

Investigations on the Strength Characteristics of Geopolymer Concrete at Ambient and Oven curing

Apoorva . S, Namrata .F. Dabali

Department of Civil Engineering, East West Institute of Technology, Bangalore

Abstract- Concrete is one of the most fundamental materials used in the field of civil engineering. In this project, an attempt has been made to replace the cement with locally available materials such as Low calcium fly ash and Ground granulated blast furnace slag (GGBS) which acts as alternative binder. Fly ash is rich in silicate and alumina and it reacts with alkaline solution to produce alumina silicate gel that binds the aggregate to produce a good concrete. GGBS is a slag which is usually used for partial replacement of cement. Geopolymer concrete members are cured at ambient temperature and also at 80°C in oven for 24 hours with varying proportions of fly ash and GGBS for 12M concentration. The alkaline solutions (sodium hydroxide and sodium silicate solutions) are prepared 24 hrs, prior of casting. The conventional method of mixing, compacting and moulding is done to produce Geopolymer concrete. Cubes, cylinders and beams are tested to find the compressive strength, tensile strength and flexural strength. The compressive, tensile and flexural strength for all members are tested for 7 days and 28 days. After the experimental investigation, it was found that the strength of geopolymer concrete increased with increase in higher percentage of GGBS and also the strength increased with age of the concrete in case of ambient curing.

Index Terms- Flyash, GGBS, Ambient curing, Oven curing

I. INTRODUCTION

Concrete is widely used as construction material. Portland cement is the main component used for making concrete. The cement industry is responsible for CO₂ emission, because the production of one ton Portland cement produces approximately one ton CO₂ to the atmosphere which is not ecofriendly. Davidovits coined the term Geopolymer to represent these binders. The Geopolymer technology states that an alternative binder can substitute the Portland cement in concrete industry. Fly ash, silica fume, ground granulated blast furnace slag, rice husk ash and metakaolin can be used as an alternative binder instead of cement.

II. GEOPOLYMER CONCRETE

Geopolymer concrete is a high strength and lightweight inorganic polymer that can be used in place of normal concrete. It is made by mixing different combinations of cementing materials such as silica fume, rice husk ash, metakaolin, Ground granulated blast furnace slag (GGBS) and Fly ash along with fine aggregate, coarse aggregates and alkaline solution. Geopolymer concrete is increasing its popularity as the demand for a green

and sustainable building material increases each year. Around 75%-80% of the mass is made of coarse and fine aggregates.

Geopolymers are produced by condensation of tetrahedral aluminosilicate units, with alkali metal ions equivalent to the charge related with tetrahedral Al. Usually, Geopolymers are synthesized from two-part mix, consisting of an alkaline solution (often soluble silicate) and solid aluminosilicate materials. These days the development of alternative materials to Portland cement concrete has become important. The design of Geopolymer concrete provides an alternative solution for production of conventional concrete. Geopolymer concrete is eco friendly and also reduces release of CO₂.

The Geopolymer concrete is manufactured by activating source materials with alkaline liquids. The fly ash and ggbs are the general source materials used to produce the Geopolymer concrete. 1.6 tonne of raw materials are required to produce one ton of cement and the duration to form the limestone is much longer than the rate at which humans use it. To produce eco friendly concrete the cement is replaced with fly ash, GGBS, etc. generally the alkaline solution used are Sodium hydroxide and sodium silicate.

Geopolymerization is the process of combining small molecules known as oligomers into a covalently bonded network. They are classified based on the ratio of Si/Al in their structures: a) Poly (sialite) (-Si-O-AL-O-) b) Poly (sialate-siloxo) (-Si-O-Al-O-Si-O-) c) Poly (sialite - disiloxo) (-Si-O-Al-O-Si-O-Si-O-). The distribution and relative amounts of Al and Si building blocks influence the chemical and physical properties of the final product. Geopolymerization takes place at ambient or slightly elevated temperature, where the leaching of solid aluminosilicate raw materials in alkaline solutions leads to the transfer of leached species from the solid surfaces into a growing gel phase, followed by nucleation and condensation of the gel phase to form a solid binder.

III. MIX DESIGN OF GEOPOLYMER CONCRETE

STEP 1: Density of concrete
= 2400 kg/m³

STEP 2: Mass of coarse aggregate
= 70%

STEP 3: Take 77% as aggregates
Total aggregates = $77/100 * 2400$
= 1848 kg/m³

STEP 4: 70% of coarse aggregate
= $70/100 * 1848 = 1294$ kg/m³
30% of fine aggregate = $30/100 * 1848 = 554.4$ kg/m³

1848 = 554 kg/m³

STEP 5: Cementitious binders

= 2400 – 1848 = 552 kg/m³

Fly ash + GGBS + NaOH

+ Na₂SiO₃ = 552 kg/m³

STEP 6: $\frac{\text{Alkaline liquid}}{\text{Fly ash + GGBS}} = 0.35$

Alkaline liquid = 0.35 * X

(X = fly ash + GGBS)

STEP 7: Fly ash + GGBS + alkaline liquid = 552 kg/m³

X + 0.35X = 552 kg/m³

X = 408 kg/m³.

STEP 8: $\frac{\text{Sodium silicate}}{\text{Sodium hydroxide}} = 2.5$

Sodium silicate = 2.5

Sodium hydroxide

STEP 9: Alkaline liquid = 0.35 ×

= 0.35 × 408 = 142.8 kg/m³

STEP 10: Sod. Silicate + Sod. Hydroxide

= 142.8 kg/m³

sodium hydroxide solution =

142.8 – Sod. Silicate solution

STEP 11: Sodium silicate solution = 2.5 (142.8 – sod silicate)

= 357 – 2.5 (Sod. Silicate)

Hence,

Amount of Sodium silicate solution = 103 kg/m³

and Sodium hydroxide solution = 41 kg/m³

IV. EXPERIMENTAL INVESTIGATIONS

In this project, Cubes of size 150 mm × 150 mm × 150 mm, Beams of size 100 mm × 100 mm × 500 mm and Cylinders of size 150 mm diameter-300 mm height to find the compressive, flexural, tensile and strength. Firstly, the fine aggregate, coarse aggregate and fly ash are mixed in dry condition for 3-4 minutes. For this Dry mix, the alkaline solution which is a mixture of Sodium hydroxide solution and Sodium silicate solution is added. The tap water in small amount was added to attain proper mixing and adequate workability. The mixing is done about 6-8 minutes for proper bonding of all the materials. The fresh concrete is grey in color. The mixtures are cohesive. The workability of the fresh concrete is measured by means of the slump test. The fresh concrete is then poured into the moulds in three layers immediately after mixing and compacted using tamping rod for 25 times. Totally two sets of 40 cubes, 30 cylinders and 30 beams are casted.

After casting, one set of the test specimens are kept for ambient curing at room temperature and another set at 80°C in oven for 24 hours and then demoulded, cured ambiently till they reach age of 7 and 28 days. After demoulding the specimens are tested to determine the various strength properties.

| | |
|-------|--------------------------|
| MIX 1 | 100% FLY ASH , 0 % GGBS |
| MIX 2 | 90 % FLY ASH , 10 % GGBS |
| MIX 3 | 80 % FLY ASH , 20 % GGBS |

| | |
|-------|--------------------------|
| MIX 4 | 70 % FLY ASH , 30 % GGBS |
| MIX 5 | 60 % FLY ASH , 40 % GGBS |

Table 1: Percentages of fly ash and GGBS for different mixes

| Description | Mix 1 (kg/m ³) | Mix 2 (kg/m ³) | Mix 3 (kg/m ³) | Mix 4 (kg/m ³) | Mix 5 (kg/m ³) |
|---|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| Fly ash | 408 | 367.2 | 326.4 | 285.6 | 244.8 |
| GGBS | - | 40.8 | 81.6 | 122.4 | 163.2 |
| Coarse aggregates | 1294 | 1294 | 1294 | 1294 | 1294 |
| fine | 554 | 554 | 554 | 554 | 554 |
| NaOH | 41 | 41 | 41 | 41 | 41 |
| Na ₂ SiO ₃ solution | 103 | 103 | 103 | 103 | 103 |

Table 2: Quantities of different materials

V. RESULTS AND DISCUSSIONS

A. Compressive strength

Compressive strength for 7 days and 28 days are tabulated below. It is seen that the compressive strength of oven cured cubes are found to be higher than the cubes cured at ambient temperature for 7 days. This may be due to the increased heat of hydration due to the addition of GGBS in geopolymerization process. compressive strength of both the sets for 28 days is found to be almost similar.

| Mixes | Average compressive strength for 7 days | | Average Compressive strength for 28 days | |
|-------|---|-------|--|-------|
| | Ambient | Oven | Ambient | Oven |
| Mix 1 | 11.8 | 16.52 | 23.5 | 24.17 |
| Mix 2 | 14.2 | 23.07 | 25.5 | 26.8 |
| Mix 3 | 17.3 | 28.67 | 33.7 | 36.02 |
| Mix 4 | 19.5 | 35.42 | 43.9 | 44.8 |
| Mix 5 | 24 | 41.9 | 51.7 | 56.47 |

Table 3: Average compressive strength of geopolymer concrete for 7 and 28 days in MPa

B. Split Tensile and Flexural strength

The split tensile and flexural strength for 7 days and 28 days are tabulated below. The split tensile strength for 7 days and 28 days at ambient curing ranges between 1.09 MPa to 3.186 MPa and for 28 days between 1.94 MPa to 10.34 MPa. For oven curing it ranges between 1.13 MPa to 8.1 MPa and 2.17 MPa to

10.67 Mpa respectively for different proportions of flyash and GGBS. Similarly the flexural strength for 7 days and 28 days at ambient curing ranges between and that for oven curing it ranges between 1.87Mpa to 8.46Mpa and 3.43 Mpa to 11.2 Mpa respectively for different proportions of flyash and GGBS. Thus it shows that higher the percentage of GGBS higher is the strength.

| Mixes | Average Split Tensile strength for 7 days | | Average Split Tensile strength for 28 days | |
|-------|---|------|--|-------|
| | Ambient | Oven | Ambient | Oven |
| Mix 1 | 1.09 | 1.13 | 1.94 | 2.17 |
| Mix 2 | 1.256 | 2.3 | 3.33 | 3.6 |
| Mix 3 | 1.72 | 3.66 | 4.97 | 5.2 |
| Mix 4 | 2.196 | 5.56 | 6.01 | 6.87 |
| Mix 5 | 3.186 | 8.1 | 10.35 | 10.67 |

Table 4: Average Split Tensile strength of geopolymer concrete for 7 days and 28 days in MPa

Table 5: Average flexural strength of geopolymer concrete for 7days and 28 days in Mpa

| Mixes | Average Flexural strength for 7 days | | Average Flexural strength for 28 days | |
|-------|--------------------------------------|------|---------------------------------------|------|
| | Ambient | Oven | Ambient | Oven |
| Mix 1 | 1.2 | 1.87 | 3.3 | 3.43 |
| Mix 2 | 1.59 | 3.26 | 4.87 | 4.83 |
| Mix 3 | 2.42 | 4.1 | 5.7 | 5.87 |
| Mix 4 | 3.31 | 5.66 | 6.94 | 7.7 |
| Mix 5 | 4.23 | 8.46 | 10.62 | 11.2 |

VI. CONCLUSIONS

- As the percentage of GGBS increase it was found that compressive, tensile and flexural strengths increased respectively.
- 7 days strength is found to be nearly 70 % – 80% of its 28 days strength for oven cured specimens.
- Use of flyash and GGBS has been found to enable large utilization of waste products without affecting quality of concrete.
- Cost of concrete that has flyash and GGBS as replacements for cement is found cheaper than concrete with Portland cement.
- By proper proportioning of GGBS and fly ash and by selecting appropriate parameters, desired strength of geopolymer concrete can be achieved.

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AUTHORS

First Author – Apoorva . S, Department of Civil Engineering, East West Institute of Technology, Bangalore
Second Author – Namrata .F. Dabali, Department of Civil Engineering, East West Institute of Technology, Bangalore