Durability Aspects of Geo-Polymer Mortar Using Single Alkaline Activator Solution

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Abstract. The present study mainly focuses on durability aspects of combination of fly Ash and GGBS based geo-polymer mortar were investigated by immersing the mortar cubes in sea water and against 5% sulphuric acid attack. To carry out the experimentation a single alkaline activator solution of sodium silicate (Na₂SiO₃) was used to produce geo-polymer mortar specimens. In this, varied parameters are mix proportion of fly ash and GGBS and binder (fly ash + GGBS) to fine aggregate selected as 1:1 and 1:3. Similarly alkaline to binder ratio are 0.45and 0.60 respectively. Casted specimens of size 100mmx100mmx100mm and tested for 7 days and 28 days and cured under ambient temperature. In this experimentation varied mix proportions are (100 % FA-0 % GGBS, 75 % FA-25 % GGBS, 50 % FA-50% GGBS, 25 % FA-75 % GGBS, and 0% FA-100 % GGBS). The mixes with higher GGBS content shows greater mass loss and strength degradation when the cubes were immersed in sulphuric acid solution. The obtained results shows that the immersed specimens in sea water shows very less mass loss and strength loss when compared with specimens immersed in sulphuric acid solution.

Keywords: Alkaline activator; Compressive Strength; outdoor curing; Geo-polymerization, Geo-polymer Mortar.

1. Introduction
In the present scenario concrete is the primary material towards construction industry. It is happening mainly due to rapid increase in infrastructure and urban development over the globe. In this aspect cement is plays vital role to act as a binder material. But there are several problems are associated with production of cement. In this mainly it requires large amount of natural resources and energy consumption also. In addition to this, it also leads to increase in carbon footprint on the planet [1]. To avoid this a development of an eco-friendly and sustainable materials is essential. These days inorganic materials are being used to replace the cement consumption in the construction industry. Especially fly ash, GGBS and metakoalin etc. are using for producing inorganic based concrete [2]. These materials are available very scantily and also overcome the landfill of these by-products.
Davidovits created the Geo-polymer binder to identify an alternative cementitious material with ceramic-like characteristics [3]. Geo-polymer concrete is a step taken towards sustainable development. Geo polymer concrete not only reduces greenhouse gas emission but also enhances the mechanical properties. Geo polymer concrete is made with material rich in silica and aluminium and Fly ash and GGBS [4]. Fly ash and GGBS blended geo-polymer concrete attained mechanical properties at room temperature [5-7]. The compressive strength and mass of the specimen are affected by the curing temperature and time [19].

Recently the study conducted by Rao and Rao [8] highlighted substitute of combination of fly ash & GGBS with different molarities of alkali solution with SS/SH ratio 2.5 and he concluded that the alkali activation of these binder based concrete of final setting time is decreased and similarly compressive strength is increased. Durability of concrete primarily depends upon its permeability characteristics. Past studies on thermal resistance of geopolymer concrete to acid environment is revealed that geopolymer concrete has good resistance when it is expose to aggressive environments [9-11]. Most of the authors investigated on the durability aspects of geopolymer concrete by using slag (GGBS) or fly ash and GGBS combination which are having good performance than the Portland cement [12-13]. Rostami [14-15] stated that activated fly ash which can performed good resistance to acids over the OPC based concrete. According to [16-18], alkali activation via NaOH and Na₂SiO₃ has a significant impact on the reactive substances and characteristics of geopolymer concrete. The aforesaid studies showed the effect of acids on GPC mortar cubes with single activator solution. However, the present study conducted on altering the GGBS and fly ash with different combination by using single activator solution.

2. Experimental Programme:

In this experimental program, geo-polymer mortars of ratio 1:1 and 1:3 and alkaline to binder ratio of 0.45 and 0.60 respectively were considered

2.1 Materials

2.1.1 Fly Ash and GGBS

Class F fly ash collected from NTPC Ramagundam, Telangana India and containing a specific gravity of 2.17. GGBS with a specific gravity of 2.9 is brought from vizag cements Pvt Ltd, A.P, India.

| Chemical Composition | Fly ash | GGBS |
|----------------------|---------|------|
| SiO₂                 | 60.10   | 34.05|
| Al₂O₃                | 26.52   | 20.00|
| Fe₂O₃                | 4.24    | 0.78 |
| SO₃                  | 0.34    | 0.90 |
| CaO                  | 4.00    | 32.50|
| MgO                  | 1.24    | 7.88 |
| Na₂O                 | 0.23    | NIL  |
| LOI                  | 0.87    | NIL  |
2.1.2 Alkaline liquid

In this experimentation, Geo activator (sodium silicate) (Na$_2$SiO$_3$) is used as alkaline activator solution. Geo activator solution is consisting of silica modulus SiO$_2$:Na$_2$O=2.92:1 with 28.9% SiO$_2$ and 9.92% Na$_2$O.

![Sodium Silicate Solution (Na$_2$SiO$_3$)](image)

2.1.3 Fine Aggregate

Natural river sand, which is available locally, is utilized and has a density of 1.43g/cc, which is Zone-2 compliant. According to IS: 383-1970 [20].

2.2 Preparation of Geo-polymer mortar

Combination of Fly ash and GGBS are mixed together until they are homogeneous. Thereafter, required amount of fine aggregate is added and it is allowed to mix for 2 minutes in an electrically operated mixer. Geo activator is added in to the same mixture and the process is continued for another 3 minutes. This fresh mix of geo-polymer mortar filled into the cubes of 100mm x 100mm x100mm size by 3 layers with proper compaction and vibration to avoid the air voids in the mortar mix. Once mixing is over then these specimens were de molded after 24 hours of casting time and these cured at outdoor curing for 28 days.

2.3 Mix proportion of geo-polymer mortar

Geo-polymer mortar of ratio 1:1 with alkaline to binder ratio of 0.45 is taken in the mix. And in each ratio consisting of fly ash to GGBS proportions are 100 % FA and 0 % GGBS, 75 % FA and 25 % GGBS, 50 % FA and 50 % GGBS, 25 % FA and 75 % GGBS and 0 % FA and 100 % GGBS were used. The density of geo-polymer mortar varied from 2200 kg/m$^3$ to 2400kg/m$^3$.

| Proportion of binders | Fly ash kg/m$^3$ | GGBS kg/m$^3$ | Fine aggregate kg/m$^3$ | Alkaline liquid kg/m$^3$ |
|-----------------------|-----------------|---------------|-------------------------|-------------------------|
| M$_1$F$_{100}$G$_0$   | 1078            | 0             | 1078                    | 485                     |
| M$_1$F$_{75}$G$_{25}$ | 808.5           | 269.5         | 1078                    | 485                     |
| M$_1$F$_{50}$G$_{50}$ | 539             | 539           | 1078                    | 485                     |
| M$_1$F$_{25}$G$_{75}$ | 269.5           | 808.5         | 1078                    | 485                     |
| M$_1$F$_0$G$_{100}$  | 0               | 1078          | 1078                    | 485                     |
Table 3. Mix proportion of geo-polymer mortar (1:3) alkaline to binder ration 0.60

| Proportion of binders | Fly ash kg/m³ | GGBS kg/m³ | Fine aggregate kg/m³ | Alkaline liquid kg/m³ |
|----------------------|--------------|------------|----------------------|----------------------|
| M₁F₁₀₀G₀           | 574          | 0          | 1722                 | 344                  |
| M₂F₇₅G₂₅           | 430.5        | 143.5      | 1722                 | 344                  |
| M₃F₅₀G₅₀           | 287          | 287        | 1722                 | 344                  |
| M₄F₂₅G₇₅           | 143.5        | 430.5      | 1722                 | 344                  |
| M₅F₀G₁₀₀           | 0            | 574        | 1722                 | 344                  |

3. Test results and Discussion

3.1 Visual observations

A visual inspection of the geo-polymer mortar cubes were shown in figure 2 after immersion of 5% sulphuric acid solution for 28 days. All the casted specimens were immersed and among those mixes the results indicate that severe surface deterioration was observed for combination of 0FA:100GGBS. As GGBS content increases the surface deterioration also increases for the mixes. The expansion of geo-polymer mortar cubes was observed. In addition, severe white deposits were observed on the specimen surface.

![Visual observation of cubes after sulphuric acid attack](image)

Figure 2. Visual observation of cubes after sulphuric acid attack

3.2 Performance of Geo-Polymer Mortar Cubes of Ratio 1:1 and alkaline to binder ratio of 0.45

Figure 3 indicates that the geopolymer mortar cubes of compressive strength for both 7 and 28 days. As per the results it is noticed that with increase of GGBS content in the mix can results in better increase in the strength of geopolymer mortar. In addition to this, specimens at 7 days age of curing shows significant increase compressive strength is observed. This is attributed may be due to the high amount of soluble calcium content is present when GGBS content is increase in the mixture, which can accelerate the strength of geopolymer mortar.
Figure 3: Compressive strength of GPC with different combinations of binder

**Acid mass loss Factor (AMLF)**

Figure 4: Difference in mass after seawater immersion
**Acid strength loss Factor (ASLF):**

![Acid Strength Loss Factor (seawater) (1:1)](image)

**Figure 5.** Difference in strength after seawater immersion

Figures 4 and 5 shows AMLF and ASLF of geopolymer mortar cubes immersed for 7 and 28 days. The mass loss factor and strength loss factor for geopolymer mortar cubes increased whereas increase in GGBS content in mix. This increase may be due to chloride ions present in seawater reacts with calcium content in binder and reduces the strength. As we increased GGBS content calcium percentage will be increased and the chlorides in seawater reacts with it and the strength reduction takes place.

**Acid Mass Loss Factor (AMLF):**

![Acid mass loss factor (H2SO4) (1:1)](image)

**Figure 6.** Difference in mass of the specimens after sulphuric acid immersion
Acid Strength Loss Factor (ASLF):

![Graph showing Acid Strength Loss Factor (ASLF)](image)

**Figure 7**: Difference in strength of the specimens after sulphuric acid immersion

Figures 6 and 7 show the AMLF and ASLF of all geopolymer mortar mixes. It is noticed that when there is an increase in exposure period, then compressive strength decreases gradually. From these figures, it can be seen that the acid strength loss factor is more for the mix prepared with (FA0:GGBS100) i.e., 48.2% and it is observed less for mix FA100:GGBS0 i.e., 13.10% which shows a negative impact when the mixes were prepared with higher GGBS contents. At higher GGBS content, loss of strength is also higher and it may be because of the reaction between sulphuric acid (H$_2$SO$_4$) and calcium, which is available more in GGBS. In the presence of water, gypsum (CaSO$_4$, 2H$_2$O) is formed, and the pH of the mixture is reduced and the weight of specimens before acid attack is less compared to after immersion in 5% sulphuric acid. And weight of these specimens increased as the GGBS content increased, i.e., low for Mix1 0.51% and more for Mix5 3.01%. As the GGBS content increases, the surface deterioration of the specimens also increased. The surface was deteriorated observed after 28 days, up to a depth of 10mm.

![Graph showing Comparison of ASLF between Seawater and Sulphuric Acid](image)

**Figure 8**: Comparison of strength loss factor of GPM cubes immersed in both seawater and Sulphuric Acid Solution
Figure 8 shows comparison of strength loss factor is observed for the geopolymer specimens and which are subjected to seawater and H$_2$SO$_4$ solution for 28 days. It is also indicated that the strength loss factor of geopolymer specimens is less in seawater when compared to sulphuric acid solution. Where the specimens immersed under sulphuric acid were shown severe effect and which results in decrease in strength of geopolymer specimens. This may be happened due to the reaction between the sulphuric acid (H$_2$SO$_4$) and calcium present in GGBS so that formation of reaction product gypsum and this is responsible to cause to internal voids and thereby more strength loss than the specimens when exposed to seawater environment.

3.3 Performance of Geo-polymer mortar of ratio 1:3 and alkaline/binder=0.60.

![Figure 9](image-url)

**Figure 9.** Compressive strength GPM of 1:3 ratios before seawater and Sulphuric Acid attack

Figure 9 shows the compressive strength of geo-polymer mortar for different mixes under varying curing periods (7 and 28 days). From the results it is shown that 100FA:0GGBS has gained poor strength when compared to all mixes. For 100FA:0GGBS 11.28 MPa was obtained for the mix prepared with 100FA:0GGBS after 28 days of outdoor curing whereas mix prepared with 100GGBS:0FA gained 91.25MPa. The increase in the strength may be due to faster polymerisation process between the ge-activator and the source material (Fly and GGBS). Based on the results it is observed that the GPC mixes prepared with higher GGBS contents have attained higher compressive strength.

**AMLF:**

Figures 10 and 11 shows the Strength Loss Factor and Mass Loss Factor of GPM cubes after seawater immersion. The strength loss factor increases as the fly ash content decreases. The strength loss factor was observed to be low 0.18% for the mix of (FA100:GGBS0) because of more amount of fly ash shows the better resistance among all the mixes whereas the strength loss factor is more for the mix (FA0:GGBS100) and the value is about 15.41%. Lower the amount of GGBS content shows better resistance among the mixes.
Figure 10. Change in mass of specimen after seawater immersion.

Figure 11: Difference in strength of specimen after seawater immersion.
Figure 12. Difference in mass of specimen after sulphuric acid immersion.

Figure 13. Difference in strength of specimen after sulphuric acid immersion.

Figure 12 and 13 shows ASLF and AMLF. In this case the strength decreases gradually with increases in the exposure period of specimens. ASLF is more for Mix5 i.e. 66.29% and less for Mix1 8.24%. The strength loss factor increases as the GGBS content increases. This may be due to decrease in pH value of concrete when reaction between sulphuric acid (H₂SO₄) and gypsum content (CaSO₄·2H₂O). And the weights of specimens before acid attack is less compared to after immersion in 5% sulphuric acid. And the percentage of weight gain is more for Mix5 (FA0:GGBS100) 2.57% and less for Mix1 (FA100:GGBS0) 0.48%. As the GGBS content increases the percentage of weight gain is also increased.
and the surface deterioration of specimen also increased. It is observed that a surface was deteriorated up to a depth of 10mm.

![Comparison of GPM for both Sea water and Sulphuric Acid](image)

**Figure 14.** comparison of strength of GPM for both seawater and sulphuric acid

*Fig 14* shows that the comparison of Strength Loss Factor between seawater environment and sulphuric acid attack solution. The strength loss factor of geopolymer cube specimens immersed in sulphuric acid solution increases as GGBS content increases in the mix. This may be happened due to due to the reaction takes place between sulfate ions and calcium which is present more amounts in the mix. The calcium present in the mix reacts with sulphuric acid solution and forms gypsum. The formation of the gypsum may be reason for decrease in the strength of the specimens. Another observation is that where the mixes with more amount of fly ash content in the mix shows the better resistance in both the environments.

4. **Conclusions**
   1. At higher GGBS content in the mixes shows that compressive strength of geopolymer mortar cubes increased in both the ratios (1:1 and 1:3).
   2. Geo-polymer mortar specimens show excellent resistance even after immersed in sea water there is no much decrease in the strength and moss of the specimens.
   3. It is also concluded that the strength loss factor and mass loss factor of geopolymer mortar cubes to be increased with increase in GGBS content for both the ratios (1:1 and 1:3).
   4. Exposure to sulphuric acid solution damages the surface of mortar specimens, as age increased the surface deterioration also increased.
   5. Compare to both ratios 1:3 showed much effect than 1:1 on geopolymer mortar specimens when subjected to seawater environment.
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