Compressive Strength of Mortar with Alkali Activated Fly ash and Ground Granulated Blast Furnace Slag

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Abstract. The geopolymer concrete is a new technology that replace ordinary cement concrete with cement less concrete using the different industrial by-products considered as waste to the society. These materials create a hazardous environmental condition. To overcome the same, many researchers have reported replacement of these materials with cement in concrete work. These materials do not possess much binding properties. Hence, an alkaline solution is utilized to activate the same. In the present study, the compressive strength of the geopolymer mortar prepared with Class F fly ash and ground granulated blast furnace slag in different ratios are examined. It is observed that the compressive strength achieved from elevated temperature cured samples is higher than the ambient temperature cured sample. Increase in ground granulated blast furnace slag content also increases the compressive strength parameters of the geopolymer mortar sample.

1. Introduction

Geopolymer is the recent type of technique used in construction industry to develop concrete without cement content to reduce the CO₂ emission and hence protect our planet. It further conserves energy consumption in the world for future [1]. Davidovit’s study states that the annual CO₂ emission worldwide is around 0.184 tonnes and OPC includes 80% of the total. The reuse of waste recycled industrial by-products decline manufacturing process of raw materials of OPC [2-4]. The industrial by-products used for the development of geopolymer concrete should be rich in alumina-silicates like Fly ash (FA) and ground granulated blast furnace slag (GGBS) which are further activated with an alkaline solution [5].

The properties and applications of geopolymer concrete such as fire resistance, thermal insulation, and thermal shock refractories is highly appreciated in many fields including engineering process technologies [3]. To use this geopolymer technology in construction industry, the fresh and hardened properties of the mixture shall be investigated. Consistency, workability, setting times of the concrete mix, type of curing and compressive strength are the important parameters to be considered [5]. The strength of concrete mainly depends on the mortar strength which is a factor of great importance. From recent studies, it is revealed that the fly ash emits 80%–90% less greenhouse gases than that of OPC manufacturing. Similarly, the production of binder with use of GGBS reduces the greenhouse gas emission rate by 80% [6]. According to A.Z. Warid Wazien et al. [7], when the solid particles of
aluminosilicate raw materials dissolve with an alkali activator solution, polycondensation process forms a 3D network structure known as geopolymerization. Curing conditions have a major role in the strength development of geopolymer mortar/concrete. The strength parameters for geopolymer concrete are much higher as compared to ordinary conventional concrete [8]. Geopolymer concrete also have good flexural [9] as well as shear [10] strength.

In the present work, geopolymer mortars are prepared with Fly ash and GGBS as binders and Sodium Hydroxide and Sodium Silicate as alkali activator solution along with some extra water for better workability. The samples are well compacted and kept for curing in both ambient and elevated temperatures for 7 days and tested for compressive strength under Universal Testing Machine (UTM). A comparative explanation between the strength parameters of the samples at both temperature curing conditions is presented.

2. Materials

Class F Fly ash and GGBS, used as the raw materials, are collected from Jindal Steel and Power Limited (JSPL), Jajpur, Odisha and Mideast Integrated Steel Limited (mesco), Jajpur, Odisha respectively. Table 1 shows the characterization of the Fly ash and GGBS carried out with help of X-ray Fluorescence test (XRF). The sand of Daya river is used as fine aggregates for the manufacturing of geopolymer mortar. The grading confirms to Zone II as per IS 383. The specific gravity and fineness modulus of the fine aggregates are recorded as 2.62 and 2.6% respectively.

Alkali Activator solution is prepared with NaOH and Na₂SiO₃. Sodium hydroxide of 14 M molarity is prepared by mixing 560 grams of Caustic Soda pellets in one litre of total solution and stirring continuously for two minutes and slowly mixing Sodium Silicate solution (Water Glass) into it. The alkaline solution is kept for 24 hrs. After which it is suitable for use. Hence the solution is needed to be prepared a day before experiment. It gives best results when used hot.

| Table 1. Chemical composition of Fly ash and GGBS in XRF test ((in percentage)) |
|-----------------------------------------------|
| Al₂O₃  SiO₂  P₂O₅  Cl  K₂O  CaO  TiO₂  V₂O₅  CrO₃  MnO  Fe₂O₃  SO₃ |
| Fly ash 28.80  59.48  0.95  0.11  1.78  1.66  2.04  429.6  259.0  409.5  4.78  - |
| GGBS 18.92  29.58  -  0.14  0.91  45.71  1.36  92.1  29.9  0.28  0.97  1.71 |

3. Experimentation and Results

Geopolymer mortar samples are prepared in different ratios of binders i.e. Class F Fly ash and GGBS. The alkaline solution-to-binder ratio is considered as 0.25 and addition water-to-binder ratio is taken as 0.2. The mix proportions for the geopolymer mortar are shown in Table 2.

| Table 2. Mix proportions (kg/m³) |
|---------------------------------|
| Samples  | Fly ash  | GGBS  | Fine Aggregates  | NaOH  | Na₂SiO₃  | AAR  | Extra Water |
|----------|----------|-------|------------------|-------|----------|------|-------------|
| M1       | 580      | -     | 1740             | 41    | 104      | 145  | 116         |
| M2       | 551      | 29    | 1740             | 41    | 104      | 145  | 116         |
| M3       | 522      | 58    | 1740             | 41    | 104      | 145  | 116         |
| M4       | 493      | 87    | 1740             | 41    | 104      | 145  | 116         |
| M5       | 464      | 116   | 1740             | 41    | 104      | 145  | 116         |
| M6       | 435      | 145   | 1740             | 41    | 104      | 145  | 116         |
| M7       | 406      | 174   | 1740             | 41    | 104      | 145  | 116         |
| M8       | 377      | 203   | 1740             | 41    | 104      | 145  | 116         |
| M9       | 348      | 232   | 1740             | 41    | 104      | 145  | 116         |
| M10      | 319      | 261   | 1740             | 41    | 104      | 145  | 116         |
| M11      | 290      | 290   | 1740             | 41    | 104      | 145  | 116         |

The Fly ash and GGBS based geopolymer mortar samples are prepared with 5%, 10%, 15%, 20%,...
25%, 30%, 35%, 40%, 45%, 50% GGBS content. Six cubes, each of dimension 70.6 mm x 70.6 mm x 70.6 mm, are casted for 7 days’ compressive strength of mortar. Out of these cubes, three set of samples are taken for ambient temperature curing and other three set of samples are used for oven curing. The ratio of binder-to-sand is kept 1: 3. For each sample, 200 gm binder and 600 gm of sand is taken as per Indian Standards. All the samples are well compacted and finished in fresh state.

Before preparing the geopolymer mortar mix, the moulds are properly cleaned and tightened. After cleaning, the moulds are well greased to achieve smooth demoulding. In each and every mould the freshly prepared mix is filled in three layers of equal depths and in each layer 25 blows of tamping rod are provided for compaction of the sample. The top surface of the sample is smoothened with help of a trowel removing excess mixture. After setting of the samples, they are demoulded and cured for 7 days.

![Figure 1. (a) Cubes after casting, (b) Cubes kept for ambient curing, (c) Cubes kept in Oven for elevated temperature curing](image)

The samples once set are demoulded and divided for different curing process. Three of the samples are kept at room temperature curing (ambient curing) and other three samples are kept in oven at 112 °C for 24 hrs and then at room temperature for the rest of the period. Figure 1 shows the before and after curing samples of geopolymer mortar.

### 3.1. Consistency Test

The procedure considered to find the normal consistency, compressive strength of geopolymer is similar like cement. In these tests, cement is replaced by fly ash and GGBFS. The geopolymer mortar in fresh state is tested in Vicat apparatus and the standard consistency is found in the range of 30-32 percentage.

### 3.2. Compressive Strength Test

The compressive strength test is carried out for geopolymer mortar with the standard cube of size 70.6mm x 70.6mm x 70.6mm. For both ambient and heat curing samples, 7 days compressive strength is found in CTM and recorded. Table 3 shows compressive strength of 11 trial mix ratios at 7 days of curing.

The compressive strength of the Fly ash-GGBS ratio 50:50, cured in elevated temperature condition, is recorded as the highest i.e. 64.325 MPa and the lowest compressive strength i.e., 27.349 MPa is observed with 100% Fly ash geopolymer mortar sample cured in ambient temperature. Figure 2 represents the compressive strength of different ratios after 7 days curing.

The compressive strength of ambient temperature curing is observed to be less than that of oven curing. The change in ratio of Fly ash and GGBS has a great effect over the compressive strength. GGBS plays an important role in strength gain in geopolymer mortar. Increase in GGBS content improves the strength of the mortar. This shows that the compressive strength of the geopolymer mortar varies with the type and quantity of binder used.
Table 3. Compressive strength (MPa)

| Test samples | Elevated Temperature Curing | Ambient Temperature Curing |
|--------------|-----------------------------|----------------------------|
| M1           | 11.682                      | 7.247                      |
| M2           | 13.450                      | 8.756                      |
| M3           | 14.235                      | 9.237                      |
| M4           | 16.862                      | 11.854                     |
| M5           | 19.275                      | 13.143                     |
| M6           | 26.423                      | 15.364                     |
| M7           | 31.918                      | 17.928                     |
| M8           | 39.254                      | 19.864                     |
| M9           | 48.487                      | 22.680                     |
| M10          | 57.873                      | 25.483                     |
| M11          | 64.325                      | 27.349                     |

Figure 2. Compressive strength of geopolymer mortar after 7 days

Figure 3. Compressive strength of geopolymer mortar at elevated temperature with variation of Fly ash and GGBFS content
Figure 4. Compressive strength of geopolymer mortar at elevated temperature with variation of Fly ash and GGBFS content

4. Conclusions
This paper has presented the compressive strength of geopolymer mortar with different ratios of Fly ash and GGBS as binder material along with river sand as fine aggregate. An alkaline solution of NaOH and Na$_2$SiO$_3$ is considered with constant ratio and concentration. The following conclusions are made from this study:

- The strength achieved for oven cured mortar sample is higher as compared to ambient cured geopolymer mortar sample.
- With increase in the percentage of GGBS in the geopolymer mix, the compressive strength increases.
- Fly ash based geopolymer mortar shows less compressive strength compared to the samples with GGBS replacement.

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