PERFORMANCE OF FLY ASH AND GGBS BASED GEOPOLYMER CONCRETE USING SINGLE ALKALINE ACTIVATOR SOLUTION AND ITS COST ANALYSIS

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Abstract

Concrete is the most durable, versatile and reliable building material in the world. Next to water, concrete is the most used material. Ordinary Portland cement production accounts for 5-7% of total greenhouse gas emissions. It also consumes a lot of energy. Today, Geopolymer concrete (GPC) has become a more sustainable concrete compared to conventional concrete. This research work focuses on the performance of Fly Ash and GGBS based geopolymer concrete cured in outdoor conditions using a single alkaline activator solution (Geo activator). The variations of Fly Ash and GGBS were (FA100-GGBS0; FA90-GGBS10; FA70-GGBS30; FA50-GGBS50). In this study, only the Geo activator is used to activate Fly Ash and GGBS in the mixtures. Geo polymer concrete of size 100 mm x 100 mm x 100 mm was used in this research work to measure compressive strength at different ages of 7 days and 28 days. The results reveal that the increase in the proportion of GGBS content in the mix increases compression strength of concrete. The cost analysis was also carried for geopolymer concrete, compared with conventional concrete and the results reveals that for the lower grades, the cost will be the same as for conventional concrete and for the higher grades, the use of geo polymer concrete can reduce the cost of construction up to some extent.

Keywords: Geopolymer concrete, Fly Ash, GGBS, Compressive Strength, Geo-activator and Cost Analysis:

1. INTRODUCTION

Concrete is the most widely used building material in the world after water, and Portland cement is the main ingredient used in concrete. Cement production releases large amounts of carbon dioxide (CO₂) into the atmosphere that contribute significantly to greenhouse gas emissions. It is estimated that a ton of carbon dioxide is released into the atmosphere when a ton of OPC is produced. World cement production per year is 2.6 billion tons. Cement production requires a large amount of limestone that is now rapidly depleting. On the other hand, fly ash is a by-product produced by the combustion of coal. And a large amount of fly ash is deposited in landfills that affect groundwater. Therefore, we can use Fly Ash as a pozzolanic material to replace cement and we can reduce waste and we can also improve concrete performance. Therefore, products such as fly ash and GGBS need to develop alternatives to existing cements that use the cement properties of the industry. GGBS is a byproduct of steel making process plants. Availability of Fly Ash and GGBS provide you with more opportunities to use more products worldwide. Davidovits developed a binder called Geo-polymer in 1978 to describe alternative cementitious materials. Geopolymer concrete is alternative to conventional concrete where cement is completely replaced by Fly Ash, GGBS, Metakolin, etc. Which are rich in silica and alumina and an ecological concrete that does not emit greenhouse gases during the polymerization process. And the reaction between materials a binding property can be achieved through the use of alkaline solutions. The geo-polymers are made of raw materials with silicon (Si) and aluminum (Al) content, so the cement can be completely replaced with fly ash and GGBS(GGBS).
2. LITERATURE REVIEW

Davidovits [1999] proposed that binders could be produced by a polymer reaction of alkaline liquids with silicon and aluminum in materials of geological origin or by-products such as fly ash and rice husk ashes. He called these binders as geopolymers. Wang SD et al. [1995] reported that NaOH and Na₂SiO₃ are commonly used in combination to form an alkaline solution. This solution activates silica and alumina in fly ash to form alumina silicate hydrate and forms calcium silicate hydrate (C-S-H) by reacting with calcium in GGBS. Pinto, A [2004] reported that the molar ratio of Na₂SiO₃ / NaOH is a factor that affects the properties of geopolymers. After several investigations, he suggested that the 2.5 ratio provides maximum compressive strength with a constant binder content.

Mallikarjuna Rao et al. [2015] studied source material of geopolymers (fly ash and GGBS) and alkaline activator consisting of sodium metasilicate and sodium hydroxide of different molarities (8, 12, 16M). The ratio of Metasilicate sodium to sodium hydroxide considered in this study is 2.5. From the results, it has been indicated that the combination of fly ash and GGBS results in a reduced final setting time and greater compressive strength. B. Rajini [2014] To study the effect of fly ash and GGBS on the mechanical properties of GPC with different proportions from 0 to 100%. Sodium silicate and sodium hydroxide are used as alkaline activators. Study of compressive strength, tensile strength divided for 7, 28, 56 and 90 days and at room temperature. J. Thaarrini [2016] studied the cost of production of 1m³ of OPC and GPC. Calculated based on the market prices. Cost of OPC and GPC is marginally same for lower grades. And the cost of OPC is higher than the GPC for higher grades. From this paper the cost of GPC is 1.7% higher than OPC for small grades M30. And the cost of GPC is 11% lower than the OPC for higher grade like M50.

3. EXPERIMENTAL STUDY

The present research paper aim is to determine the compressive strength of Fly Ash and GGBS based geo-polymer concrete using single alkaline activator solution and cured at ambient temperature and its cost analysis.

3.1 Materials

Fly ash: fly ash is a byproduct of coal obtained from the La Mangada Thermal Power Plant (NTPC). In this experiment we use class F flyash as the source material.

GGBS: The crushed blast furnace slag is a byproduct of the steel processing plant that replaces the cement obtained from Toshali Cement Pvt. Ltd Bayyavaram India.

| Chemical Composition | Fly ash | GGBS |
|----------------------|---------|------|
| SiO₂                 | 60.11   | 34.06|
| Al₂O₃                | 26.53   | 20   |
| Fe₂O₃                | 4.25    | 0.8  |
| SO₃                  | 0.35    | 0.9  |
| CaO                  | 4.00    | 32.6 |
| MgO                  | 1.25    | 7.89 |
| Na₂O                 | 0.22    | NIL  |
| LOI                  | 0.88    | NIL  |

The fine aggregates: used according to 383: 1970 according to Zone II are obtained from the sand of
nearby rivers.
Coarse aggregate: The substance that remains above the aggregate size of 4.75 mm in the BIS sample is called coarse aggregate. We use locally available coarse aggregate with a maximum size of 16 mm. In this experiment, aggregates of various sizes were used.

16 mm - 12.5 mm - 30%
12.5 mm - 10 mm - 40%
10 mm - 4.75 mm - 30%

Geo activator: In this experiment, only a single alkaline liquid was used, namely geo activator, and no sodium hydroxide and sodium silicates were used. Geo activator Solutions of silica modulus SiO$_2$:Na$_2$O (M$_r$) = 2.92:1 with 28.98% SiO$_2$, 9.92% Na$_2$O by weight, which was produced from KIRAN GLOBAL Ltd, Chennai India.
Super plasticizer: to improve the workability of fresh concrete water, the super plasticizer based on naphthalene was reduced and added to the mixture.

3.2 Mix Design
In this experiment, we designed four different mix proportions for conventional concrete: Mix A (20MPa), Mix B (30MPa), Mix C (40MPa) and Mix D (50MPa) and the same mix proportions were used for geo-polymers concrete. For Mix A the ratio was set to 1: 1.5: 3: 0.50. And of Mix B 1: 1.51: 2.52: 0.43, Mix C 1: 2.56: 3.26: 0.40, Mix D 1: 1.09: 3.52: 0.36. In geopolymer concrete, the mix design is the same as conventional concrete, where only a single alkaline solution was used. And the cement is completely replaced by fly ash and GGBS in four different mixtures at different proportions. And water is completely replaced by geo-activator. The alkali / binder ratio is equal to the water / cement ratio. The amount of water we use in conventional concrete is the same amount of geoactivator solution used in geopolymer concrete.

**Table 2: Mix proportions of conventional concrete**

| Mix no | Binder (kg/m$^3$) | Alkaline/binder | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Water (kg/m$^3$) | SP (kg/m$^3$) |
|--------|-------------------|-----------------|--------------------------|----------------------------|------------------|---------------|
| MIX A  | 396               | 0.50            | 608                      | 1216                       | 192              | NIl           |
| MIX B  | 438               | 0.43            | 660                      | 1104                       | 190              | NIl           |
| MIX C  | 350               | 0.40            | 896                      | 1140                       | 140              | 2.64          |
| MIX D  | 427               | 0.36            | 466                      | 1504                       | 130              | 3.42          |

**Table 3: Mix proportions of Geo-polymer concrete**

| Mix no | Binder (kg/m$^3$) | FA:GGBS | Alkaline/binder | Fine aggregate (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Alkaline liquid (kg/m$^3$) | SP (kg/m$^3$) |
|--------|-------------------|---------|-----------------|--------------------------|----------------------------|---------------------------|---------------|
| Mix A  | 396               | 100:0   | 0.50            | 608                      | 1216                       | 198                       | NIl           |
| Mix B  | 438               | 90:10   | 0.43            | 660                      | 1104                       | 190                       | NIl           |
| Mix C  | 350               | 70:30   | 0.40            | 896                      | 1140                       | 140                       | 2.64          |
| Mix d  | 427               | 50:50   | 0.36            | 466                      | 1504                       | 130                       | 3.42          |
4. RESULTS AND DISCUSSIONS

Figure 1: compressive strength of conventional concrete between 7 and 28 days.

Figure 1 shows the compressive strength of conventional concrete at 7 and 28 days. Mix A is of 20MPa, Mix B is 30MPa, Mix C is 40MPa and Mix D is 50Mpa. Strength after 28 days obtained as 22.41, 35.62, 47.5, and 57.39MPa. With increase in the cement content for different grades of concrete the strength was also improved. The increase in the strength is due to formation of the calcium silicate hydrate gel. The gain of strength of concrete improved with increase in the age of the concrete for different grades. The gain of the strength can be observed from figure 1

Figure 2: compressive strength of GPC between 7 and 28 days
From figure 2, we can observe the compressive strength of geopolymer concrete cubes tested for 7 and 28 days. The compressive strength of GPC mix A shows the lesser strength compared with other mixes. The strength of geopolymer mainly depends up on the fly and GGBS content in the mixes. For mix A only fly ash content was taken as the source material it shows very less strength due to slow polymerization process. Whereas for other mixes the strength gain for 7 days is high and up to 28 days it was continued. The reason for more strength gain is due to faster polymerization process and dissolution of the GGBS particles were high and the form of the C-A-S-H gel is more for Mix B, Mix C and Mix D.

**figure 3:** comparison of 7 days compressive strength between Conventional Concrete and GPC

From figure 3, we compared the strength between 7 days for conventional concrete and Geopolymer concrete. The strength of GPC was less compared with conventional concrete. In conventional concrete the strength gain is due to the formation of C-S-H gel whereas for the geopolymer concrete the strength of geopolymer specimens was due to polymerization process and it was the slow process and the strength gain was very less compared with conventional concrete specimens. The polymerization process was also depends up on the alkaline activator and particle size distribution of the source materials.
Figure 4: Comparison of 28 days compressive strength between conventional Concrete and GPC

From Figure 4 we can see the compressive strength for 28 days between the conventional concrete and the geopolymer concrete. The strength gain for 28 days is less geopolymer concrete specimens compared with conventional concrete specimens. For the same mix proportions, the strength of the conventional concrete specimens and geopolymer concrete specimens were compared at 28 days. The same conventional strength can be achieved without cement content. In our study we tried to replace the total cement content with fly ash and GGBS and water with the geo-activator solution. The strength was almost similar at 28 days curing period and hence for in-situ conditions also this concrete will be most suitable. In previous studies the geopolymer concrete specimens were prepared with sodium silicate and sodium hydroxide solution and cured under oven curing at 60⁰ for 24 hours, these mixes were not suitable at in-situ conditions and they were quite costlier because of the source materials and activator solutions. Now in the present study the mixes were prepared with single activator solution and the cost comparison was also done, these mixes were helpful to cast geopolymer concrete under in-situ condition with required strength.

Table 4: shows the binder content, alkaline/binder ratio and compressive strength of OPC and GPC.

| Mix NO | Binder kg/m³ | FA: GGBS | Alkaline/binder | Conventional concrete (MPa) | Geo-polymer concrete (MPa) |
|--------|--------------|----------|-----------------|----------------------------|----------------------------|
| Mix A  | 396          | 100:0    | 0.50            | 22.41                      | 20.02                      |
| Mix B  | 438          | 90:10    | 0.43            | 35.62                      | 31.59                      |
| Mix C  | 350          | 70:30    | 0.40            | 47.50                      | 44.73                      |
| Mix D  | 427          | 50:50    | 0.36            | 57.39                      | 57.20                      |

4.1 Cost Analysis

The components of GPC and OPC and their cost are shown in Table 5. Buy bulk materials from suppliers, you can get them at low cost.

Table 5: Ingredient Materials and their cost

| S.NO | MATERIALS | Rate in Rs./per |
|------|-----------|-----------------|
| 1    | Cement    | 330/50kg        |
| 2    | Fly ash   | 800/MT          |
| 3    | GGBS      | 1.5/kg          |
| 4    | Fine aggregate | 1000/MT    |
| 5    | Coarse aggregate | 700/MT     |
| 6    | Sodium silicate (Na₂SiO₃) | 16/kg     |
| 7    | Super plasticizers (conplast sp430) | 250/kg   |

4.2 Cost analysis for OPC and GPC
Table 6: shows the cost of producing 1 m³ of OPC in grades 20MPa and 30MPa is calculated based on the amount of material.

| S. No | Materials    | Rates in Rs | unit | Mix A (20MPa) | Mix B (30MPa) |
|-------|--------------|-------------|------|---------------|---------------|
|       |              |             |      | Quantity      | Amount        |
|       |              |             |      | Quantity      | Amount        |
| 1     | Cement       | 330         | 50 kg| 396           | 2614          |
| 2     | Fine Aggregate | 1000       | MT   | 608           | 608           |
| 3     | Coarse Aggregate | 700     | MT   | 1216          | 851           |
|       | **Total**    |             |      | **4073/-**    | **4324/-**    |

Table 7: shows the cost of producing 1 m³ of OPC in grades 40MPa and 50MPa is calculated based on the amount of material.

| S.NO  | Materials     | Rates in Rs | Units | Mix C(40MPa) | Mix D(50MPa) |
|-------|---------------|-------------|-------|--------------|--------------|
|       |               |             |       | Quantity     | Amount       |
|       |               |             |       | Quantity     | Amount       |
| 1     | Cement        | 330         | 50 kg | 350          | 2310         |
| 2     | Fine aggregate | 1000       | MT    | 896          | 896          |
| 3     | Coarse aggregate | 700     | MT    | 1140         | 1628         |
| 4     | Super plasticizer | 250   | kg    | 2.64         | 660          |
|       | **Total**     |             |       | **5494/-**   | **5618/-**   |

Table 8: The cost of production of 1 m³ of GPC of grade 20MPa and 30MPa.

| S.NO  | Materials   | Rates in Rs | Units | Mix A(20MPa) | Mix B(30MPa) |
|-------|-------------|-------------|-------|--------------|--------------|
|       |             |             |       | Quantity     | Amount       |
|       |             |             |       | Quantity     | Amount       |
| 1     | Fly ash     | 800         | MT    | 396          | 316.8        |
| 2     | GGBS        | 1.5         | 1 kg  | 0            | 0            |
| 3     | Fine aggregate | 1000       | MT    | 608          | 608          |
| 4     | Coarse aggregate | 700     | MT    | 1216         | 851          |
| 5     | Geo activator | 16         | 1 kg  | 198          | 3168         |
|       | **Total**   |             |       | **4943.8/-** | **4854/-**   |
Table 9: The cost of production of 1 m³ of GPC of grade 40MPa and 50MPa.

| S.NO | Materials     | Rates in Rs | Units | MIX C (40MPa) Quantity | Amount | MIX D (50MPa) Quantity | Amount |
|------|---------------|-------------|------|------------------------|--------|------------------------|--------|
| 1    | Fly ash       | 800         | MT   | 245                    | 196    | 213.5                  | 170.8  |
| 2    | GGBS          | 1.5         | 1 kg | 105                    | 158    | 213.5                  | 320.25 |
| 3    | Fine aggregate| 1000        | MT   | 896                    | 896    | 466                    | 466    |
| 4    | Coarse aggregate| 700     | MT   | 1140                   | 798    | 1504                   | 1052.8 |
| 5    | Geo Activator | 16          | 1 kg | 140                    | 2240   | 130                    | 2048   |
| 6    | Super plasticizer | 250     | 1 kg | 2.8                    | 700    | 3.4                    | 850    |
|      | Total         |             |      |                        | 4988/- |                        | 4758.4/- |

Table 10: Savings in cost of production for GPC and OPC concrete.

| Grade of concrete | Cost of production of 1 m³ of OPC | Cost of production of 1 m³ of GPC | Savings in cost (Rs) | Savings in % |
|-------------------|-----------------------------------|----------------------------------|----------------------|--------------|
| MIX A (20MPa)     | 4073/-                            | 4943.8/-                         | -870.8/-             | -17.61%      |
| MIX B (30MPa)     | 4324/-                            | 4854/-                           | -530/-               | -10.92%      |
| MIX C (40MPa)     | 5494/-                            | 4988/-                           | 506/-                | 9.21%        |
| MIX D (50MPa)     | 5618/-                            | 4758.4/-                         | 859.6/-              | 15.30%       |

The above calculations show that the cost of producing OPC is higher than the cost of producing GPC concrete for higher grade. For 20MPa grade concrete of GPC, the production cost is slightly higher (17.61%) than the small grade OPC. For the 30MPa grade of GPC, the production cost is higher than OPC of the same grade (10.92%). For 40MPa grade OPC, production costs are higher than GPC of the same grade (9.21%). For the 50MPa grade of concrete, the OPC cost is 15.30% higher than the GPC of the same grade. Therefore, it was concluded that cost savings could be maximized in the production of high-grade than the low-grade Geo-Polymer concrete.

5. CONCLUSION

- The combination of fly ash and GGBS can be used in the development of GPC without the need for heat curing to satisfy the compressive strength.
- The compressive strength of geopolymer concrete with 100% fly ash provides 25% strength, or 25% strength, for 7 days and provides more strength as 100% increases in 28 days.
- The compressive strength of geopolymer concrete increases with the increase in the GGBS replacement
rate of fly ash. The increase in intensity is 7 days more than 28 days.

• The combination of fly ash and GGBS is the solution to develop geopolymer concrete under outdoor hardening conditions.

• The dry density for the combination of fly ash and GGBS varies from 2400-2500 Kg / m³, similar to ordinary concrete.

• The maximum density observed in the geopolymer sample represents a maximum compressive strength of 7 days of age for different alkali to binder ratios and different combinations of fly ash and GGBS.

• Depending on the change in binder content, the compressive strength was increased in different combinations.

• In the cost analysis, we observe that the production of OPC is higher than the cost of producing high-grade GPC. And the cost of GPC is slightly higher than the cost of OPC for a small grade like M20.

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