Influence of Alkaline Activator Ratio on Compressive Strength of GGBS Based Geopolymer Concrete

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Abstract. Due to the ample advantages and quite a lot of applications, ‘Geopolymer concrete’ is considered to be the alternative of conventional concrete. Moreover it is an eco-friendly and pollution controlled construction materials. The prime objective of this present study is to examine the effect of different activator ratio on the compressive strength of Ground Granulated Blast Furnace Slag (GGBS) based geopolymer concrete. The alkaline solution used in this study is sodium hydroxide (NaOH) and sodium silicate (Na$_2$SiO$_3$) in the ratio of 1:2½. Cube specimens of size 100 x 100 x 100 mm are cast and cured at ambient temperature. This study results concluded that the activator ratio 0.30 performs well under compressibility studies.

1. Introduction
In many researches, the alternative for Portland cement is described as ‘Geopolymer concrete, because of its wide advantages and applications such as strength, light weight, mechanical properties, acid resistance and fire resistance [1,2]. This type of concrete is developed in 1978 by Joseph Davidovits due to the huge demand in the construction industry; the usage of cement is also increasing. In those circumstances, an enormous amount of CO$_2$ is emanated and that leads to the issues of global warning. The development of geopolymer concrete will have the solution to prevail this problem and moreover this will be a eco-friendly in nature [1]. The foremost constituents of geopolymer concrete comprises of sodium or aluminium which is the alkaline solution (in this study, combination of sodium silicate and sodium hydroxide) and thermally activated natural material [3, 4]. The setting time of geopolymer concrete is rapid when compared to conventional and other types. The geopolymer concrete is allowed under the curing of ambient temperature which intends to save the water in the normal curing [5,6]. Hence an attempt is made to study the influence of various alkaline activator ratios such as 0.3, 0.35, 0.4, 0.45 and 0.5 on the strength parameters of Ground Granulated Blast Furnace Slag (GGBS) based geopolymer concrete.

2. Materials Used
2.1 Fine aggregate
The river sand which is retained after sieving 2.36 mm sieve is used as a fine aggregate with the specific gravity of 2.80. It is confirming to zone II of IS 382 – 2016 and its fineness modulus is 3.28.

2.2 Coarse aggregate
Crushed coarse aggregate that retained in 4.75 mm is used in this study. Based on the test as per IS 383-1970, the specific gravity and fineness modulus is obtained as 2.808 and 7.05 respectively.

2.3 Ground granulated blast furnace slag (GGBS):
GGBS is the by-product obtained from the blast furnace during the process of iron manufacturing. Its
specific gravity is 2.9. The best features of GGBS are found out from the XRF analysis as referred in Figure 1 which is highly resistant to sulphate and other chemicals.

Figure 1. XRF Analysis of GGBS

2.4. Alkaline liquids
For this experimental study, sodium hydroxide solution (NaOH) and sodium silicate solution (Na$_2$SiO$_3$) are used as to prepare alkaline activator solution and it is mixed in the ratio of 1:2 ½.

2.5. Admixture
La-Hypercrete S-30 is the hyper plasticizer based on modified carboxylic ether is used as an admixture for this study.

3. Preparation of Geopolymer mix
The mix proportions for different activator ratio such as 0.3 kg/m$^3$, 0.35 kg/m$^3$, 0.4 kg/m$^3$,0.45 kg/m$^3$,0.5 kg/m$^3$ are listed in table 1.

| Activator Ratio | 0.3 (kg/m$^3$) | 0.35 (kg/m$^3$) | 0.4 (kg/m$^3$) | 0.45 (kg/m$^3$) | 0.5 (kg/m$^3$) |
|----------------|----------------|----------------|----------------|----------------|----------------|
| Sodium Silicate | 118            | 138            | 157            | 177            | 196            |
| Sodium hydroxide| 47             | 55             | 63             | 71             | 79             |
| GGBS            | 550            | 550            | 550            | 550            | 550            |
| Coarse aggregate| 1070           | 1035           | 998            | 962            | 926            |
| Fine aggregate  | 559            | 540            | 521            | 503            | 484            |
| Admixture       | 5.5            | 5.5            | 5.5            | 5.5            | 5.5            |

For the preparation of alkaline solution (combination of sodium hydroxide and sodium silicate) sodium hydroxide is required for the preparation for the concentration of 12 molarities. The required amount of NaOH pellets (as shown in figure 2) are calculated by the product of molarity and molecular weight. Therefore 480 gms of pellets are required and these calculated pellets are dissolved
in one litre of distilled water to prepare the NaOH solution (as shown in figure 3).

![Figure 2. Sodium Hydroxide pellets](image1.png)  ![Figure 3. Sodium Hydroxide Preparation](image2.png)

As per the mix ratio 1 (NaOH): 2 ½ (Na₂SiO₃), the alkaline activator solution is prepared before 24 hours of mixing process. GGBS, coarse aggregates and fine aggregates are uniformly mixed in the dry condition and care to be taken to avoid any lumps. The geopolymer concrete mix is prepared by adding activator solution and admixture solution (5.5 kg/m³) into the dry mixture and it is thoroughly mixed in the mixing machine to ensure the homogeneity as shown in figure 4 to 6.

![Figure 4. Sodium Silicate Solution](image3.png)  ![Figure 5. La Hypercrete solution](image4.png)

**Figure 6. Mix preparation of geopolymer concrete**

**4. Experimental Study**

After the preparation of geopolymer concrete mix as discussed in the section 3, the concrete is cast into the mould of cube of size 100 mm x 100 mm x 100 mm. Totally 75 cubes are cast against 3, 7, 14, 28 and 56 age of curing days for each of the activator ratios as mentioned in the Table 1. The casted specimens are allowed to cure at ambient temperature as shown in figure 7. The main objective of this study is to evaluate the compressive strength of the geopolymer concrete of various activator ratios and to arrive the optimized ratios for the better performance of the strength factor. The test is carried
out in the universal testing machine of 1000 kN capacity. The test set up is as shown in figure 8.

![Figure 7. Specimens curing at ambient temperature](image_url)

![Figure 8. Compression test set up](image_url)

5. Results and Discussions

Table 2 shows the average compressive strength test results of the geopolymer concrete for different activator ratios. From the results, it is observed that, the maximum 3 days strength is 28.3 N/mm² and the minimum strength is 13.2 N/mm² for the activator ratio 0.3 and 0.5 respectively. Similarly for 7 days, 14 days, 28 days and 56 days, the maximum strength is found in the activator ratio 0.3 and minimum is in activator ratio 0.5. It is observed that, the increase in activator ratio decline the compressive strength. Figure 9 shows the graph of compressive strength and age of curing days for different activator ratios and it is an evident that, the activator ratio is inversely proportional to the strength factor. It is also observed that, an increase in the age of curing days, the strength is also getting increased for all activator ratios as shown in figure 10. There is an increasing trend in the compressive strength of around 1.15 to 1.2 times for 56 days in comparison with 28 days for various activator ratios. It is seen that, for all activator ratios, the minimum M30 strength is achieved after 28 days age, however for activator ratio 0.3, the strength increased by 1.6 times of the estimated strength(M30) similarly for activator ratio 0.35, 0.4 and 0.45 the strength is increased by 1.39, 1.26 and 1.16 times respectively. For activator ratio 0.50, the estimated strength is almost of the observed strength.

| Activator Ratio (kg/m³) | 0.3  | 0.35 | 0.4  | 0.45 | 0.50 |
|------------------------|------|------|------|------|------|
| Age of Curing (Days)   | Average Compressive Strength (N/mm²) |
| 3                      | 28.3 | 25.23| 21.86| 18.31| 13.2 |
| 7                      | 33.93| 31.47| 27.6 | 23.76| 17.36|
| 14                     | 37.3 | 34.53| 30.9 | 27.4 | 23.43|
| 28                     | 48.27| 41.86| 37.9 | 34.96| 30.5 |
| 56                     | 58.04| 53.1 | 46   | 41.26| 35.36|

Table 2. Compressive strength test results
It is observed that, the activator ratio 0.3 polymerizes the materials (GGBS and aggregates) into the molecular chains and its networks is enhanced the binding property. This ensures the good Geopolymerization process for that concerned the activator ratio due to the formation of effective alumina-silicate gel which assures the binding property of the concrete. It is also noticed that, the 3 days strength is around to be maximum of 80% of the estimated strength M30 in 28 days which is higher than conventional concrete. This clearly aimed that, the GGBS based geopolymer concrete can be used in the places where high early strength is much required.

**6. Conclusions**

The following conclusions are arrived based on this experimental study.

(i) The effect of alkaline activator ratio is one of the primary key factors which determine the strength of the geopolymer concrete.

(ii) The activator ratio 0.3 is found as optimum, since the compressive strength is increased by 1.6 times the estimated strength M30.

(iii) For 3 days, around 80% of the estimated strength is achieved. Therefore geopolymer concrete gains an early compressive strength than conventional concrete.
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