Effect on Strength Characteristics of Low Calcium Fly Ash based Geopolymer Concrete - An Initiative towards Green Concrete

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Abstract

The main objective of this current study is to develop a cement free concrete material because of the green house effect during the manufacture of cement. It is reported that every one tonne production of cement emits one tonne carbon dioxide which causes global warming and in broad sense disturbs the entire ecological system. It results the promotion of geopolymer concrete where silica and alumina will bind together with alkaline solution during the process of polymerization. The researchers taken greater initiatives in geopolymer concrete there is no specific study related to the mix design because of commercialization and patenting. Hence the authors interested in identifying specific mix design using trial proportion of low calcium fly ash and alkaline solutions (sodium silicate and sodium hydroxide). This investigation deals with five different trial mixes with different molarity of NaOH (8M, 10M, 12M and 14M) and super plasticizer combinations under the curing temperature of 60ºC. The fresh and hardened properties have been
studied and found that 12M of NaOH concentration with 1% of super plasticizer and 8M of NaOH with 1.5% of super plasticizer produces high strength characteristics.

**Keywords:** Low Calcium Fly Ash, Geopolymer, Polymerization, Alkaline Solution, Plasticizer, and Molarity.

**Introduction**
Concrete is the second most consumed material after water and is the basis for the urban development. It can be roughly estimated that 30 billion tonnes of concrete are manufactured globally each year. Concrete is generally made from cement, fine aggregate (sand), coarse aggregate (stone and gravel) and water. It is estimated that the production of cement is reported by 150 countries and reached 3.7 billion tonnes in 2012 (USGS, 2013a). The Demand for cement in India totaled 154 million metric tons in 2007, representing the second largest market in the world behind China. The production of cement is in critical conditions due to high amount of carbon dioxide gas released to the atmosphere. The trading of carbon dioxide (CO$_2$) emissions is a critical factor the cement industries, as the greenhouse effect created by the emissions is considered to produce an increase in the global temperature that may result in climate changes. Hence the researchers intended to identify a new material which has not even required cement as a binder material to control global warming in broad sense. This research is one such attempt to produce green concrete using industrial by product such as low calcium (class F) fly ash, contains high silica and alumina which is activated by alkaline solution to produce binder known in the name of geopolymer concrete.

**Geopolymer Concrete**
Geopolymer is an inorganic polymer and having a chain structure formed with Al and Si ions. The chemical composition of this geopolymer material is similar to natural zeolitic materials, but they have amorphous microstructure instead of crystalline (Palomo, Grutzeck et al. 1999; Xu and van Deventer 2000). The polymerisation process is a fast chemical reaction under highly alkaline environment on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits 1999).

**Source Materials for Geopolymer Concrete:**
Materials which contain Si and Al may be tried as geopolymer source materials. In the initial stages many minerals and industrial by products such as metakaolin, calcined and non calcined minerals, fly ash, silica fume, granulated blast furnace slag and combinations of the above were investigated as a source material (Davidovits 1999; Barbosa, MacKenzie et al. 2000, Teixeira-Pinto, Fernandes et al. 2002, Palomo, Grutzeck et al. 1999; Swanepoel and Strydom 2002, Xu and Van Deventer 2000, 2002, Cheng and Chiu 2003). They found that the materials listed above are very
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expensive except fly ash, further Low calcium (ASTM Class F) fly ash is preferred as a source material than high calcium (ASTM Class C) fly ash. The presence of calcium in high amount may interfere with the polymerisation process and alter the microstructure (Gourley 2003). The suitability of various types of fly ash to be geopolymer material has been studied by Fernández-Jiménez and Palomo (2003). The study insisted that to bring out optimal binding properties, the low-calcium fly ash should have unburned material less than 5%, Fe₂O₃ content not more than 10%, low CaO content, the content of reactive silica should be between 40-50%, and 80-90% of particles should be smaller than 45 μm. The most common alkaline activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Davidovits 1999; Palomo, Grutzeck et al. 1999; Barbosa, MacKenzie et al. 2000; Xu and van Deventer 2000; Swanepoel and Strydom 2002; Xu and van Deventer 2002).

Experimental Programme
This present study mainly focuses on the strength characteristics of low calcium fly ash based geopolymer concrete. Since the available literatures are not sufficient to identify the mix proportion, trial mixtures are selected to identify the mechanical properties. The materials used in the study are listed below.

Materials:
Fly ash:
In this study locally available low calcium fly ash obtained from Kadaieswari Ready Mix Plant, Coimbatore was used. The chemical composition of fly ash used and Ordinary Portaland Cement were compared and tabulated below in Table 1. It can be observed in the table 1 that the fly ash contains low calcium oxide, the molar ratio of Si to Al is 2 and Iron oxide content was higher than Cement. The specific gravity of the fly ash was 2.30 and fineness modulus was 1.38.

Table 1: Comparison of Chemical Composition of Fly ash and Cement

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>Cement</th>
<th>Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>21.0</td>
<td>56.8</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>5.9</td>
<td>28.2</td>
</tr>
<tr>
<td>CaO</td>
<td>64.7</td>
<td>&lt;3</td>
</tr>
<tr>
<td>MgO</td>
<td>0.9</td>
<td>5.2</td>
</tr>
<tr>
<td>SO₃</td>
<td>2.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Alkali Na₂O</td>
<td>0.4</td>
<td>0.14</td>
</tr>
<tr>
<td>Chloride Content</td>
<td>0.0004</td>
<td>&lt;0.0005</td>
</tr>
</tbody>
</table>

Alkaline Activators:
A combination of sodium silicate solution and sodium hydroxide solution were chosen as the alkaline liquid. Sodium hydroxide in pellets form with 97% purity and
sodium silicate solution of 0.1N were used. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in distilled water. Preparation of NaOH solution resulted in emission of heat of 60°C. The mass of NaOH solids in a solution varied in the current study as 8, 12 & 14 Molarities.

**Aggregates:**
Natural river sand passing through 4.75mm IS sieve was used for making concrete. The specific gravity test was conducted and the result was 2.65 and fineness modulus was 2.25. As per IS: 383-1973 natural river sand was categorized under grading zone II. Crushed angular shaped coarse aggregate of size 20mm, 12mm and 6mm were used in different combinations. The specific gravity test results showed 2.66 & fineness modulus show 6.40.

**Mixing and Curing:**
The aggregates and the fly ash were mixed in the mixer machine and the alkaline solution (Na₂O=14.7%, SiO₂=29.4%, and 55.9% of water, by mass prepared 24 hrs before casting), the super plasticizer (CONPLAST SP430) and the water, was added to the solids, and the mixing continued for the required duration. The fresh concrete was then cast in cube mould of size 150 mm x 150 mm x 150 mm, cylindrical mould of size 150 mm x 300 mm and prism of size 100 mm x 100 mm x 500 mm. Compaction was performed using the vibration table. After casting, the concrete samples were cured in oven at 60°C temperature for two days and after that the specimens were left in atmospheric curing for 7, 14 and 28 days. The trial mixes are listed in Table 2 and the entire experimental programme are shown in Figure 1.

<table>
<thead>
<tr>
<th>Trial Mix</th>
<th>Aggregates (kg)</th>
<th>Fly ash (kg)</th>
<th>NaOH Solution Mass (kg)</th>
<th>Molarity (M)</th>
<th>Sodium Silicate (kg)</th>
<th>Added Water (kg)</th>
<th>Super Plasticizer (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>670</td>
<td>447</td>
<td>668</td>
<td>400</td>
<td>44.8</td>
<td>8</td>
<td>95</td>
</tr>
<tr>
<td>2.</td>
<td>716</td>
<td>477</td>
<td>672</td>
<td>377</td>
<td>44</td>
<td>10</td>
<td>109</td>
</tr>
<tr>
<td>3.</td>
<td>776</td>
<td>517</td>
<td>702</td>
<td>394</td>
<td>16.2</td>
<td>12</td>
<td>112</td>
</tr>
<tr>
<td>4.</td>
<td>554</td>
<td>647</td>
<td>647</td>
<td>408</td>
<td>41</td>
<td>14</td>
<td>103</td>
</tr>
<tr>
<td>5.</td>
<td>554</td>
<td>647</td>
<td>647</td>
<td>408</td>
<td>41</td>
<td>8</td>
<td>103</td>
</tr>
</tbody>
</table>

**Results and Discussion**

**Fresh Concrete Testing:**
Workability refers to the mobility or flow ability of concrete experimented by slump test. The slump test was carried out for all the trial mixes of geopolymer concrete. The workability of all trail mixes has been good and authors found no trouble during mixing. Eventually authors want to point out that when the molarity of NaOH increases slump factor decreases accordingly (Figure 2).
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Figure 1 (a) (b) (c) - Sequential Activities during Experimentation of Geopolymer Concrete

(a) Alkaline Solution Preparation

(b) During Slump Test, Casting and Oven Curing

(c) During Compression and Flexural Testing
Compressive Strength of Geopolymer Concrete:
The compressive strength test was performed with 2000 KN capacity compression testing machine. The compressive strength of various trial mixes has been tested and the graph is shown in Figure 3. The performance of geopolymer concrete increases when atmospheric curing period increases (Figure 3) in all trial mixes. Hence bonding may not be the problem in geopolymer concrete. Trial mix 3 which contains NaOH concentration of 12M performs better than other mixes in the lot, which show a higher compressive strength of 30.01 N/mm². The compressive strength gradually enhances according to NaOH concentration up to 12M and after that there was a sudden decrease in compressive strength recorded as 28.98%. Even though a better percentage of super plasticizer was added to mix 4 still there is no improvement in compressive strength. So, this is a clear indication that there is no impact was identified with use of super plasticizer when NaOH concentration rose more than 12M. The bonding property also a trouble when NaOH concentration getting increases more than 12M, the authors found difficulty of early settlement of NaOH. The effect of super plasticizer was notable in the trial mix 3 which gave a 38.10% increase in compressive strength than that of mix 1.
Split Tensile Strength of Geopolymer Concrete:
Cylindrical specimen were tested by the indirect tensile test method using compression testing machine for all the trial mixes and the graph was drawn (Figure 4). Split tensile strength was gradually increases up to 12M of NaOH and mix 3 showcases the higher strength here. Hence the hypotheses which the authors derive were defended here in tensile strength also. The role of super plasticizer was notable in the split tensile strength of geopolymer concrete because mix 3 produces higher strength considerably than mix 1.
Flexural Strength of Geopolymer Concrete:
The prism specimens of various trail mixes were tested in the flexural testing machine. The results show a gradual strength enhancement up to 12M NaOH concentration. Similarly here also mix 3 proves better flexural strength than other mixes. Mix 5 showcase good flexural strength enhancement and proves the impact of super plasticizer in the 8M NaOH concentration.

Here it was evident in the Figure 3 - Figure 5 that 12M NaOH concentration and 8M NaOH concentration which have been added with super plasticizer performs better in all indispensible strength. Further it is clearly understood that the increase in sodium silicate will enhance the mechanical properties of geopolymer concrete.

![Figure 5: Flexural Strength of Geopolymer Trial Mixes](image)

Conclusion
The above said discussions made the authors to derive the following conclusion:
- The 12 Molar concentration of sodium hydroxide solution results in higher mechanical properties in the tested low calcium based geopolymer concrete.
- The addition of super plasticizer provides increment in all indispensible strength in the lower concentration of sodium hydroxide solution which was added in the geopolymer concrete.
- Higher the amount of sodium silicate enhances the compressive, tensile and flexural strength of geopolymer concrete.
- Longer in atmospheric curing time resulted in gradual increment of all the
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- The slump value of geopolymer reduces when there was an increase in alkaline liquid.
- The usage of geopolymer concrete will greatly reduce the cement production which indeed the reduction of CO₂ emission in the environment. Hence this product may be a step towards a greener and cleaner environment.

References


