Comparison of Mechanical properties of flyash-GGBS based GPC and flyash-alccofine based GPC with different concentrations of alkaline activators

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Abstract: Geo-polymer concrete (GPC) is the perfect solution to replace the conventional concrete making use of unwanted materials such as fly ash, GGBS, Alccofine etc.. It is noted that many researchers have worked on geopolymer concrete and a tremendous work is going on too, but unlike conventional concrete there is no proper methodology available to follow. GPC has preferable mechanical properties when differentiate to conventional concrete. Replacing GGBS and alccofine with fly ash upto some extend can eliminate oven curing and it becomes suitable to use ambient curing conditions effectively. and This study deals with different proportion of various source materials and concludes at which proportion and concentration the compressive strength and workability is higher. For Alccofine combination with fly ash gives better results than GGBS combination with fly ash but if economy is the criteria alccofine is not preferable as it is costlier than that of GGBS.

Key words alccofine, GGBS, geopolymer concrete, compressive strength, workability, alkaline activator

1. Introduction

According to basic economic theory of demand and supply, the concrete demand as a construction material is very high due to the demand in the infrastructure, particularly in the Asian countries like India and China. Due to the huge demand the manufacturing of cement has to reach its zenith. Meanwhile the extravagant usage of the cement causes the greenhouse gas emission produced in a year was approximately 1.35 billion tonnes, which is 7% of the total emission. Another point to be noted is that the Portland cement is non renewable resource, so we can clearly state that in the nearby future there will be extinction of cement due to over usage. Meanwhile as a substitute to the cement we can use fly ash and GGBS that is available as a waste material produced by coal and steel industries respectively. It is estimated that on an average of 780 million tonnes of fly ash is to be produced by the year 2010[1]. Production of cement is not only causing environmental pollution in addition to that the production of cement requires huge amount of raw materials. Due to the excess usage of raw materials they may face a danger of getting extricated in the nearby future. To stop the destruction of raw materials and also the loot of raw materials we can adopt a new type of material of construction called Geopolymer concrete which can be made using source materials such fly ash, GGBS, alccofine, metakaoline, rice husk ash etc along with alkaline activators namely sodium hydroxide, sodium silicates, potassium hydroxide and potassium
silicates etc. It is also known that fly ash and GGBS are the waste materials from the industries, so there will not be any issue with extinction of raw materials from the Earth crust. Fly ash contains huge amount of alumina and silica which helps in building the strength and plasticity to the concrete. In addition to that it contains sufficient amount of pozzolana to help the concrete to increase workability and can easily react with the alkaline activators[2].

Concrete manufactured by using fly ash and other source materials as combination gives better strength when compared to conventional concrete and geopolymer concrete is a preferable choice for the structural applications and it also perform in a better way in providing the resistance to the sulphate attack. Creep produced due to dead loads shall also be very less using GPC and this shows minimum amount of drying shrinkage[3]. By using geopolymer concrete we can produce high strength structural elements besides the problem of dumping source materials such as fly ash and GGBS can be eliminated with ease[4-6]. Several experiments have been going on to get a better idea about GPC but due to its nature and lack of having proper code of practice it became difficult to adopt it as a construction material replacing normal concrete[7-12]. Generally GPC is prepared using source materials along with alkaline activators like sodium hydroxide (NaOH) and sodium silicates(Na2SiO3) in proper proportion. Most of the researchers adopted Na2SiO3/NaOH ratio as 2.5 and molarity of the solution may vary between 4M and 8M[13-15]. Curing conditions are completely different when compared to conventional concrete, there is no need of water to cure GPC as it is cured at ambient temperature(25-27 degree centigrade) or it can be cured in oven curing conditions. Alccofine 1203 is a fine material sold by Ambuja Cements Ltd becoming the source material of GPC to give better compressive strength[16-21,34,35,36,37].

### Table 1. Chemical composition of source materials (% by mass)

| Chemical composition | Fly ash[12] | GGBS[2] | Alccofine[22] |
|----------------------|------------|--------|---------------|
| SiO2                 | 55.3       | 34.06  | 32.84         |
| Al2O3                | 25.8       | 20     | 22            |
| Fe2O3                | 5.5        | 0.8    | 2.5           |
| SO3                  | 0.3        | 0.9    | 0.3           |
| CaO                  | 2.9        | 32.6   | 36.10         |
| MgO                  | 0.8        | 7.89   | 4             |
| Na2O                 | -          | NIL    | 0.34          |
| LOI                  | 3.2        | 3.72   | 0.49          |

2.Significance of the study

There is a need for alternative of conventional concrete as a construction material as well to protect the environment from green house gases. GPC is the best material that we can replace without compromising the compressive strength but there is no proper methodology to follow. A lot of research is going on but many factors are affecting to adopt GPC. Combination of source materials and concentration of alkaline solution plays a crucial role in attaining strength and workability. In this paper, compressive strength of GPC with different combinations of fly ash-GGBS, fly ash-alccofine at different concentrations of alkaline solution is estimated and compared accordingly.

3.Experimental programme

3.1. Materials used

3.1.1 Source materials

Various source materials used in this study include fly ash, GGBS, alccofine. Fly ash contains large amount of silica and alumina and shape of the particles is spherical, GGBS particles are crystalline and angular in shape and alccofine 1203 is a low calcium silicate slag properties are almost similar as GGBS but size is different. Micro structure properties of source materials can be observed using scanning electron microscope(SEM) and X-ray diffraction(XRD) with ease[2,23].

3.1.2 Alkaline activators
Sodium hydroxide (NaOH) and sodium silicates (Na2SiO3) with proper proportion were utilized in this study. These activators are very important for activation of cementitious properties of source materials and play a crucial role in the geopolymerization process[24-29]. Na2SiO3/NaOH ratio is taken as 2.5 as it is adopted by many of the researchers and molarities of the solution is taken as 4M, 6M and 8M[30-33].

3.1.3 Aggregates
Both coarse and fine aggregates which are well graded and in dry condition are taken according to IS 383-1970 and IS 2386 (part 1)-1963 respectively[23]. Natural river sand and coarse aggregates were preferably taken according to the code of practice guidelines. Physical properties of fine and coarse aggregates are given in table 2.

Table 2. Physical properties of fine and coarse aggregates

| Physical property       | Fine aggregates | Coarse aggregates |
|-------------------------|-----------------|-------------------|
| Specific gravity        | 2.70            | 2.75              |
| Bulk density            | 1.30            | 1.65              |
| Water absorption        | 1.90%           | 0.75%             |
| Fineness modulus        | 3.0             | 8.5               |

3.1.4 Superplasticizer
As the viscosity of alkaline solution prepared by sodium silicates and sodium hydroxide is greater than water, geopolymer concrete becomes less workable so it is necessary to improve workability by using a superplasticizer. In this study sulphonated naphthalene based superplasticizer (Fosroc Conplast SP430) was used with the guidelines of IS 9103 1999.

3.2. Preparation of alkaline solution
Alkaline solution is prepared one day before casting as the solution is hot and needs to be cooled. 40 grams of NaOH pellets per liter for every 1 molar solution i.e., 160 grams per liter for 4 molar solution, 240 grams per liter for 6 molar solution and 320 grams per liter for 8 molar solution and so on[2,4,9].Na2SiO3/NaOH ratio is maintained as 2.5 hence the solution of required molarity is prepared[13,15]. Care should be taken during the preparation of alkaline solution as the reaction is exothermic in nature.

3.3 Mix proportions
Trail mixes were prepared according to the guidelines of IS 10262-2019, Indian standard concrete mix proportioning-guidelines (second revision)[18]. Some procedures of literature of certain researchers were followed to decide content of source materials (fly ash, GGBS, alccofine), alkaline/binder ratio and proportion of binding materials [2,13,15,34]. Details of mix proportions are given in table 3 and 4.

3.4. Casting and curing of specimens
Specimens of geopolymer mortar and concrete of size 70mm x 70mm x 70mm and 100mm x 100mm x 100mm respectively were prepared. For mortar specimens hand mixing is used and for concrete specimens rotating drum mixer is used. Table vibration is given for 45 seconds to the specimens[3]. The demoulded specimens after a period of 24 hours were left at room temperature(25°-27° centigrade) for curing as the ambient curing is more practical than oven curing. The calculations of compressive strength were taken for 7 days and 28 days using compression testing machine.

Table 3. Different proportion of materials(flyash + GGBS)

| Molality | Mixure | Alkaline solution/binder | Binder (fly ash+GGBS) | Alkaline solution (kg/m³) | Fine aggregate (kg/m³) | Coarse aggregate (kg/m³) | Fly ash (kg/m³) | GGBS (kg/m³) | Superplasticizer (kg/m³) |
|----------|--------|--------------------------|------------------------|---------------------------|------------------------|--------------------------|----------------|-------------|-------------------------|
| 4        | F100 G0 | 0.5                      | 370                    | 185                       | 740                    | 1110                      | 370            | 0           | 3.0                     |
| 4        | F90    | 0.5                      | 370                    | 185                       | 740                    | 1110                      | 333            | 37          | 3.5                     |
Note F and G indicates proportion of fly ash and GGBS in percentage respectively.

Table 4. Different proportion of materials(flyash+alcocfine)

| Mol  |
|------|
| arity| Mixture  | Alkaline | Binder( fly ash+alcocfine) | Alkaline | Fine aggregate s(kg/m³) | Coarse aggregate s(kg/m³) | Fly ash(kg/m³) | Alccofine( kg/m³) | Superplasticizer(kg/m³) |
|------|----------|----------|-----------------------------|----------|--------------------------|-----------------------------|----------------|-----------------|------------------------|
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 370            | 0               | 3.0                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 333            | 37              | 5.0                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 296            | 74              | 5.5                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 222            | 148             | 6.0                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 185            | 185             | 6.5                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 185            | 185             | 7.0                    |
| 4    | F₁₀₀₀₀ G₀₀₀₀ | 0.5      | 370                         | 185      | 740                      | 1110                        | 185            | 185             | 7.5                    |
4. Results and discussion

4.1. Workability

Workability of GPC is conducted at fresh state using slump cone of dimension 100mm X 200mm X 300mm. Different proportions of material with constant alkaline binder ratio of 0.5 and binder content of 370kg/m³. It is obvious that workability of concrete is dependent on shape of binder particles, concentration of alkaline solution and amount of binder material[2,7,19,23]. As increasing the GGBS content and molarity of alkaline activator, there is a noticeable decrease in the slump value. 10% alccofine along with 90% fly ash is showing good workability of GPC but slump value is goes down when there is an increase in the proportion of alccofine. Slump values for different proportion of material are presented in table 5.

4.2. Compressive strength

Undoubtedly compressive strength is the most important for any concrete, the actual strength of any structure is decided by this parameter only. In this study it is given utmost importance to find the compressive strength of concrete cubes of size 150mm X 150mm X 150mm with different proportions of source materials i.e., fly ash, GGBS and alccofine using compression testing machine of capacity 2000kN. For each proportion 1 sample of cubes i.e., 3 specimens were prepared for 3 days, 7 days and 28 days, the average of 3 specimens is taken as the compressive strength of that particular proportion at given molarity of alkaline solution.

It is observed that as increase in the concentration of alkaline solution improved the compressive strength because the concentration of NaOH alters the strength but as we take the higher concentration of alkaline activation the cost of solution and ultimately the cost of preparation of geopolymer concrete

| A40 | A50 | A60 | A70 | A80 |
|-----|-----|-----|-----|-----|
| 4   | 5   | 6   | 7   | 8   |
| F30 | 0.5 | 0.5 | 0.5 | 0.5 |
| A30 | 370 | 370 | 370 | 370 |
| A50 | 185 | 185 | 185 | 185 |
| A60 | 740 | 740 | 740 | 740 |
| A70 | 1110| 1110| 1110| 1110|
| A80 | 185 | 185 | 185 | 185 |
| A90 | 5   | 4.0 | 4.5 | 5.0 |
| A100| 0   | 2.5 | 3.0 | 3.5 |

Note F and A indicates proportion of fly ash and alccofine in percentage respectively.
increases. So, optimum concentration of 8M is suggested. Fly ash is replaced by GGBS and alccofine to improve workability upto some extend at optimum proportion only and it can definitely eliminate oven curing hence we can opt for easy and convenient way of curing i.e., outdoor curing[23]. It is noticed that increase in the proportion of both GGBS and alccofine there is an increase in compressive strength but workability may be effected at high proportion of replacement. Alccofine and fly ash based geopolymer concrete is giving better strength when compared to fly ash and GGBS based geopolymer concrete at almost of all the proportions taken. The compressive strengths of various proportions are given in table 5.

4.3. Split tensile strength

It is a salient and essential mechanical property related to cracking resistance of any part of a structure that can crack at a particular load. It is conducted by using 150mm X 300mm cylinder following the guidelines of IS 5816 1999 and IS 456 2000. There is a distinguishable change in strength is observed with increase in the proportion of GGBS and alccofine. The results are shown in table 6.

4.4. Flexural strength

It is useful in some cases where there is a need of tensile strength which can able to resist the bending force applied when there is no reinforcement is given for a concrete beam or slab and it is also called as modulus of rupture of concrete. The specimens of size 500mm X 100mm X 100mm were casted and tested by following the guidelines of IS 516-1959 and shown in table 6. The flexural strength is found to be increasing with increase in the proportion of GGBS and alccofine and NaOH concentration also shows an impact in increasing the strength along with increasing molarity of alkaline solution.

| Table 5. Compressive strength and workability of geopolymer concrete |
| --- |
| **Proportion** | **Molarity of solution** |
|  | 4M | 6M | 8M | 4M | 6M | 8M | 4M | 6M | 8M |
|  | Slump (mm) | Strength (MPa) | Slump (mm) | Strength (MPa) | Slump (mm) | Strength (MPa) | Slump (mm) | Strength (MPa) | Slump (mm) | Strength (MPa) |
| F<sub>100</sub> G<sub>0</sub> | 118 | 32 | 122 | 33.5 | 145 | 35 |
| F<sub>90</sub> G<sub>10</sub> | 111 | 34 | 117 | 35 | 132 | 37 |
| F<sub>80</sub> G<sub>20</sub> | 107 | 36.5 | 112 | 38 | 124 | 38.5 |
| F<sub>70</sub> G<sub>30</sub> | 105 | 37 | 109 | 38.5 | 114 | 41 |
| F<sub>60</sub> G<sub>40</sub> | 101 | 38.5 | 106 | 40 | 110 | 43 |
| F<sub>50</sub> G<sub>50</sub> | 96 | 39 | 99 | 42.5 | 107 | 47 |
| F<sub>100</sub> A<sub>0</sub> | 118 | 32 | 122 | 33.5 | 145 | 35 |
| F<sub>90</sub> A<sub>10</sub> | 120 | 35.5 | 126 | 36 | 147 | 38 |
| F<sub>80</sub> A<sub>20</sub> | 128 | 37 | 131 | 38 | 151 | 40.5 |
| F<sub>70</sub> A<sub>30</sub> | 132 | 39 | 136 | 41.5 | 159 | 44 |
| F<sub>60</sub> A<sub>40</sub> | 137 | 41 | 141 | 43 | 163 | 48 |
| F<sub>50</sub> A<sub>50</sub> | 142 | 41.5 | 149 | 46 | 172 | 51.5 |

| Table 6. Split tensile strength and flexural strength of geopolymer concrete |
| --- |
| **Proportion** |
|  | **Molarity of solution** |
|  | 4M | 6M | 8M | 4M | 6M | 8M | 4M | 6M | 8M |
|  | Split tensile strength(MPa) | Flexural strength (MPa) | Split tensile strength(MPa) | Flexural strength (MPa) | Split tensile strength(MPa) | Flexural strength (MPa) |
| F<sub>100</sub> G<sub>0</sub> | 0.15 | 0.25 | 0.25 | 0.30 | 0.30 | 0.45 |
| F<sub>90</sub> G<sub>10</sub> | 0.25 | 0.65 | 0.35 | 0.75 | 0.45 | 0.80 |
| F<sub>80</sub> G<sub>20</sub> | 0.50 | 0.80 | 0.60 | 0.95 | 0.70 | 1.05 |
| F<sub>70</sub> G<sub>30</sub> | 0.70 | 0.95 | 0.80 | 1.10 | 0.90 | 1.35 |
Figure 1. Compressive strength Vs proportion of materials at 3 different molarities.
Figure 2. Slump value Vs proportion of materials at 3 different molarities

Conclusions
After observing all the results of this study, it is concluded as follows
1. Multiple results of compressive strength, split tensile strength and flexural strength of geopolymer concrete with various proportions of GGBS and alccofine along with fly ash showed that alccofine and fly ash based geopolymer concrete is better in terms of workability and strength.
2. Replacement of alccofine and GGBS can successfully eliminate oven curing hence the curing can be done at ambient curing conditions only.
3. F50G50 and F50A50 cases where fly ash is replaced upto 50% by GGBS and alccofine respectively are giving higher compressive strength when compared to other proportions.
4. Molarity of alkaline solution shows a great impact on strength, increasing concentration of solution improved the strength but decreased workability and cost of preparation of geopolymer concrete is also increased.
5. At F50A50 the strength of concrete is found to be the highest but the proportion of alccofine taken upto 50% is uneconomical as it is costlier than GGBS.
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