AN EXPERIMENTAL STUDY ON GEOPOLYMER CONCRETE BY USING FLYASH, GGBS AND ALCCOFINE

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Abstract. In this study concentrated on the development of GPC by using industrial waste products such as fly ash, alccofine (1203) and GGBS. GPC is an advanced eco-friendly concrete manufactured by activating source minerals rich in alumina and silica by alkaline liquids to form aluminosilicates based on inorganic polymers. Where cement was complete replaced with mix proportion of 50% fly ash, 25% alccofine (1203) and 25% GGBS for different molarities (8M, 10M and 12M) of alkaline activators which is solving the problem of unsustainable usage of limestone and pollutant related to the manufacturing process of cement. The present paper reports the cube compressive strength, cylindrical split tensile strength and flexural strength of GPC and which is compared with M25 grade of control specimens. It was observed that the strength of GPC is increased than normal concrete as molarities increases of 8 M, 10M and 12M. The paper explains about the effectiveness of fly ash, alccofine (1203) and GGBS materials.

Keywords: Geo polymer concrete (GPS), Fly ash, Alccofine, Compressive strength, Split tensile strength and Flexural strength.

1. INTRODUCTION

Concrete is the most widely used construction materials in the word to day next to water, that resulting in huge cement production, thereby huge quantity of CO₂ is resulting in atmosphere. To limit the usage of normal Portland concrete, researchers investigated and identified a special material, with this we produced Geo-polymer concrete and lot of research is going on Geo-polymer concrete in the last two decades in India as well as in the worldwide. Geo-polymer concrete having the property of higher durability, lower global warming potential, better serviceability and overall economy. Growing industrialization, leads to the release waste such as Fly ash, Ground Granulated Blast Furnace Slag (GGBS) and rice husk ash which are pozzolanic in nature. Globally, there are lot of research is going on showing concern about the reducing of emission of CO₂, claimed this CO₂ emission is the main reason for global warming. The byproducts of iron industries, thermal power plants, rice industries, steel industries and mining industries create a serious of thrust to the environment if you disposed of without treatment. These industrial by products such as GGBS, Fly ash, Rice husk, Silica fume, Metakaolin and Alccoine 1203 requires a wider area of land for their disposal. This paper presents the production of concrete the cement is fully replaced with cementineous materials fly ash (50%), Metakaolin (25%) and Alccoine 1203 (25%) along with fine aggregate and coarse aggregate along with alkaline liquid solution (NaOH and Na₂Sio₃) with different molarities 8M,10M and
12M. The normal concrete of M25 grade designed as per IS 10262-2019 as a control specimens and Geo-polymer concrete is produced without cement and Normal concrete of M25 grade is also produced and cast the cubes, cylinders and beams for cube compression, cylindrical split tensile strength and flexural strengths. Compare the strengths of Normal concrete with the Geo-polymer concrete. Joseph Davidovits, 1978 [1] proposed the idea of producing Geo-Polymer concrete, based on the concept of Geo- polymerization and formulate the mechanism of primary reaction, comprising of chemical reaction with alkaline liquid activator-NaOH or KOH with suitable materials rich in Alumina and Silicon such as fly ash [2], Silica fume [3], Metakaolin [4], Slag [5] and Rice husk ash. The industrial by products such as GGBS, fly ash, Alccofine 1203, Metakaolin, rice husk ash and silica fume are rich in Silica and Alumina are used as primary precursor for forming amorphous Geo-Polymer binder in presence of Alkaline Solution [6,7]. Aleem and Arumairaj, 2012 [8] conducted an experiment to find out the optimum mix design for the geopolymer concrete. For determination of optimum mix different trial were conducted and the compressive strengths was found for 7 days and 28 days. The alkali activator solution of sodium hydroxide and that of sodium silicate was used in the ratio 2.5. Rao.G.M. et al [9] developed and studied the geopolymer concrete and explained the importance of alkali solution, which is required which physically and chemically reacts with these silica, calcium and alumina.

2. EXPERIMENTAL PROGRAMME

2.1 Methodology

In this study, one normal concrete mix of M25 grade (M1) and three geopolymer mixes (M1, M2 and M3) are prepared. In normal concrete we use cement as binder material, in geopolymer concrete cement is fully replace by Fly ash (50%), Alccofine 1203 (25%) and GGBS (25%) with different molarities of 8M, 10 M and 12 M and the material composition of normal concrete are shown in Table 1.

| S.No | Material      | Quantity (Kgs/m³) |
|------|---------------|-------------------|
| 1    | Cement        | 384               |
| 2    | Fine Aggregate| 695               |
| 3    | Coarse Aggregate| 1139             |
| 4    | Water         | 192               |

In geopolymer concrete all the materials Fly ash, GGBS, Alccofine, Coarse aggregate, Fine aggregate and water quantities are constant only the variables are NaOH and Na₂SiO₃ and are shown in Table 2. In the mix design of the geopolymer concrete mix the total mass of the coarse aggregate and fine aggregate as taken as 68% of concrete mix and the fine aggregate are taken as 38% of the total aggregate mass of the coarse aggregate is taken and water is constant for all the geopolymer mixes as 27.80 litters.

| Mix Designation | Fly Ash | GGBS | Alccofine 1203 | CA (20 mm) | CA (12.5 mm) | FA | SS Solution | SH Solution | SH pellets | Water in liters |
|-----------------|--------|------|---------------|------------|--------------|----|-------------|-------------|------------|----------------|
| M1              | 288    | 144  | 144           | 683        | 456          | 695| 102.2       | 40.9        | 13.08      | 27.80          |
| M2              | 288    | 144  | 144           | 683        | 456          | 695| 102.2       | 40.9        | 16.36      | 27.80          |
Prepare the alkaline liquid at least one day prior to casting of specimens. Firstly, the NaOH solution is mixed with Na2SiO3 in 1:2.5 proportions. The test specimens were prepared for different molarities with 8M, 10M and 12 M, Alkaline solution of different molarities depending upon the quantity of solid NaOH pellets in total volume water. To obtain 1molarity of alkaline solution, we have to add 1*40gms of NaOH pellets in total volume of water. i.e., liter of alkaline solution contains 40gms of sodium hydroxide pellets for 1molarity of solution. Mix proportions for the above molarity are shown in Table 3.

| S. No | Molarity | Activator cementineous material | Sand to cementineous ratio |
|-------|----------|--------------------------------|---------------------------|
| 1     | 8        | 0.35                           | 1.0                       |
| 2     | 10       | 0.35                           | 1.0                       |
| 3     | 12       | 0.35                           | 1.0                       |

### 3. EXPERIMENTAL PROGRAMME

Following material generally used for production of Normal concrete and Geopolymer concrete.

- Cement
- Alcofine 1203
- Fly ash
- GGBS
- Fine Aggregate
- Coarse Aggregate

#### 3.1 Normal Portland Cement

Normal Portland cement of 43 grade confirming to IS 8112-1983, coarse aggregate, fine aggregate, potable water was used for the manufacturing of control specimens. The physical properties of the cement that are used in this investigation are shown in Table 4.

| S. No | Description                               | OPC-43 confirming to IS 8112-2013[10] |
|-------|------------------------------------------|--------------------------------------|
| 1     | Fineness (Sq.m/Kg)                       | 305                                  |
| 2     | Normal consistency (%)                   | 32                                   |
| 3     | Setting time (Minutes)                   |                                       |
|       | a) Initial setting time                  | 90                                   |
|       | b) Final setting time                    | 420                                  |
| 4     | Specific gravity                         | 3.14                                 |
3.2 Alccofine 1203
Alccofine 1203 is a processed slag based high glass content. Alccofine improves the workability and reduced water demand. The strength properties of concrete are improved due to Ultra-fine particle size. Alccofine 1203 can be used as a cement replacement or an addition to improve the concrete pavements both in fresh and hardened state and chemical composition of Alccofine 1203 are shown Table 5 and physical composition are shown in Table 6.

Table 5. Chemical composition of Alccofine 1203

| S.No | Constituents          | Composition (wt.%) |
|------|-----------------------|--------------------|
| 1    | Silica (SiO₂)         | 35.30              |
| 2    | Calcium oxide (CaO)   | 32.20              |
| 3    | Alumina (Al₂O₃)       | 21.4               |
| 4    | Magnesia (MgO)        | 8.20               |
| 5    | Iron oxide (Fe₂O₃)    | 1.20               |
| 6    | Sulphur trioxide (SO₃)| 0.13               |

Table 6. Physical properties of Alccofine 1203

| S.No | Physical property          | Result |
|------|----------------------------|--------|
| 1    | Bulk density (Kgs/m³)      | 680    |
| 2    | Specific gravity           | 2.70   |
| 3    | Particle size distribution | D₁₀ 1.8 D₅₀ 4.4 D₉₀ 8.9 |
| 4    | Specific surface area(cm²/gm) | 1200  |

3.3 Fly ash
Low Calcium fly-ash (Class F) is confirming to IS:3812-2003 is used in this investigation [8]. The physical properties and chemical composition of fly ash are given Table 7.

Table 7. Physical and chemical composition of fly ash

| S. No | Composition (%) wt.% | Fly Ash | IS 3812-2003 requirements [11] |
|-------|----------------------|---------|---------------------------------|
| 1     | Silica fume + Alumina + iron Oxide (SiO₂+Al₂O₃+Fe₂O₃) | 95.91   | 70.0 (Min)                      |
| 2     | Calcium Oxide (CaO)  | 0.87    | Not specified                   |
| 3     | Silica (SiO₂)        | 62.55   | 35.0 (Min)                      |
| 4     | Magnesium oxide (MgO)| 0.39    | 5.0 (Max)                       |
| 5     | Sodium oxide (Na₂O)  | 0.46    | 1.5 (Max)                       |
| 6     | Sulphur dioxide (SO₃)| 1.32    | 3.0 (Max)                       |
| 7     | Total chlorides      | 0.05    | 0.05 (Max)                      |
3.4 GGBS
GGBS is by product and formed in blast furnace during in the manufacturing process of iron from its ore. GGBS having high silica and alumina content also possessing high Cao content in comparison with fly ash. The XRD pattern shows that the GGBS is more amorphous and the particle size is generally 95% finer than the 30 microns, which enhances the reactivity. In general, the particle shape of the GGBS is in crystalline and angular form which also varies according to the grinding techniques. Table 8 shows the typical chemical composition of GGBS.

Table 8. The chemical composition of GGBS

| S.No | Composition               | GGBS % by mass |
|------|---------------------------|----------------|
| 1    | Silica fume (SiO$_2$)     | 34.06          |
| 2    | Iron Oxide (Fe$_2$O$_3$)  | 0.8            |
| 3    | Alumina (Al$_2$O$_3$)     | 20.00          |
| 4    | Sulphur dioxide (SO$_3$)  | 0.9            |
| 5    | Calcium Oxide (Cao)       | 32.6           |
| 6    | Magnesium oxide (MgO)     | 7.89           |

3.5 Fine Aggregate
The locally available Pennar river sand confirming to Zone-II grade of IS 383-1970[12] has been used as a Fine aggregate. Test has been carried out as per procedures that are given in IS codes and the results were tabulated in Table 9 and Table 10.

Table 9. Sieve analysis of fine aggregate

| S.No | I.S. Sieve | Wt. retained (gms) | % wt. retained | Cumulative % of weight retained | % of passing |
|------|------------|--------------------|----------------|---------------------------------|-------------|
| 1    | 10 mm      | 0.00               | 0.00           | 0.00                            | 100         |
| 2    | 4.75 mm    | 54.00              | 5.4            | 5.4                             | 94.60       |
| 3    | 2.36 mm    | 91.00              | 9.1            | 14.5                            | 85.50       |
| 4    | 1.18 mm    | 143.00             | 14.30          | 28.8                            | 71.20       |
| 5    | 600µ       | 203.00             | 20.3           | 49.10                           | 50.90       |
| 6    | 300µ       | 313.00             | 31.3           | 80.40                           | 19.60       |
| 7    | 150µ       | 178.00             | 17.80          | 98.20                           | 1.80        |
| 8    | Pan        | 18.00              | 1.8            |                                 | Total=276.4 |

Fineness modulus =2.76

Table 10. Physical properties of fine aggregate

| S.No | Property            | Value |
|------|---------------------|-------|
| 1    | Specific Gravity    | 2.63  |
3.6 Coarse Aggregate

The locally available crushed granite has been used in this investigation as a coarse aggregate. The mix design of normal concrete and geopolymer concrete it is necessary to know the properties of materials i.e., specific gravity, sieve analysis, density and water absorption. The tests were been carried out as per the IS codes procedure and the results were tabulated in Table 10, 11 and 12.

Table 11. Sieve analysis of 20 mm coarse aggregate

| S.No | I.S. Sieve | Wt. retained (gms) | % Wt. retained | Cumulative % of weight retained | % of passing |
|------|------------|--------------------|----------------|--------------------------------|-------------|
| 1    | 40 mm      | 0.00               | 0.00           | 0.00                           | 100         |
| 2    | 20 mm      | 324.00             | 3.24           | 3.24                           | 96.76       |
| 3    | 10 mm      | 8416.00            | 84.16          | 87.4                           | 12.6        |
| 4    | 4.75 mm    | 1260.00            | 12.60          | 100.00                         | 0.00        |
| 5    | 2.36 mm    | -                  | -              | -                              | -           |
| Total|            | 10000              |                |                                |             |

Table 12. Sieve analysis of 12.5 mm coarse aggregate

| S.No | I.S. Sieve | Wt. retained (gms) | % wt. retained | Cumulative % of weight retained | % of passing |
|------|------------|--------------------|----------------|--------------------------------|-------------|
| 1    | 40 mm      | 0.00               | 0.00           | 0.00                           | 100.00      |
| 2    | 20 mm      | 0.00               | 0.00           | 0.00                           | 100.00      |
| 3    | 12.5 mm    | 192.00             | 3.84           | 3.84                           | 96.16       |
| 4    | 10 mm      | 2896.00            | 57.92          | 61.76                          | 38.24       |
| 5    | 4.75 mm    | 1694.00            | 33.88          | 95.64                          | 4.36        |
| 6    | 2.36 mm    | 218.00             | 4.36           | 100.00                         | 0.00        |
| Total|            |                    |                |                                |             |

Table 13. Physical properties of Coarse Aggregate

| S.No | Property       | Value  |
|------|----------------|--------|
| 1    | Specific gravity | 2.66   |
| 2    | Bulk density (Kgs/m³) | 1320   |
|      | Compacted       | 1535   |
| 3    | Water absorption (%) | 0.52   |
4. CASTING OF TEST SPECIMEN
The cubes, cylinders and beam specimens were prepared for the normal concrete M1 and Geopolymer concretes M2, M3 and M4. The numbers of specimens are shown in Table 13. And the ingredients of geopolymer concrete and casted specimens were shown in Figure 1. The cube moulds were used in this investigation are of size 150x150x150 mm and cylinder of size 150x300 mm and for beam mould of size 150x150x700 mm.

| S.No | Nomenclature | No. of cube specimens | No. of cylindrical specimens | No of beam specimens |
|------|--------------|------------------------|------------------------------|----------------------|
| 1    | M1           | 6                      | 6                            | 6                    |
| 2    | M2           | 6                      | 6                            | 6                    |
| 3    | M3           | 6                      | 6                            | 6                    |
| 4    | M4           | 6                      | 6                            | 6                    |

Figure 1 The Geopolymer concrete ingredients and specimens

For each mix 6 specimens are prepared, 3 specimens for 7 days and remaining 3 specimens for 28 days. After casing the specimens, they are cured in the curing pond for specified days i.e. 50% of the specimens for 7 days and remaining for 28 days. After desired period of curing the specimens were tested as per the procedure mentioned in relevant I.S Codes.

5. RESULTS AND DISCUSSION
Based on experimental investigation, the normal concrete (M1) and Geo-polymer concretes (M2, M3 and M4) cube compressive strength for 7 days and 28 days are shown in Table 13.
Table 15. Cube compressive strength of normal concrete and Geopolymer concrete

| S.No | Nomenclature | Compressive strength at the age of 7 Days | Compressive strength at the age of 28 Days |
|------|--------------|------------------------------------------|------------------------------------------|
| 1    | M1           | 24.89                                    | 31.11                                    |
| 2    | M2           | 27.56                                    | 34.44                                    |
| 3    | M3           | 29.33                                    | 36.67                                    |
| 4    | M4           | 31.64                                    | 39.56                                    |

5.1 Compressive strength

Cube compressive strengths are performed on cubes of size 150mm x 150mm x 150 mm. Cube compressive strengths were with compliance of IS 516-1959 [13] was performed on 7 days and 28 days. For normal concrete (M1) observed 7 days strength are 24.89 Mpa whereas the Geopolymer concrete M1, M2 and M3 shows 27.56 Mpa, 29.33 Mpa and 31.64 Mpa respectively. Similarly for 28 days normal concrete (M1) shows 31.11 Mpa and the Geopolymer concrete M1, M2 and M3 shows 34.44 Mpa, 36.67 Mpa and 39.56 Mpa respectively and are shown in Figure 2.

5.2 Split tensile strength

Split tensile strength were performed on cylinders of size 150mm x 300mm. Split tensile strength confirming to IS 5816-1999 [14] were performed on ordinary concrete and Geopolymer concrete. The normal concrete (M1) observed 7 days strengths are 2.12 Mpa and that of geopolymer concrete M2, M3 and M4 shows 2.41 Mpa, 2.62 Mpa and 2.83 Mpa respectively, whereas for 28 days strengths are for M1 concrete shows 2.65 Mpa and that of M2, M3 and M4 shows 3.01 Mpa, 3.27 Mpa and 3.54 Mpa respectively. In the split tensile strength also when molarity increases the split tensile strength are increased. The split tensile strength is shown in Table 14 and graphs shown in Figure 3.
Table 16. Split tensile strength of normal concrete and Geopolymer concrete

| S.No | Nomenclature | Split strength at the age of |
|------|--------------|-----------------------------|
|      |              | 7 Days | 28 Days |
| 1    | M1           | 2.12   | 2.65    |
| 2    | M2           | 2.41   | 3.01    |
| 3    | M3           | 2.62   | 3.27    |
| 4    | M4           | 2.83   | 3.53    |

Figure 3. Split tensile strength of ordinary concrete and geopolymer concrete

5.3 Flexural strength of concrete
Flexural strength test is conducted on the beams of size 150x150x700 mm and the 7 days strength for M1 concrete shows 3.49 Mpa, whereas the geopolymer concrete shows M2, M3 and M4 are 3.67 Mpa, 3.79 Mpa and 3.93 Mpa. Similarly, for 28 days M1 shows 3.90 Mpa and that of geopolymer concrete shows 4.10 Mpa, 4.24 Mpa and 4.40 Mpa respectively and are shown in Table 15. In this case also when the molarity increases flexural strength also increased with respect to normal concrete and are shown in Figure 4.

Table 17. Flexural strength of normal concrete and Geopolymer concrete

| S.No | Nomenclature | Flexural strength at the age of |
|------|--------------|--------------------------------|
|      |              | 7 Days | 28 Days |
| 1    | M1           | 3.49   | 3.90    |
| 2    | M2           | 3.67   | 4.10    |
| 3    | M3           | 3.79   | 4.24    |
6. CONCLUSIONS

The following conclusions were drawn from this experimental work.

- Ground granular blast furnace slag, fly ash and Alccofine are fully replaced with the cement, they are showing better results than the normal concrete where we use cement in normal concrete.
- Geopolymer concrete gains compressive strength at 7 days and 28 days shows higher values than the normal concrete.
- An average increase of about 25% in the cube compressive strength of concrete has been observed for 7 days and 28 days.
- Increase amount of fly ash and presence of GGBS and Alccofine leads to better compressive strengths, split tensile strength and flexural strengths than the ordinary concrete in 7 days as well as 28 days.
- The particle size of and high surface area of GGBS, fly ash and Alccofine 1203, we can observe better consistency of the mix.
- Due to higher surface area of the cementineous materials GGBS, fly ash and Alccofine 1203 and also while going higher molarity 8M, 10M and 12M the compressive strengths, split tensile strengths and flexural strengths are improved.

Figure 4. Flexural strength of ordinary concrete and geopolymer concrete
REFERENCES

[1] Davidovis J 1994 Special Publication 144, 383-98.
[2] T Xie T O 2015 Ceramic International 15 5945-58.
[3] Adak D, M. Sarkar and S. MANDAL 2014 Building Materials 70 453-59.
[4] Ozer I and S Soyer-Uzm 2015 Ceramic international, 41 10192-98
[5] Kumar S, R Kumar and S P Mehrotra 2010 Journal of material Science 45 607-15
[6] G B maranan, A C Manoli, B Benmokrane, W Larimasena, P Mendis and T Q Naguyen 2019
[7] Engineering Structures 2019, 24 183-141.
[8] Buchwarld A, Dombrowski K and Weilm 2005 Proce.. of the 2nd inter..symp... of non-traditional Cement and Concrete, 25-26.
[9] Aleem, M.I. Abdul, Arumairaj, P.D 2012, Ind. Jour. of Sci. and Technology 5 2299-2301
[10] Rao. G.M, Rao.T.G, Reddy.M.S.N and Sheshu D.R, 1994, World resource review 6 263-78.
[11] BIS, IS:8112 2013 Ordinary Portland cement 43 grade specifications, Bureau of Indian Standards, New Delhi, India.
[12] BIS, IS 3812-2003 Pulverized Fuel Ash- Specifications, Bureau of Indian Standards, New Delhi, India.
[13] BIS, IS 383-1970, Specification for coarse and fine aggregate from natural source for concrete, Bureau of Indian Standards, New Delhi, India.
[14] BIS, IS 516-1959, Methods of test for strength of concrete, Bureau of Indian Standards, New Delhi, India.
[15] BIS, IS 5816, Split tensile strength of concrete-Method of test, Bureau of Indian Standards, New Delhi, India.