Effect of Molarity of Sodium Hydroxide and Curing Method on the Compressive Strength of Ternary Blend Geopolymer Concrete

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Abstract. Concrete plays a vital role in the development of infrastructure and buildings all over the world. Geopolymer based cement-less concrete is one of the current findings in the construction industry which leads to a green environment. This research paper deals with the results of the use of Fly ash (FA), Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin (MK) as a ternary blend source material in Geopolymer concrete (GPC). The aspects that govern the compressive strength of GPC like the proportion of source material, Molarity of Sodium Hydroxide (NaOH) and Curing methods were investigated. The purpose of this research is to optimise the local waste material and use them effectively as a ternary blend in GPC. Seven combinations of binder were made in this study with replacement of FA with GGBS and MK by 35%, 30%, 25%, 20%, 15%, 10%, 5% and 5%, 10%, 15%, 20%, 25%, 30%, 35% respectively. The molarity of NaOH solution was varied by 12M, 14M and 16M and two types of curing method were adopted, viz. Hot air oven curing and closed steam curing for 24 hours at 60°C (140°F). The samples were kept at ambient temperature till testing. The compressive strength was obtained after 7 days and 28 days for the GPC cubes. The test data reveals that the ternary blend GPC with molarity 14M cured by hot air oven produces the maximum compressive strength. It was also observed that the compressive strength of the oven cured GPC is approximately 10% higher than the steam cured GPC using the ternary blend.

Key words: Ternary Blend, Geopolymer concrete, Compressive strength, Curing method, Alkaline activators.

1. Introduction

Cement is the only material used in the concrete which is manufactured in the factory, and it is the key ingredient which binds all other materials in the concrete. The production of cement leads to many environmental effects due to the emission of a large amount of carbon dioxide (CO₂) during the manufacturing process. It is mandatory to develop an alternate binder for the concrete to reduce the effect of CO₂ from the cement industry for a sustainable environment. GPC is considered as one of the best alternatives as it results in cementless concrete which leads to an Eco-friendly construction material. It can also take advantage of using the Industrial waste in the concrete without any harmful effects to the environment.

GPC results from the source material that is rich in Silica and Alumina with an alkaline activator solution by the polymerisation process. The properties of the GPC are mainly depending on
the composition of the source materials, type of curing and the alkaline activator. The compressive strength of the dry-cured GPC is approximately 15% larger than that of steam-cured fly ash based GPC [1]. It was reported that using GGBS with the addition of Metakaolinite affects the setting time of geopolymer mix by curing temperature, composition of source material and the type of alkaline liquid [2].

Among the source materials, Fly ash draws the attention of many researchers because of its availability and other dumping issues related to it. Metakaolin is formed from kaolinite clay which requires very low temperature and releases less CO₂ than Portland cement. It was reported that increase in GGBS content in GPC will improve the compressive strength [3]. The aluminous and siliceous structures in FA, GGBS and MK will have a higher dissolution rate in the alkaline solution. The concrete developed from these source materials will have better properties than the conventional concrete and also possess low carbon footprint.

2. Materials

2.1 Fly ash
Low-calcium Class F FA confirms to IS 3812:2003 [4] collected from Mettur Thermal Power Station, Tamil Nadu was used as a primary material for the ternary blend. The colour of the FA is dark grey, and the average particle size is 75 microns. It has a specific gravity of 2.30 and mainly consists of 55.36% of SiO₂ and 27.75% of Al₂O₃.

2.2 GGBS
GGBS, confirming to BS 6699:1992 [5] was used in this work. The colour of the GGBS is off-white, and the mean size of the particle is 30 microns. The specific gravity of the GGBS is 2.88. It is mainly composed of 77.36% of combined CaO, MgO and SiO₂.

2.3 Metakaolin
MK was also used in the ternary blend which contains more than 92% of combined SiO₂, Al₂O₃ and Fe₂O₃ elements. It has an appearance of Creamish Ivory Powder and the average particle size is 2-3 microns. The MK used in this work is having a specific gravity of 2.56.

2.4 Fine aggregate
M-sand passing through 4.75mm IS sieve confirming to zone II of IS 383:1970 (reaffirmed 2002) [6] was used as a fine aggregate. The fineness modulus and the specific gravity of the fine aggregate were found to be 2.92 and 2.39 respectively.

2.5 Coarse aggregate
Locally available granite stone with a maximum size of 12.5mm and a specific gravity of 2.78 was used. The coarse aggregate was having a fineness modulus of 6.92.

2.6 Alkaline liquid
A combination of Sodium Silicate (Na₂SiO₃) and Sodium Hydroxide (NaOH) was used as an alkaline liquid. The Na₂SiO₃ solution consists 8% of Na₂O, 28% of SiO₂ and 64% of water by mass. NaOH was in pellets form with 99% purity.

2.7 Superplasticizer
Naphthalene based superplasticizer (SP), Conplast SP 430 with a specific gravity of 1.2 was used for the better workability of the GPC.
3. Mixing of GPC
The mix proportion is based on the recommendations given by Prof. B V Rangan [4]. The ratio of Na$_2$SiO$_3$ to NaOH was kept constant as 2.5 and the alkaline liquid to binder ratio was also chosen as 0.3. Seven combinations of the ternary binder were selected and mixed based on volume proportion. The NaOH solution was prepared by mixing water with NaOH pellets. To prepare a 12M concentration of NaOH, 480 grams (Molarity x Molecular weight) of NaOH pellets was dissolved in water and makeup to 1 litre. It is recommended to mix the NaOH solution with Na$_2$SiO$_3$ solution 24 hours before mixing the concrete to ensure the reactivity of the solution. The mass of combined aggregates was taken as 77% of the total mass of GPC mix. SP was taken as 1.5% by the weight of binder and the water to binder ratio was selected as 0.2 for all the GPC mix for better workability. Table 1 shows the summary of the ternary blend GPC mix proportion.

Table 1. Ternary Blend GPC Mixture Proportions adopted in this work.

| Binder proportion (%) | FA  | GGBS | MK  | Coarse agg. | Fine agg. | NaOH sol. | Na$_2$SiO$_3$ | SP  | Water |
|-----------------------|-----|------|-----|-------------|-----------|------------|--------------|-----|-------|
|                       | kg/m$^3$ |     |     | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ | kg/m$^3$ |
| F60-G35-M05           | 234.15 | 169.25 | 21.21 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G30-M10           | 235.80 | 146.10 | 42.72 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G25-M15           | 237.47 | 122.61 | 64.53 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G20-M20           | 239.17 | 98.79 | 86.66 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G15-M25           | 240.89 | 74.62 | 109.10 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G10-M30           | 242.64 | 50.11 | 131.87 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |
| F60-G05-M35           | 244.41 | 25.24 | 154.97 | 1293.60 | 554.4 | 36.4 | 90.99 | 6.37 | 84.92 |

4. Casting and Curing
The dry materials were mixed in the horizontal concrete mixer for about 3-4 minutes. The Alkaline activator and the SP along with water were added to the mix and mixed for another 4 minutes. A total number of 126 ternary blend GPC cubes of size 100mm were cast and cured in a Hot air oven at 60°C for 24 hours. Another set of 42 numbers of ternary blend GPC cubes of size 100mm were cast with different proportion of source material with 14M concentration of NaOH (Maximum compressive strength) and cured in closed steam chamber at 60°C for 24 hours. 6 cubes were cast in each proportion and 3 cubes were tested for each 7days and 28days compressive strength. The GPC concrete cubes moulds were vibrated using table vibrator and covered with polythene film to reduce the water loss during the curing process. After curing the GPC cubes were removed from the mould and left to cool to room temperature until testing. Figure 1 and 2 shows the curing of GPC cubes in a Hot air oven and closed steam chamber respectively.

Figure 1. Hot air oven used for curing.

Figure 2. Closed steam chamber used for curing.
5. Results and Discussion
The GPC cubes were tested in a compressive testing machine and the mean compressive strength of three cubes was tabulated for each proportion. Table 2 shows the results of the compressive strength for different mix proportion of GPC cubes kept in Hot air oven curing and closed steam chamber curing. The maximum compressive strength of GPC was achieved by Hot air oven curing and with a molarity of 14M. The study shows that the improvement in the compressive strength of ternary blend GPC cubes by Hot air oven curing over closed chamber curing was not affected significantly by the different proportions of the source material.

Table 2. Compressive Strength Results for Different Mixtures of Ternary Blend GPC cubes.

| Binder proportion (%) | Molarity of NaOH | Average Compressive Strength (N/mm²) |
|-----------------------|-----------------|-------------------------------------|
|                       | 7 days 28 days  | Hot air oven curing     | Closed steam Curing |
|                       | 7 days 28 days  | 7 days 28 days            | 7 days 28 days      |
| F60-G35-M05           | 12   43.83      | 52.30                   | -                   |
|                       | 14   50.17      | 56.87                   | 44.78               | 51.16               |
|                       | 16   49.52      | 53.12                   | -                   |
| F60-G30-M10           | 12   52.63      | 56.39                   | -                   |
|                       | 14   52.46      | 59.82                   | 47.56               | 53.12               |
|                       | 16   52.46      | 56.55                   | -                   |
| F60-G25-M15           | 12   54.59      | 58.35                   | -                   |
|                       | 14   59.33      | 63.74                   | 52.63               | 57.37               |
|                       | 16   54.75      | 59.66                   | -                   |
| F60-G20-M20           | 12   42.33      | 48.54                   | -                   |
|                       | 14   45.60      | 50.50                   | 41.84               | 45.93               |
|                       | 16   41.35      | 46.74                   | -                   |
| F60-G15-M25           | 12   35.14      | 42.33                   | -                   |
|                       | 14   31.54      | 36.93                   | 28.93               | 33.51               |
|                       | 16   29.26      | 32.20                   | -                   |
| F60-G10-M30           | 12   28.18      | 33.34                   | -                   |
|                       | 14   30.24      | 34.16                   | 27.46               | 31.22               |
|                       | 16   20.27      | 24.18                   | -                   |
| F60-G05-M35           | 12   20.10      | 25.66                   | -                   |
|                       | 14   23.21      | 27.14                   | 21.08               | 24.52               |
|                       | 16   14.22      | 19.78                   | -                   |

It can be noted that with an increase in the molarity of NaOH there is an increase in compressive strength up to 14M and then a further increase in molarity decreases the compressive strength. The maximum compressive strength was obtained with the ternary blend contains 60% FA, 25% GGBS and 15% MK. It can be observed that increase in MK content up to 15% increases the compressive strength and further results in degradation in the strength. The density of the GPC was found to be in the range of 2400 to 2500 kg/m³ and it was also noted that curing method does not affect the density of the samples. The lowest compressive strength was found to be 19.78 MPa which contains 60% FA, 05% GGBS and 35% MK with NaOH molarity of 16M.
6. Conclusion
The compressive strength of ternary blend GPC by Hot air oven and closed steam chamber curing was obtained. The following findings were drawn from the test results with different molarity of NaOH and the curing methods.
1. The compressive strength of ternary blend GPC increased with the increase in GGBS content up to 25% and further addition of GGBS decreases the strength.
2. In both types of curing, 80-90% of the 28 days compressive strength was achieved within 7 days in which the samples were cured for 24 hours at 60°C and then kept in ambient temperature till testing.
3. The compressive strength achieved by hot air oven curing was 10% higher than the closed steam curing for the ternary blend GPC.
4. The maximum compressive strength was obtained with 14M molarity of NaOH with ternary blend of 60% FA, 25% GGBS and 15% MK.
5. It can be concluded that the ternary blend GPC using FA, GGBS and MK can be used effectively as an alternate material to concrete for a sustainable development.

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