

# Investigation on Influence of Size of the Aggregate in Flyash and GGBS Based Geopolymer Concrete with Complete Replacement of River Sand by M-Sand

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**ABSTRACT:** Concrete is the most commonly used construction material across all over the world. But, due to its increase in productivity, there is a increased emission of CO<sub>2</sub> that results in global warming. Hence, there came an existence of newer green material popularly known as “Geopolymer concrete”. In this project work, the influence of size of aggregate content on mechanical properties of Flyash and GGBS based geopolymer concrete were analyzed at low molarity (6M) with complete replacement of river sand by M-Sand. Flyash and GGBS Based geopolymer was tried at low molarity because with increase in molarity of sodium hydroxide solution there is an increase in cost for overall production of geopolymer concrete. At 6M, cost in production of GPC was almost equal to the cost required for the production of normal conventional concrete. All geopolymer concrete mixes were prepared for varying proportion of two different size of aggregate and cured in direct sun light since ground granulated blast furnace slag have a significant effect on the setting time and strength development of Geopolymer concrete. Geopolymer concrete specimens were tested for compressive strength. Testing was done at the ages of 3 days, 7 days and 28 days. Flyash and Ground granulated blast furnace slag based geopolymer concrete give significant strength at 6M molarity of NaOH solution. So ordinary Portland cement concrete can be replaced by ground granulated blast furnace slag based geopolymer concrete which helps in reducing of CO<sub>2</sub> during manufacturing of cement by reducing the use of cement

**KEYWORDS:** flyash, GGBS, M-sand, Geopolymer, ambient curing, compressive strength.

## I. INTRODUCTION

The global use of Ordinary portland cement is second next to water. World business council for sustainable development reveals that 5% of CO<sub>2</sub> emission worldwide is from cement industry. This increased level of greenhouse gases which contributes to global warming lead to the necessity to look for a new alternative greener material. In this respect, Geopolymer concrete is one such alternative that shows a promising application in concrete industry. In Geopolymer concrete by-products from different industries such as ground granulated blast furnace slag, Fly Ash and Rice Husk Ash are used as source material, alkaline activator solution combination of alkali hydroxide and alkali silicate is used to activate these source materials so as to form geopolymer mortar which acts as binding material for coarse and fine aggregates to hold them together in the matrix.

Davidovits proposed that the ancient buildings such as the Roman Coliseum and Egyptian Pyramids were made out of a material similar to the geopolymer concrete (GPC) which means it is more durable than OPC. He alleged that the ancient "Roman cement" is geopolymer cement, but in reality this material is chemically unlike alkali activated geopolymer cements because it is made using lime and forms calcium-silicate-hydrates, making it much closer to Portland cement. Thus, the geopolymer concrete can be defined as ‘the concrete in which binder is produced by a

polymeric reaction of alkaline liquid with silicon and aluminium as source material of geological origin or by using byproduct materials such as flyash, GGBS, Rice husk.,etc.’

## II. MATERIAL PROPERTIES

### 2.1 Materials

Flyash, GGBS, alkaline solution and coarse aggregate are the materials used in the preparation of concrete. Flyash is brought from ennore thermal power station which is coal based located in Chennai. GGBS is brought from the local shop available in Chennai. The alkaline solutions used in this study are sodium hydroxide in flake form (NaOH with 98 % purity) dissolved in water and sodium silicate solution ( $\text{Na}_2\text{O}=14.7\%$ ,  $\text{SiO}_2 =29.4\%$ , and water=55.9%). Both the solutions are mixed together and the alkaline liquid is prepared at least one day prior to use.

Two types of locally available aggregates comprising 20 mm and 12mm for coarse aggregates and for fine aggregate M-Sand is used.

### 2.2 Fly ash

Flyash used is an industrial byproduct of coal based thermal power station. In this study, two types of flyash were used, where one was dark grey in colour (20%) and other was light grey (80%) in colour. Dark grey colour flyash imparts good colour to the concrete and also delays the setting time. The properties of fly ash are shown in Table 2.2.

**Table 2.2: Properties of fly ash**

S.No	Physical properties	Result
1.	Specific gravity	2.2
2.	Physical form	Powder
3.	Size (Micron)	0.1
4.	Colour	Dark grey , light grey
5.	Density	1500 k g/m <sup>3</sup>



**Figure 2.1 flyash**

### 2.3 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS) is an industrial by-product resulting from rapid water cooling of molten steel. It is known to have advantageous properties for the concrete industry as it is relatively inexpensive to obtain, highly resistant to chemical attack and maintains excellent thermal properties. Major components of the slag product are  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{MgO}$  and  $\text{Al}_2\text{O}_3$ . These components are responsible for cementitious property of slag.

**Table 2.2: Properties of fly ash**

S.No	Physical properties	Result
1.	Specific gravity	2.85
2.	Physical form	Powder
3.	Size (Micron)	0.3
4.	Colour	White
5.	Blaine fineness	400 m <sup>2</sup> /kg
6.	Density	2800 kg/m <sup>3</sup>



**Figure 2.2 ground granulated blast furnace slag**

#### 2.4 Alkaline Activator Solution

In the Geopolymer concrete alkaline activator solution is very important constituents. The most common alkaline activator solution used in geopolymerization is a mixture of Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate (Na<sub>2</sub>SiO<sub>3</sub>) or Potassium Silicate (K<sub>2</sub>SiO<sub>3</sub>). In this experimental work Sodium Hydroxide (NaOH) and Sodium Silicate (Na<sub>2</sub>SiO<sub>3</sub>) is used as alkaline activator solution since Al-Si minerals are more soluble in Sodium based compound. Also, the sodium hydroxide solution with a concentration of 6M consisted of 6x40 = 240 grams of sodium hydroxide solids (in flakes form) per litre of the solution, where 40 is the molecular weight of sodium hydroxide is prepared.



**Figure 2.3 mixed solution of sodium hydroxide and sodium silicate**

### 2.5 Coarse aggregates

In this study, coarse aggregates of size 12 mm and 20 mm conforming to specifications as given in IS: 383- 1970 is used.

### 2.6 Fine aggregates

The study is carried by completely replacing river sand with M-Sand so that behaviour of geopolymer concrete with M-Sand is determined. Fine aggregate used in the experimental work have specification conforming to IS: 383- 1970

## III. MIX DESIGN

### 3.1 General

GPC is a new constructional material which has developed in recent decades. So there is no codal provision for mix design till now. Therefore the methods which has been employed by researchers frequently in past to design the mix have been used in this study. A preliminary study has been carried out to understand basic design method of developing GPC mix. Preliminary study is carried out for 3 days compressive strength of GPC samples to fix certain mixture parameters and to develop an understanding of the trial mix proportioning of GPC. Parameter such as sodium silicate to sodium hydroxide ratio, alkaline solution to binder content ratio, molarity of NaOH and water to geopolymer solids are kept constant and its value are 2.5, 0.4, 6M and 0.25 respectively had taken. Also, the Ratio of flyash and GGBS is taken as 0.7: 0.3.

### 3.2 Trial 1 mix design:

Unit weight of concrete = 2400 Kg/m<sup>3</sup>

Total mass of combined aggregates assumed = 78% of 2400 = 1872 Kg/m<sup>3</sup>

Mass of fine aggregate (Coarse sand) = 38% of 1872 = 711.36 Kg/m<sup>3</sup>

Mass of coarse aggregates = 1872-711.36 = 1160.64 Kg/m<sup>3</sup>

Mass of 20 mm coarse aggregates = 52% of 1160.64 = 603.53 Kg/m<sup>3</sup>

Mass of 12 mm coarse aggregates = 1160.64 – 603.53 = 557.12 Kg/m<sup>3</sup>

Mass of source material (GGBS) and alkaline liquid = 2400-1872 = 528 Kg/m<sup>3</sup>

Alkaline liquid to source material ratio = 0.35

Mass of Source material (flyash and GGBS) = 528/ (1.35) = 391.11 Kg/m<sup>3</sup>

Mass of alkaline liquid = 156.89 Kg/m<sup>3</sup>

Na<sub>2</sub>SiO<sub>3</sub>/NaOH = 2.5

Mass of NaOH solution = 156.89/(1+2.5) = 44.825 kg/m<sup>3</sup>

Mass of Sodium silicate solution = 156.89-44.825= 112.06 Kg/m<sup>3</sup>

### Problems in trial 1:

For trial1, Surface finish is not good after remolding of samples due to segregation and inequity in distribution of coarse aggregate in geopolymer concrete. Also, the solution did not bind with the aggregate as the alkaline solution

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to binder content ratio and molarity of NaOH was very less. To overcome this problem, trial mix 2 is performed with increased alkaline solution to binder content and solution is prepared before 2 hours of casting of the specimen.

### 3.3 Trial 2 mix design:

In trial 2, all the parameters are as same as that followed in trial mix1, except alkaline to binder content, which is increased to 0.5. Total aggregate content is 75% and that of ratio of fine aggregate to coarse aggregate is 0.35.

$$\text{Unit weight of concrete} = 2400 \text{ Kg/m}^3$$

$$\text{Total mass of combined aggregates assumed} = 75\% \text{ of } 2400 = 1800 \text{ Kg/m}^3$$

$$\text{Mass of fine aggregate (Coarse sand)} = 35\% \text{ of } 1800 = 630 \text{ Kg/m}^3$$

$$\text{Mass of coarse aggregates} = 1800 - 630 = 1170 \text{ Kg/m}^3$$

$$\text{Mass of 20 mm coarse aggregates} = 52\% \text{ of } 1170 = 670 \text{ Kg/m}^3$$

$$\text{Mass of 12 mm coarse aggregates} = 1170 - 670 = 500 \text{ Kg/m}^3$$

$$\text{Mass of source material (GGBS) and alkaline liquid} = 2400 - 1800 = 600 \text{ Kg/m}^3$$

$$\text{Alkaline liquid to source material ratio} = 0.5$$

$$\text{Mass of Source material (flyash and GGBS)} = 600 / (1.50) = 400 \text{ Kg/m}^3$$

$$\text{Mass of alkaline liquid} = 200 \text{ Kg/m}^3$$

$$\text{Na}_2\text{SiO}_3/\text{NaOH} = 2.5$$

$$\text{Mass of NaOH solution} = 200 / (1 + 2.5) = 57.14 \text{ kg/m}^3$$

$$\text{Mass of Sodium silicate solution} = 200 - 57.14 = 142.86 \text{ Kg/m}^3$$

$$\text{Additional water added} = 10\% \text{ of the binder content} = 40 \text{ Kg/m}^3$$

$$\text{AVERAGE COMPRESSIVE STRENGTH OF 3 DAY CURING} = 22.22 \text{ N/mm}^2$$

### Problems in trial 2:

For trial2, the Surface finish was little good after demoulding of samples. Yet, there was no perfect surface finish and the mix was very stiff. This is due to the large proportion of 20mm aggregate. Thus, to overcome the problem of workability of the concrete and to obtain perfect surface finish, increased proportion of small sized aggregate is taken.

### 3.4 Mix Proportions

In this experimental work, to determine the influence of size of the aggregate on compressive strength of geopolymer concrete, 4 different mixes of mix1, mix 2, mix 3 and mix 4 are prepared by varying the proportion of 20mm aggregate to 0%, 20%, 40%, 60% respectively.

GGBS	= 280 kg/m <sup>3</sup>
Fly Ash	= 120 kg/m <sup>3</sup>
Water	= 120 kg/m <sup>3</sup>
Sodium hydroxide	= 57.14 kg/m <sup>3</sup>
Sodium silicate solution	= 142.86 kg/m <sup>3</sup>
Fine aggregate	= 630 kg/m <sup>3</sup>
Coarse aggregate	= 1170 kg/m <sup>3</sup>

The table 3.1 shows the mix proportion of concrete.

Mix proportions	Flyash kg/m <sup>3</sup>	GGBS kg/m <sup>3</sup>	Sodium hydroxide Solution (6M)	Sodium silicate solution	Fine Aggregate (M-Sand) kg/m <sup>3</sup>	Coarse Aggregate (20mm) kg/m <sup>3</sup>	Coarse Aggregate (12mm) kg/m <sup>3</sup>	Extra Water kg/m <sup>3</sup>
Mix 1(0%)	120	280	57.14	142.86	630	-	1170	40
Mix 2(20%)	120	280	57.14	142.86	630	234	936	40
Mix 3(40%)	120	280	57.14	142.86	630	468	702	40
Mix 4(60%)	120	280	57.14	142.86	630	702	468	40

Table 3.1 Mix proportion

#### IV. EXPERIMENTAL PROGRAM

##### 4.1 Preparation of alkaline solution

To prepare the alkaline solution of 6M for the manufacture of the geopolymer concrete, 240 grams (6x40) of sodium hydroxide in flakes form is dissolved in one litre of water. This solution is mixed for about 2 minutes until the solids get dissolved in water completely. The required quantity of sodium silicate solution is then mixed with sodium hydroxide. This solution is agitated for about 4 minutes so that proper mixing of the two solutions is ensured. The solution is prepared 2 hours before casting.



Figure 4.1 mixing of solution



#### 4.2 Casting of the specimen

In this study, hand mixing is adopted. From the table 3.1, the required quantity of aggregate for three cube specimens is taken and spread over the floor for mixing. Since two different size of aggregate (20mm and 12mm) is used, coarse and fine aggregates are mixed together before the addition of the binder. Similarly, flyash and GGBS are mixed together before adding with aggregate. Now the aggregate, binder and alkaline solution are mixed and casted into the cube mould of size 150mm x 150mm x 150mm. Mixing of concrete after the addition of solution is done for about 4 minutes.



**Figure 4.3 Adding solutions to the binder and aggregate mixture**

#### 4.3 Curing of the specimen

The specimen is demoulded after 24 hours of casting. This specimen is then cured in direct sunlight for 3 day, 7 day, 28 day curing.

#### 4.4 Compressive strength Test (Ref: IS: 516-1959)

The compressive strength test was conducted as per IS: 516-1959. The geopolymer concrete specimens were tested for compressive strength after 3, 7 days of direct sun light curing. This test was performed on cube of standard size 150mm×150mm×150mm. the compressive strength of any mix was taken as average of strength of three samples.

All the specimens were tested using a compression testing machine (CTM) of 2000 KN capacity equipped with a monitor to display the results. The failure load and corresponding compressive stress value was read from the screen and noted down. The compressive strength is the ratio of crushing load to the surface area of the specimens expressed in  $N/mm^2$ .



**Fig 4.1 Test Set up for Compressive Strength Test**

## V.RESULTS AND DISCUSSION

### 5.1 General

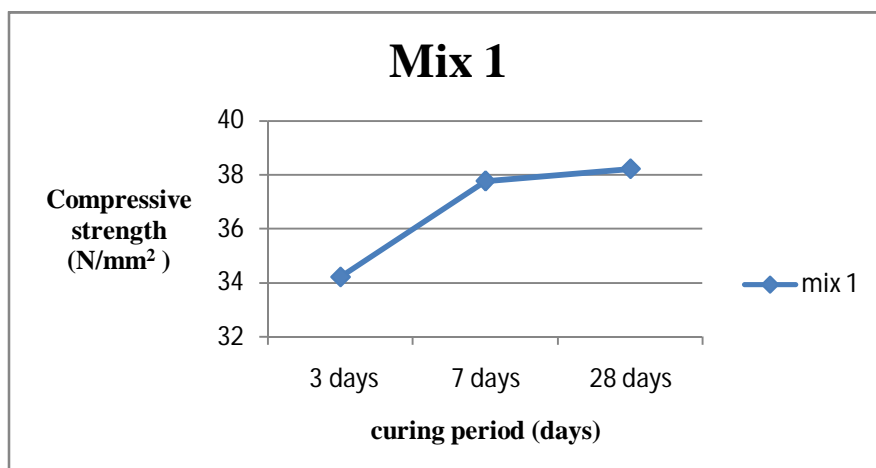
Compressive strength of the flyash and GGBS based geopolymer was determined by varying the proportion of different size of the aggregate (20mm and 12mm aggregate) at low molarity (6M) and the test results were compared.

### 5.2 Compressive strength

The compressive strengths were determined for 3 day, 7day and 28 day curing for all the 4 types of mixes.

**Table 5.1: Compressive Strength of Cubes with complete replacement of River sand by M-Sand**

Curing period (days)	Compressive strength (N/mm <sup>2</sup> )			
	Mix 1(0%)	Mix 2(20%)	Mix 3(40%)	Mix 4(60%)
<b>3 days</b>	34.22	30.66	26.66	22.22
<b>7 days</b>	37.77	34.22	29.77	24.44
<b>28 days</b>	38.22	35.11	30.66	25.33



**Figure 5.1 Effect of curing period on compressive strength of geopolymer concrete for Mix 1**



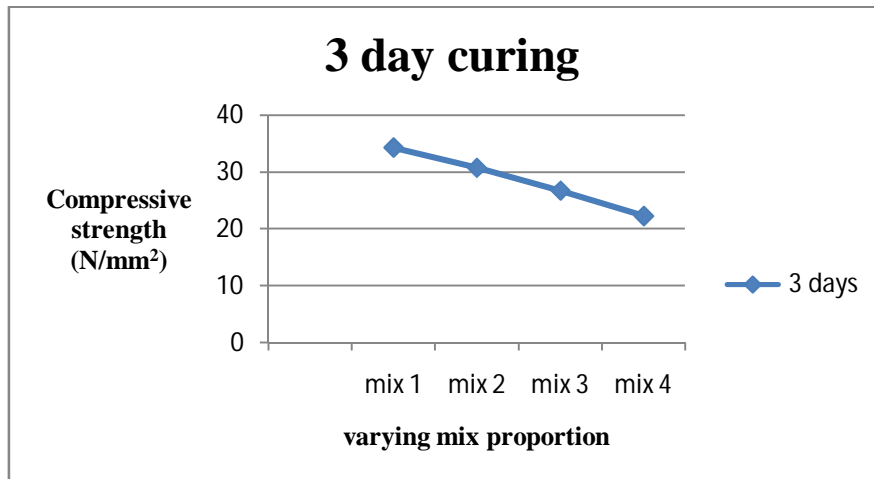


Figure 5.2 Effect of varying proportion of 20mm size aggregate on compressive strength of the geopolymer concrete

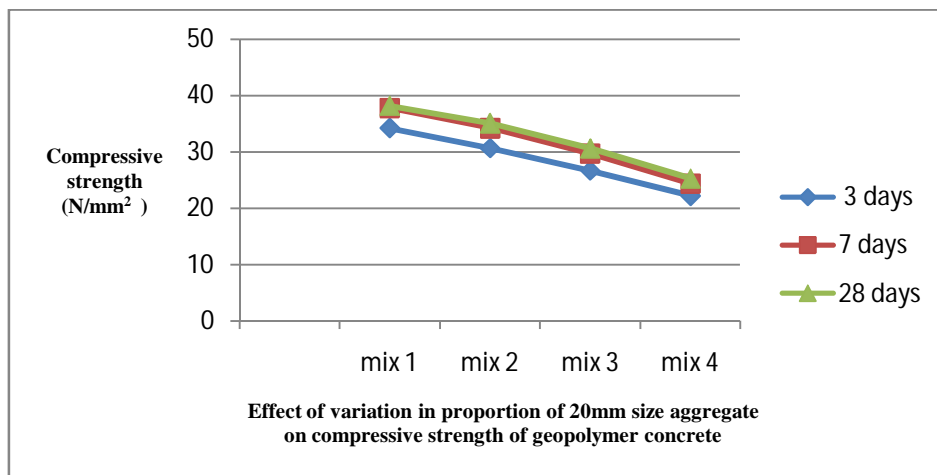


Figure 5.3 Comparisons on Influence of 20mm size aggregate on compressive strength of the geopolymer concrete at 3 day, 7 day and 28 day curing

From the figure 5.1, it is found that the compressive strength of the concrete is increased to nearly about 10% from 3 day to 7 day curing and there is no significant increase after 7 day of curing.

The figure 5.2, shows that there is a decrease in compressive strength with increase in proportion of 20mm size aggregate.

#### VI.CONCLUSION

Study on the compressive strength of geopolymer concrete made from alkali activated fly ash has been presented. Aggregate of nominal size 20 mm, 12mm and M- sand are used in the study. The alkalis used are Sodium Silicate and Sodium Hydroxide. The curing temperature is carried out at ambient temperature (30 °C). Major conclusions derived based on the present study could be summarized as follows:

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- i. Workability of the concrete decreased with increased proportion of 20mm size aggregate. This indicated that increased proportion of small sized aggregate increases the workability of the geopolymer concrete.
- ii. Production of geopolymer concrete at direct sunlight was made achieved with 70% of GGBS and 30% of flyash. The problem of heat curing is eliminated with addition of GGBS to the concrete.
- iii. There is no progressive increase in compressive strength after 3 day and 7 day curing.
- iv. Compressive strength of the concrete was increased with decreased proportion of 20mm size aggregate. This proved that, required compressive strength can be achieved with large proportion of small sized aggregate.
- v. Compressive strength achieved with complete replacement of river sand by M-Sand at 6M molarity was nominal to be used in the construction industry.
- vi. Also proper surface finish is achieved with appropriate selection of total aggregate content, ratio of fine aggregate to total aggregate and size of the aggregate.

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