78 | 62.81 | 1690 | 75.11 | 76.14 |
| | | 1430 | 63.55 | | 1720 | 76.44 | |
| | | 1420 | 63.11 | | 1730 | 76.88 | |
| 40 | 60 | 1410 | 62.66 | 63.40 | 1780 | 79.11 | 79.7 |
| | | 1450 | 64.44 | | 1790 | 79.55 | |
| | | 1420 | 63.11 | | 1810 | 80.44 | |
| 20 | 80 | 1440 | 64 | 64.59 | 1900 | 84.44 | 84.59 |
| | | 1450 | 64.44 | | 1920 | 85.33 | |
| | | 1470 | 65.33 | | 1890 | 84 | |
| 0 | 100 | 1460 | 64.88 | 65.62 | 2100 | 93.33 | 93.92 |
| | | 1490 | 66.23 | | 2020 | 89.77 | |
| | | 1480 | 65.77 | | 2220 | 98.66 | |

### 3. Split Tensile Strength Test:

The Split tensile strength of Geo-polymer concrete has been measured for 28 days by sun-dry curing. The results are tabulated in Table 7. The Split tensile strength was found to be increasing with the increase in the percentage of GGBS as tabulated in Table 7. The maximum Split tensile strength achieved was 21.19MPa for 28 days of curing.

Table 7: Split Tensile Strength Values for Different Batches of GPC

| **SPLIT TENSILE STRENGTH** | | |
|---|---|---|
| **Load (Kn)** | **Strength ($N/Mm^2$)** | **Avg Strength ($N/Mm^2$)** |
| Batch 1 | 14.82 | 14.069 |
| | 14.033 | |
| | 13.354 | |
| Batch 2 | 14.48 | 15.38 |
| | 16.29 | |
| | 15.39 | |
| Batch 3 | 15.61 | 16.29 |
| | 16.52 | |
| | 16.75 | |
| Batch 4 | 17.54 | 18.06 |
| | 18.44 | |
| | 18.22 | |
| Batch 5 | 20.48 | 20.06 |
| | 19.46 | |
| | 20.25 | |
| Batch 6 | 20.37 | 21.19 |
| | 21.27 | |
| | 21.95 | |

### 4. Water absorption of Geo-polymer concrete

Absorption studies were carried out on different mix batches of alkali activated slag concrete. The absorption of 7 days has been considered to measure water absorption value of alkali activated concrete. The initial dry weight measured was 8.1-8.3 kg. After measurement of weight the specimens were immersed in water and after 7 days of immersion their weight was measured. The measured weight was 8.3-8.7 kg.
From the Table 5.4, give the test results of water absorption for the different mix batches.

Table 8: Water Absorption for Different Mixes of GPC

| **Batch** | **Combination of fly ash-ggbs (%)** | **Initial weight of specimen** | **Final weight of specimen** | **Water absorption (%)** |
|---|---|---|---|---|
| 1 | 100-0 | 8.160 | 8.390 | 2.818 |
| 2 | 80-20 | 8.195 | 8.475 | 3.416 |
| 3 | 60-40 | 8.210 | 8.420 | 2.555 |
| 4 | 40-60 | 8.235 | 8.455 | 2.670 |
| 5 | 20-80 | 8.290 | 8.625 | 4.040 |
| 6 | 0-100 | 8.260 | 8.515 | 3.080 |

## IV. CONCLUSIONS

The following conclusions are drawn from the present study

1. The investigations have shown that using Fly ash along with GGBS as base material, it is possible to produce Geo-polymer concrete of compressive strengths in the order of 60-66Mpa for 7 days and 66-94 MPa for 28 days at sun-dry curing (without elevated temperature curing).
2. Slag, one of the base materials results in early initial strength and it makes possible to de-mould the laboratory specimens very early (4-6 hours) similar to that of cement concrete. This is important for in-situ applications of AAC in construction industry.
3. Higher concentrations of GGBS (Slag) result in higher compressive strength of Geo-polymer concrete.4. Cost of geo-polymer is not hard and fast. Generally the source material flyash and ggbs are much cheaper than Portland cement as they are the industrial by-product. However, cost of activator is much higher. In average the cost of geo-polymer binder is around 10-20% higher than Portland cement. In terms of concrete, around 30% less geo-polymer binder is required for the same strength level to OPC concrete. So, there will be similarity in concrete price.
4. Geo-polymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster.
5. Other potential near-term applications are precast pavers & slabs for paving, bricks and precast pipes.
6. It can also be used in road works because of its very early attainment of strength. The economic benefits and contribution of geopolymer concrete to sustainable development have also been outlined.

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