GEO POLYMER CONCRETE WITH BASE MATERIAL AS A FLY ASH BASE MATERIAL

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Abstract —Concrete is one of the most widely used construction material. It is usually associated with Portland cement as the main component for making concrete. The demand for concrete as a construction material is on the increase. It is estimated that the production of cement will increase from 1.5 billion tons in 1985 to 2.2 billion tons in 2010(Malhotra, 1999). On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern during the last decade. The global warming is caused by the emission of greenhouse gases such as CO₂, to the atmosphere by human activities. Among the greenhouse gases CO₂ contributes about 65% of global warming. The cement industries are responsible for above 6% of all CO₂ emissions, because the production of one ton of Portland cement emits approximately one ton of CO₂ into the atmosphere. To solve the problem of emission of CO₂ we can use geo polymer as a binding agent in concrete. In geo polymer we are using two chemicals sodium silicate and sodium hydroxide, and base material as a fly ash. In geo polymer concrete cement is not playing any role so geo polymer concrete dose not emits any kind of green gases. The strength and costing of geo polymer is same as the normal concrete.

Keywords—About four key words or phraseseco-friendly concrete, geo-polymer concrete, fly ash,acid resistance.

I. INTRODUCTION

Concrete is one of the most widely used construction material. It is usually associated with Portland cement as the main component for making concrete. The demand for concrete as a construction material is on the increase. It is estimated that the production of cement will increase from 1.5 billion tons in 1985 to 2.2 billion tons in 2010(Malhotra, 1999). On the other hand, the climate change due to global warming, one of the greatest environmental issues has become a major concern during the last decade. The global warming is caused by the emission of greenhouse gases such as CO₂, to the atmosphere by human activities. Among the greenhouse gases CO₂ contributes about 65% of global warming. The cement industries are responsible for above 6% of all CO₂ emissions, because the production of one ton of Portland cement emits approximately one ton of CO₂ into the atmosphere(Davidovits, 1999; McCaffrey, 2002). The cement industries are responsible for above 6% of all CO₂ emissions, because the production of one ton of Portland cement emits approximately one ton of CO₂ into the atmosphere(Davidovits, 1999; McCaffrey, 2002).

Although, the use of Portland cement is still unavoidable until the foreseeable future, many efforts have been made in order to reduce the use of Portland cement in concrete. This efforts include the utilization of supplementary cementing material such as fly ash, silicafume, granulated blast furnace slag, rice husk ash, and metakaolin, and finding alternative binders to Portland cement. In this respect the geopolymer technology proposed by Davidovits(1998a, 1998b) shows considerable promise for application in concrete industries as an alternative binder to Portland cement. Interms of reducing the global warming, the geopolymer technology can reduce the CO₂ emission to the atmosphere caused by cement and aggregates industries by about 80%(Davidovits, 1994c).

II. FLY ASH BASED GEOPOLYMER CONCRETE

In Geopolymer concrete is manufactured using source materials that are rich in silica and alumina. While the cement based concrete utilizes the formation of calcium silica hydrates(CSHs) for the matrix formation and strength, geopolymers involve the chemical reaction of alumino silicates oxides with alkali silicates yielding polymeric Si-O-Al bonds. In this experimental work fly ash is used as the source concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, in fly ash based geopolymer concrete, the aggregates occupy the largest volume i.e. about 75-80% by mass.

Sodium based activators were chosen because they were cheaper than potassium based activators. The Sodium Hydroxide was used in flake or pallet form. It is recommended that the alkaline liquid is prepared by mixing both solution together at least 24 hours prior to use. The mass of NaOH solids in the solution varied depending on the concentration of the solution expressed in terms of molarity. The concentration of sodium hydroxide solution can vary in range between 12M to 16M. The mass of water is major component in both the alkaline solution. In order to improve the workability, a melamine based superplasticiser has been added to the mixture.

III. RESEARCH IMPORTANCE

The linear technique upgrading of new technology has been going on in Portland cement concrete industries. The ordinary cement production is more energy intensive and consume significant amount of non renewable natural
resources such as calcium stone deposits, stone etc. Therefore, the ordinary Portland cement industries does not quite fit the contemporary desirable image of a sustainable ecofriendly industries.

This are a need to find out an alternative binder material which could be similar or superior to that of Portland cement for use in concrete in respect of parameters such as processing condition for production of concrete mixes, mechanical and durability properties, long term chemical stable for the binding system with common filler aggregates system such as sand, crushed natural stone etc. because low internal energy and low CO2 contents of ingredients of geopolymer based composites compare to those conventional ordinary Portland cement concretes, the new composites can be considered to be more ecofriendly environmental and their utility in practical application need to be developed.

IV OBJECTIVES & SCOPE OF WORK

4.1 Objectives
To study various parameters, following objectives are decided for the major project.
- To study salient parameters that affect the properties into fly ash based geopolymer concrete.
- To develop the mix design process for fly ash based geopolymer concrete.
- To study the change in compressive strength of geopolymer concrete with change in Fly ash and chemical contents.
- To compare a results on oven and sunlight cure specimen.
- To study the change in mechanical properties i.e. split tensile strength and flexural strength, compressive split tensile strength and flexural strength of computed mix at different ages.
- To study the durability properties i.e. acid resistance of mixes after various days of exposure.

4.2 Scope of work
- The normal information about constituents required to produce geopolymer concrete such as fly ash coarse aggregate, alkaline liquid, fine aggregates and superplasticizer are to be studied.
- For the primary studies, the effect of eleven parameters i.e. composition of alkaline liquid, ratio of alkaline liquid to fly ash replacements, concentration of NaOH solution, ratio of Na2SiO3 solution to NaOH solution, addition of superplasticizer, cure time, cured temperature, resting period, water content of mix are investigated.
- Nine mix concrete mixes are produced for studying the salient parameters of geopolymer concrete as a part of prem investigation. It is planned to cast 9 cubes of size 150mmx150mmx150mm for the study.
- Planning to cast total of 9 cubes for geopolymer concrete for calculated mechanical properties at 3, 7, and 28 days respectively.
- Cubes of 150mmx150mmx150mm for the compressive strength test is to be used as per IS provision.

V. METHODOLOGY

5.1 Experimental Program
This chapter provide for the experimental work. This includes material, mix proportions, method of mixing, compaction, curing specimen are used. Various parameters and test procedure would be described as under.

5.2 Material
Materials use for this study are fly ash as the source material, aggregate, water alkaline liquids which consist of sodium hydroxide and sodium silicate and super plasticizer.

5.2.1 Fly Ash
Fly ash obtaining from ultratech cements (alccofine-1206) are presented in table 1.

<table>
<thead>
<tr>
<th>Oxides</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>60.54</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>26.20</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.87</td>
</tr>
<tr>
<td>CaO</td>
<td>1.91</td>
</tr>
<tr>
<td>MgO</td>
<td>0.38</td>
</tr>
<tr>
<td>K₂O+Na₂O</td>
<td>1.02</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.23</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>2</td>
</tr>
</tbody>
</table>
5.2.2 Aggregates
Locally available 10mm and 20mm crushed aggregates had been used as coarse aggregates. Locally river sand is used as fine aggregates in the mixes. Testing for fine and coarse aggregates were conducting as per IS:2386-1963[20] and IS:383-1970[21]. The sieve analysis of the fine aggregates are shown in Table 3.2. The sieve analysis of the coarse aggregate are shown in Table 2 and Table 3.

<table>
<thead>
<tr>
<th>Table:2</th>
<th>Sieve analysis of fine aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>Retained on each sieve</td>
</tr>
<tr>
<td>Wt</td>
<td>%</td>
</tr>
<tr>
<td>40mm</td>
<td>0</td>
</tr>
<tr>
<td>20mm</td>
<td>0</td>
</tr>
<tr>
<td>16mm</td>
<td>0</td>
</tr>
<tr>
<td>12.5mm</td>
<td>0</td>
</tr>
<tr>
<td>10mm</td>
<td>0</td>
</tr>
<tr>
<td>6.3mm</td>
<td>0</td>
</tr>
<tr>
<td>4.75mm</td>
<td>136g</td>
</tr>
<tr>
<td>2.36mm</td>
<td>263g</td>
</tr>
<tr>
<td>1.18mm</td>
<td>201g</td>
</tr>
<tr>
<td>600 micron</td>
<td>273g</td>
</tr>
<tr>
<td>300 micron</td>
<td>103g</td>
</tr>
<tr>
<td>150 micron</td>
<td>20g</td>
</tr>
<tr>
<td>Passing 150 micron</td>
<td>4g</td>
</tr>
<tr>
<td>Total</td>
<td>398</td>
</tr>
</tbody>
</table>

Fineness modulus = 398/100=3.98 and zone-I

<table>
<thead>
<tr>
<th>Table:3</th>
<th>Sieve analysis of 10mm aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>Retained on each sieve</td>
</tr>
<tr>
<td>Wt</td>
<td>%</td>
</tr>
<tr>
<td>40mm</td>
<td>0</td>
</tr>
<tr>
<td>20mm</td>
<td>0</td>
</tr>
<tr>
<td>16mm</td>
<td>0</td>
</tr>
<tr>
<td>12.5mm</td>
<td>0</td>
</tr>
<tr>
<td>10mm</td>
<td>151g</td>
</tr>
<tr>
<td>6.3mm</td>
<td>769g</td>
</tr>
<tr>
<td>4.75mm</td>
<td>80g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table:4</th>
<th>Sieve analysis of coarse aggregate(20mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>Retained on each sieve</td>
</tr>
<tr>
<td>Wt</td>
<td>%</td>
</tr>
<tr>
<td>40mm</td>
<td>0</td>
</tr>
<tr>
<td>20mm</td>
<td>640g</td>
</tr>
<tr>
<td>16mm</td>
<td>180g</td>
</tr>
<tr>
<td>12.5mm</td>
<td>103g</td>
</tr>
<tr>
<td>10mm</td>
<td>68g</td>
</tr>
<tr>
<td>6.3mm</td>
<td>9g</td>
</tr>
</tbody>
</table>

5.2.3 Alkaline liquid
The alkaline liquid were a combination of sodium hydroxide and sodium silicate solution. 12M, 14M, 16M solution are used. Where M=Molarity. Sodium hydroxide is commonly available in Flakes form is shown in as shown in Fig.3.1.2.1. Sodium Hydroxide(NaOH) in flakes of 98% purity is purchased from local suppliers had been used. The sodium hydroxide(NaOH) solution is prepared by dissolving the flakes in water. The mass of NaOH solids in a
solution varies depending on the concentration of the solution expressed in terms of molarity (M). Mass of NaOH solids are only a fraction of the mass of NaOH solution and water will be major component. Normal tap water is used to dissolve the NaOH pallets.

FIG:1 NaOH pallets

Sodium silicate solution (Na₂SiO₃) are available in liquid form are used. First NaOH flakes were mixed with water than sodium silicate solution is added. The alkaline solution was prepare one day before the casting of the specimen or concrete cubes.

5.3 Geopolymer Concrete Mix Design

In a geopolymer concrete, the silicon and aluminium oxides in fly ash with alkaline liquid to form the geopolymer bond between the coarse aggregate and fine aggregate to together to form the geopolymer concrete. The average density of fly ash based geopolymer concrete had been considered similar to that of OPC concrete of 2440 kg/m³ based on literature. The ratio of alkaline liquid to fly ash takes as 0.4, mass of Fly ash and mass of alkaline liquid were found out. By taking the ratio of sodium silicate solution to sodium hydroxide solution were 2.5, We have find out the mass of sodium silicate solution and sodium hydroxide solution.

Using the above procedure, the mix has been designed

Casting for M25 Mpa

Density: It has been observed that the density for the Fly ash based geopolymer concrete varies between 2370 to 2480 kg/m³.

Aggregates: Mass of combined aggregates is selected as 75% of mass of concrete

Total aggregate = 0.75X2400 = 1800 kg/m³

Assume 35% of fine aggregate to the total mass of aggregate,

Fine aggregate = 0.35X1800 = 630 kg/m³

Coarse aggregate = 1800 - 630 = 1170 kg/m³

Assume 60% of 20mm aggregate and 40% of 10mm aggregate to the total mass of coarse aggregate,

10mm aggregate = 1170X0.4 = 468 kg/m³

20mm aggregate = 1170 - 468 = 702 kg/m³

Fly ash: Mass of fly ash and alkaline liquid = 2400 - 1800 = 600 kg/m³

Ratio of (Na₂SiO₃+NaOH)solution: fly ash is 0.4

Mass of Fly ash replacement = 600/(1+0.4) = 428.57 kg/m³

Alkaline liquid: Mass of alkaline liquid = 600 - 428.57 = 171.43 kg/m³

Ratio of Na₂SiO₃ solution to NaOH solution = 2.5

Mass of sodium hydroxide solution = 171.43/(2.5+1) = 48.98 kg/m³

Mass of sodium silicate solution = 171.43 - 48.98 = 122.45 kg/m³

Extra water: It has been observed that 10% of extra water required for the workability of the geopolymer concrete

Extra water = 428.57X0.1 = 42.86 kg/m³
Table: Geopolymer Concrete Mix design

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Quantity (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of geopolymer Concrete</td>
<td>2400</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1670</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>630</td>
</tr>
<tr>
<td>Total Aggregate</td>
<td>1800</td>
</tr>
<tr>
<td>10 mm aggregate</td>
<td>600</td>
</tr>
<tr>
<td>20 mm aggregate</td>
<td>702</td>
</tr>
<tr>
<td>Mass of fly ash: alkaline liquid</td>
<td>0.4</td>
</tr>
<tr>
<td>Mass of fly ash</td>
<td>428.57</td>
</tr>
<tr>
<td>Mass of (Na₂SiO₃+NaOH) solution</td>
<td>171.43</td>
</tr>
<tr>
<td>Ratio of (Na₂SiO₃+NaOH) solution: fly ash is 0.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Mass of sodium hydroxide solution</td>
<td>48.98</td>
</tr>
<tr>
<td>Mass of sodium silicate solution</td>
<td>122.45</td>
</tr>
<tr>
<td>Extra water</td>
<td>42.86</td>
</tr>
</tbody>
</table>

Based on above mix design and proportion, we have decided the total masses of all the constituents of geopolymer concrete and prepare a table for various concentration of sodium hydroxide solution i.e. 12M, 14M, 16M. Following calculation are the total mass of sodium hydroxide solution and sodium silicate solution for 3 cubes each consisting of 12, 14 and 16M concentration of sodium hydroxide solution.

Table: Masses of solids of NaOH and Proportions for alkaline liquid

<table>
<thead>
<tr>
<th>Molarity (NaOH) solution</th>
<th>Mass of Na₂SiO₃, solution</th>
<th>Mass of NaOH solution</th>
<th>Mass of solids in NaOH solution</th>
<th>Mass of water in NaOH solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>12M</td>
<td>1.25 kg</td>
<td>495.92 g</td>
<td>238.2 g</td>
<td>257.5 g</td>
</tr>
<tr>
<td>14M</td>
<td>1.25 kg</td>
<td>495.92 g</td>
<td>277.9 g</td>
<td>218.3 g</td>
</tr>
<tr>
<td>16M</td>
<td>1.25 kg</td>
<td>495.92 g</td>
<td>318 g</td>
<td>179 g</td>
</tr>
</tbody>
</table>

5.4 Conventional Concrete Mix Design

Conventional concrete mix design for M25 grade is done as per IS:10262-2009[23]. Test data for materials:
- Specific gravity of cement = 2.5
- Specific Gravity for coarse aggregate = 2.78
- Specific Gravity of fine aggregate = 2.55
- Fine aggregate Zone = I
- Maximum water cement ratio = 0.45
- Water Content for 75 mm slump = 191.58 litre
- Cement = 375 kg/m³
- Cement = OPC 53 Grade

Table: Mix design for M25 grade of conventional concrete

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Quantity (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>192.45</td>
</tr>
<tr>
<td>Cement</td>
<td>358</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>711.44</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1111.54</td>
</tr>
</tbody>
</table>

5.5 Casting method for geopolymer.

The mixing procedure was very important for getting consistency in production of geopolymer concrete. If mixing procedures was not followed in the proper order, it is possible that the concrete may set in the mixer machine or inappropriate result from that fix is obtained. Specimen moulds are made ready for pouring of concrete by coating with the appropriate lubricant. Cubes of size 150mm x 150mm x 150mm were used. The procedure for mixes are as follows. The sodium hydroxide flakes were dissolved in distilled water to make a solution with a desired concentration at least one day prior to use.

The fly ash and the aggregates were first mixed together in a pan mixer for about three minutes.

The sodium hydroxide and the sodium silicate solutions were mixed together with superplasticizer then added to the dry materials and mixed for about four minutes.

The fresh concrete was cast into the molds immediately after mixing, in three layers and compacted with manual strokes and vibrating table.
After casting, the specimens were cured at 60°C for 24 hours. Two types of curing were applied, Heat curing and Ambient curing. For heat curing, the specimens were cured in an oven as shown in Fig. and for Ambient curing the specimens were left to air for desires period. The heat cured specimens were left to air-dry in the laboratory for the next six days until testing on the 7th day and 28th day.

For the designated grade of Geopolymer concrete mix about 7 mixture proportions were tested and optimized by taking the mix which is giving maximum compressive strength at 28 days under Heat curing (Oven curing) and Ambient cured conditions.

Based on earlier research conducted in Materials testing lab by the author, the following parameters were maintained constant throughout the Experimental work.

The parameters for curing are as follows:
- The ratio of sodium silicate to sodium hydroxide = 2.5
- The curing Temperature = 60°C
- The curing duration = 24 Hrs
- Ratio of Fine aggregate to total Aggregate = 0.35

The other parameters vary between different grades of concrete.

![Figure:2 Mixture used for casting of concrete](image1.png)

![Figure:3 Geopolymer Cubes after casting](image2.png)

![Figure:3 Geopolymer Cubes after casting](image3.png)

![Figure:5 Fresh geopolymer Concrete](image4.png)
5.6 Compressive strength

The compressive strength of concrete has been evaluated using 2000kN capacity hydraulic testing machine. There are two types of cube sizes are 150mmX150mmX150mm size of cubes used. For compressive strength test cube of size 150mmX150mmX150mm are tested in compression in accordance with test procedure given in IS:516-1959. Fig. shows the cube specimen which is being tested in compression testing machine. Finding out the compressive strength of cube specimen following equation is used:

\[
\text{Compressive strength of concrete (N/mm}^2\) = \frac{P}{A}
\]

Where,

\(P\) = failure of load of cube (KN)

\(A\) = area of concrete cube specimen in \(\text{mm}^2\) (150mmX150mm)

5.7 Results

In this chapter, results of preliminary analysis are presented in detail. To develop Fly ash based geopolymer concrete, various mix proportion to compare with M25, the change in compressive strength of concrete with change in concentration of sodium hydroxide solution i.e Molarity (M) was observed by keeping all other parameters like curing temperature, sodium silicate to sodium hydroxide solution ratio constant, resting time. There are two different curing are carried out i.e. oven curing and sunlight curing for all trial mixes.

**Table 8: Comparison of Compressive strength of different geopolymer mixes with conventional mix**

<table>
<thead>
<tr>
<th>Strength following days</th>
<th>Conventional Concrete</th>
<th>Geopolymer Concrete(12M)</th>
<th>Geopolymer Concrete(14M)</th>
<th>Geopolymer Concrete(16M)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O.C</td>
<td>S.C</td>
<td>O.C</td>
<td>S.C</td>
</tr>
<tr>
<td>3</td>
<td>16.05</td>
<td>19.85</td>
<td>14.81</td>
<td>22.37</td>
</tr>
<tr>
<td>7</td>
<td>21.77</td>
<td>23.11</td>
<td>19.7</td>
<td>34.07</td>
</tr>
<tr>
<td>28</td>
<td>33.62</td>
<td>26.67</td>
<td>21.63</td>
<td>36.3</td>
</tr>
</tbody>
</table>
Figure 7. Compressive strength of Geopolymer Concrete (12M)

Figure 8. Compressive strength of Geopolymer Concrete (14M)
From the above result, it is found that geopolymer concrete gain more strength in oven curing than sunlight curing. So, the strength of oven curing is compared to the conventional concrete’s compressive strength for 3, 7, 28 days respectively.

Comparision between Compressive strength of Geopolymer Concrete(16M) O.C & S.C

From above data, it is found that keeping other parameters constant the strength of geopolymer concrete consisting of concentration of 14M of sodium hydroxide solution which is cheaper as well as gave same properties like conventional concrete in terms of compressive strength.

VI. Conclusion

- From the investigation it is clear that for Water/binder ratio & alkaline liquid/Flyash ratio are the governing factors in designing the Geopolymer mix design for various grades. The Water/binder ratio 0.21 and Alkaline liquid to flyash ratio of 0.40 are suggested for G40 which indicates improvement in compressive strength of geopolymer concrete can be achieved by decreasing water binder ratio.
- The compressive strength attained at 28 days for Geopolymer concrete under ambient curing is almost equal to compressive strength achieved by Geopolymer concrete at 7 days. Because of the slow reactivity of flyash at ambient temperature, considerable heat must be applied to increase the geopolymerization process.
The decrease in water content favors the formation of geopolymerization process, which demands for increase of concentration of Sodium hydroxide and sodium silicate silicates. Hence increase in concentration of NaOH results in increase of compressive strength. Hence it is recommended 14M concentrations for medium grade.

It is recommended to add Superplasticizers for high strength Geopolymer concretes, which is analogous to Conventional concrete of higher grades to secure required workability.

It also reported that unlike in the past literature, inclusion of high alkaline solution content to the mix need not increases the strength which can be seen from reported Geopolymer mixes in the present work.

VII. Future Work

In future work after finding the suitable concentration of sodium hydroxide solution we are looking ahead of other properties that is acid resistance tests and all other properties and we are finding the work wheather geopolymer concrete supports reinforcement or not. So in future we are designing prestressed geopolymer concrete which has ultimate strength after prestressing or post tensioning so we are looking ahead for designing the prestressed geopolymer concrete beams and small structural members in future.

REFERENCES