EFFECT OF ALKALI MATERIALS ON GEO POLYMER CONCRETE

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ABSTRACT

The use of Portland cement in concrete construction is under critical review due to high amount of carbon dioxide gas released to the atmosphere during the production of cement. In recent years, attempts to increase the utilization of fly ash to partially replace the use of Portland cement in concrete are gathering momentum. Most of this by-product material is currently dumped in landfills, creating a threat to the environment. Geopolymer concrete is a ‘new’ material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as fly ash, that are rich in Silicon (Si) and Aluminium (Al), are activated by alkaline liquids to produce the binder. Hence concrete with no Portland cement.

This paper reports the details of development of the process of making fly ash-based geopolymer concrete. Due to the lack of knowledge and know-how of making of fly ash based geopolymer concrete in the published literature, this study is based on performance analysis reported by, hardjito et al, who have done a rigorous trial and error process to develop the technology of making, and to identify the salient parameters affecting the properties of fresh and hardened concrete. As far as possible, the technology that is currently in use to manufacture and testing of ordinary Portland cement concrete were used.

Fly ash was chosen as the basic material to be activated by the geopolimerization process to be the concrete binder, to totally replace the use of Portland cement. The binder is the only difference to the ordinary Portland cement concrete. To activate the Silicon and Aluminium content in fly ash, a combination of sodium hydroxide solution and sodium silicate solution was used. The main parameters affecting the compressive strength of hardened fly ash-based geopolymer concrete are the curing temperature and curing time, the molar H2O-to-Na2O ratio. Fresh fly ash-based geopolymer concrete has been able to remain workable up to at least 120 minutes without any sign of setting and without any degradation in the compressive strength.
A comparison between geo polymer concretes has been done, which were activated by different activators viz. sodium hydroxide (NaOH), potassium hydroxide (KOH) and combination of both.

INTRODUCTION

After wood, concrete is the most often used material by the community. Concrete is conventionally produced by using the ordinary Portland cement (OPC) as the primary binder. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the amount of energy required to produce OPC is only next to steel and aluminium. On the other side, the abundance and availability of fly ash worldwide create opportunity to utilise this by-product of burning coal, as partial replacement or as performance enhancer for OPC. Fly ash in itself does not possess the binding properties, except for the high calcium or ASTM Class C fly ash. However, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. This pozzolanic action happens when fly ash is added to OPC as a partial replacement or as an admixture. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60-65% by mass (Malhotra 2002; Malhotra and Mehta 2002), can be regarded as a landmark in this attempt.

GEO POLYMER CONCRETE

The polymerisation process involves a substantially fast chemical reaction under highly alkaline condition on Si-Al minerals, that results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Davidovits 1999):

\[ \text{Mn}\left[-(\text{SiO}_2)\ z-\text{AlO}_2\right]n.\ w\text{H}_2\text{O} \quad (2-1) \]

Where: M = the alkaline element or cation such as potassium, sodium or calcium; the symbol – indicates the presence of a bond, n is the degree of polycondensation or polymerisation; z is 1, 2, 3, or higher, up to 32.

The schematic formation of geopolymer material can be shown as described by Equations (2-2) and (2-3) (van Jaarsveld, van Deventer et al. 1997; Davidovits 1999). These formations indicate that all materials containing mostly Silicon (Si) and Aluminium (Al) can be processed to make the geopolymer material.
To date, the exact mechanism of setting and hardening of the geopolymer material is not clear, as well as its reaction kinetics. However, most proposed mechanism consist of the following (Davidovits 1999; Xu and van Deventer 2000):

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Transportation or orientation or condensation of precursor ions into monomers.
- Setting or polycondensation/polymerisation of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately (Palomo, Grutzeck et al. 1999). Davidovits (1999) proposed the possible applications of the geopolymer material depending on the molar ratio of Si to Al, as given in Table 2.1.

<table>
<thead>
<tr>
<th>Si/Al</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bricks, ceramics, fire protection</td>
</tr>
<tr>
<td>2</td>
<td>Low CO₂ cements, concrete, radioactive &amp; toxic waste encapsulation</td>
</tr>
<tr>
<td>3</td>
<td>Heat resistance composites, foundry equipments, fibre glass composites</td>
</tr>
<tr>
<td>&gt;3</td>
<td>Sealants for industry</td>
</tr>
<tr>
<td>20&lt;Si/Al&lt;35</td>
<td>Fire resistance and heat resistance fibre composites</td>
</tr>
</tbody>
</table>

Table 1: Applications of Geopolymer Material

CONSTITUENTS OF GEOPOLYMER

Source Materials

Any material that contains mostly Silicon (Si) and Aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Several minerals and industrial by-product materials have been investigated in the past. Metakaolin or calcined kaolin (Davidovits 1999; Barbosa, MacKenzie et al. 2000; Teixeira-Pinto, Fernandes et al. 2002), ASTM Class F fly ash (Palomo, Grutzeck et al. 1999; Swaneport and Strydom 2002), natural Al-Si minerals (Xu and van Deventer 2000), combination of calcined mineral and non calcined materials (Xu and van Deventer 2002), combination of fly ash and metakaolin (Swaneport and Strydom 2002; van Jaarsveld, van Deventer et al. 2002), and combination of granulated blast furnace slag and metakaolin (Cheng and Chiu 2003) were investigated as source materials.
Metakaolin is preferred by the niche geopolymer product developers due to its high rate of dissolution in the reactant solution, easier control on the Si/Al ratio and the white colour (Gourley 2003). However, for making concrete in a mass production state, metakaolin is very expensive. 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).

Alkaline Activators

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). The use of a single alkaline activator has been reported (Palomo, Grutzeck et al. 1999; Teixeira-Pinto, Fernandes et al. 2002), Palomo et al (1999) concluded that the type of activator plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline activator contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. Xu and van Deventer (2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline activator enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

Fresh Geopolymers and Manufacturing Process

Only limited information on the behaviour of the fresh geopolymers has been reported. Using metakaolin as the source material, Teixeira Pinto et al (2002) found that the fresh geopolymer mortar became very stiff and dry while mixing, and exhibited high viscosity and cohesive nature. They suggested that the forced mixer type should be used in mixing the geopolymer materials, instead of the gravity type mixer. An increase in the mixing time increased the temperature of the fresh geopolymers, and hence reduced the workability. To improve the workability, they suggested the use of admixtures to reduce the viscosity and cohesion.

While Teixeira Pinto et al (2002) concluded that Vicat needle apparatus is not appropriate to measure the setting time of fresh geopolymer concrete, Cheng and Chiu (2003) reported the only information available to date on the quantitative measure of the setting time of geopolymer material using the Vicat needle. For the fresh geopolymer paste based on metakaolin and ground blast furnace slag, they measured the setting time of the geopolymer material both at room and elevated temperature. In the elevated temperature, the measurement was done in the oven.

They found that the initial setting time was very short for geopolymers cured at 60oC, in the range of 15 to 45 minutes. (Barbosa, MacKenzie et al. 1999) measured the viscosity of fresh metakaolin-based geopolymer paste, and reported that the viscosity of the geopolymer paste increased with time.

Most of the manufacturing process of making geopolymer paste involved dry mixing of the source materials, followed by adding the alkaline solution and then further mixing for another specified period of time (van Jaarsveld, van Deventer et al. 1998; Swanepoel and Strydom 2002; Teixeira-Pinto, Fernandes et al. 2002).

However, Cheng and Chiu (2003) reported the mixing of the KOH and metakaolin first for ten minutes. Sodium silicate and ground blast furnace slag were then added, followed by a further mixing for another five minutes. The paste samples were then cast in 50x50x50 mm cube moulds and vibrated for five minutes.
For curing, a wide range of temperatures and curing periods were used, ranging from room temperature to about 90°C, and from 1 hour to more than 24 hours. Geopolymers produced by using metakaolin have been reported to set at ambient temperature in a short time (Davidovits 1999). However, curing temperature and curing time have been reported to play important roles in determining the properties of the geopolymer materials made from by-product materials such as fly ash.

Palomo et al (1999) stated that increase in curing temperature accelerated the activation of fly ash, and resulted in higher compressive strength. Barbosa et al (2000) elaborated the process of manufacturing geopolymers by allowing the fresh mixtures to mature in room temperature for 60 minutes, followed by curing at 65°C for 90 minutes, and then drying at 65°C.

Factors Affecting the Properties of Geopolymers

Several factors have been identified as important parameters affecting the properties of geopolymers. Palomo et al (1999) concluded that the curing temperature was a reaction accelerator in fly ash-based geopolymers, and significantly affected the mechanical strength, together with the curing time and the type of alkaline activator. Higher curing temperature and longer curing time were proved to result in higher compressive strength. Alkaline activator that contained soluble silicates was proved to increase the rate of reaction compared to alkaline solutions that contained only hydroxide.

Van Jaarsveld et al (2002) concluded that the water content, and the curing and calcining condition of kaolin clay affected the properties of geopolymers. However, they also stated that curing at too high temperature caused cracking and a negative effect on the properties of the material. Finally, they suggested the use of mild curing to improve the physical properties of the material. In another report, van Jaarsveld et al (2003) stated that the source materials determine the properties of geopolymers, especially the CaO content, and the water-to-fly ash ratio. Based on a statistical study of the effect of parameters on the polymerisation process of metakaolin-based geopolymers, Barbosa et al (1999; 2000) reported the importance of the molar composition of the oxides present in the mixture and the water content. They also confirmed that the cured geopolymers showed an amorphous microstructure and exhibited low bulk densities between 1.3 and 1.9.

Based on the study of geopolymerisation of sixteen natural Si-Al minerals, Xu and van Deventer (2000) reported that factors such as the percentage of CaO, K2O, and the molar Si-to-Al ratio in the source material, the type of alkali activator, the extent of dissolution of Si, and the molar Si-to-Al ratio in solution significantly influenced the compressive strength of geopolymers.

Geopolymer Concrete Products

Palomo et al (2004) reported the manufacture of fly ash-based geopolymer concrete railway sleepers. They found that the geopolymer concrete structural members could easily be produced using the existing current concrete technology without any significant changes. The engineering performances of the products were excellent, and the drying shrinkage was small.

Earlier, Balaguru et al (1997; 1999) reported the use of geopolymer composites layers to strengthen concrete structures as well as geopolymer coating to protect the transportation infrastructures. They reported that geopolymer composites have been successfully applied to strengthen reinforced concrete beams. The performance of geopolymers was better than the organic polymer in terms of fire resistance, durability under ultra violet light, and did not involve any toxic.
EXPERIMENTAL PROGRAM

MATERIALS

Fly Ash
In the present experimental work, fly ash from itihad cements corporation (ICC and co) was used.

Alkaline Activators
To activate the fly ash, a combination of sodium hydroxide solution and sodium silicate solution was chosen as the alkaline activator. Sodium-based activators were chosen because they were cheaper than Potassium-based activators. The sodium hydroxide used was either a technical grade sodium hydroxide in flakes form (3 mm), with a specific gravity of 2.130, 98% purity, and obtained from M.Y and CO.,Maisuma Srinagar. or a commercial grade in pellets form with 97% purity, obtained from M.Y and CO.,Maisuma Srinagar.

The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentrations. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10M: 314 grams, 12M: 361 grams, 14M: 404 grams, and 16M: 444 grams. Note that the mass of NaOH solids was only a fraction of the mass of NAOH solution, and water is the major component.

Sodium silicate solution (Vitrosol D - A53) obtained from M.Y. and CO. was used. The chemical composition of the sodium silicate solution was Na2O=14.7%, SiO2=29.4%, and water 55.9% by mass. The other characteristics of the sodium silicate solution were specific gravity=1.53 g/cc and viscosity at 20oC=400 cp.

Aggregates
Aggregates currently used by the local crusher in lasjan. Coarse aggregates were obtained in crushed form; majority of the particles were of granite type. The fine aggregate was obtained from the sand dunes in uncrushed form.

LABORATORY WORK

No code in world has yet given the mix designs of geopolymers concretes. Thus, the mix adopted in the project work has been reported by Hardjito et al in his papers and in his thesis under heading “preliminary laboratory work”. In the beginning, he manufactured numerous trial mixtures of geopolymers concrete, and made test specimens in the form of 100*100*100 mm cubes or 100x150 mm cylinders. the mixing was done manually.

Mixing
It was found that the fresh fly ash-based geopolymer concrete was dark in colour (due to the dark colour of the fly ash), and was cohesive. The amount of water in the mixture played an important role on the behaviour of fresh concrete. Hardjito’s Communication with Davidovits (2002), suggested that it is preferable to mix the sodium silicate solution and sodium hydroxide solution before adding it to the solid constituents. He also suggested that the sodium silicate liquid obtained from the market usually is in the form of a dimer or a trimer, instead of a monomer, and mixing it together with the sodium hydroxide solution assists the polymerization process. When this
suggestion was followed, it was found that the occurrence of bleeding and segregation ceased. Thus, it was decided to observe the following standard process of mixing in all further studies.

- Mix sodium hydroxide solution and sodium silicate solution together prior to adding to the dry materials.
- Mix all dry materials in the pan mixer for about three minutes. Add the liquid component of the mixture at the end of dry mixing, and continue the wet mixing for another four minutes.

**Curing**

Geopolymer concrete specimens should be wrapped during curing at elevated temperatures in a dry environment (in the oven) to prevent excessive evaporation. Unlike the small geopolymer paste specimens, which can easily be wrapped by placing a lid on the mould, a suitable method was needed for large size geopolymer concrete specimens. Fly ash-based geopolymer concrete do not set immediately at room temperature. When the room temperature was less than 30°C, the setting did not occur at least for 24 hours. Also, the handling time is a more appropriate parameter (rather than setting time used in the case of OPC concrete) for fly ash-based geopolymer concrete.

**MIXTURE PROPORTION**

Based on the limited past research on geopolymer pastes available in the literature and the experience gained during the preliminary experimental work by Hardjito et al (Section 3.3), the following ranges were selected for the constituents of the mixtures used in further studies described in Chapter 4.

- Low calcium (ASTM Class F) fly ash
- Alkaline activators as NaOH and KOH.

The mixture proportion taken is as follows:

| Table 2.0: proportion of GPC in case of NaOH as an activator |
|-----------------|-----------------|-----------------|
| Materials       | Mixture 1       | Mixture 2       |
| Coarse aggregate|                 |                 |
| 20mm            | 277             | 277             |
| 14mm            | 370             | 370             |
| 7mm             | 647             | 647             |
| Fine Sand       | 554             | 554             |
| Fly Ash         | 408             | 408             |
| Sodium silicate solution | 103 | 103 |
| Sodium hydroxide solution | 41 | 41(extra water) |
|   8 Molar       | 14 molar        |

| Table 3.0: Proportion of ingredients in case of KOH as activator |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Ingredients     | unit            | Mixture 1       | Mixture 2       | Mixture 3       | Mixture 4       |
| Fly ash         | Kg/m3           | 425             | 425             | 425             | 425             |
| Fine aggregates | Kg/m3           | 505             | 505             | 505             | 505             |
| Coarse aggregates | Kg/m3         | 442             | 442             | 442             | 442             |
| Alkaline solution | Kg/m3       | .35             | 0.35            | 0.35            | 0.35            |
| KOH             | Kg/m3           | 2.5             | 2.5             | 2.5             | 2.5             |
| Molarity        | Kg/m3           | 8M              | 10M             | 12M             | 14M             |
MIXING, CASTING AND CURING

The solids constituents of the fly ash-based geopolymer concrete, i.e. the aggregates and the fly ash, were dry mixed for about three minutes. The liquid part of the mixtures, i.e. the sodium silicate solution, the sodium hydroxide solution, added water (if any), were premixed then added to the solids. The wet mixing usually continued for another four minutes. The fresh fly ash-based geopolymer concrete was dark in colour and shiny in appearance. The mixtures were usually very cohesive.

In total, thirteen (13) castings were done with different molarities of different alkali activators. The workability of the fresh concrete was measured by means of the conventional slump test.

Compaction of fresh concrete in the cylinder steel moulds was achieved by applying sixty manual strokes per layer in three equal layers, followed by compaction on a vibration table for ten seconds.

Compressive and Tensile Strength Tests

The compressive and tensile strength tests on hardened fly ash-based geopolymer concrete were performed on a compression testing machine (CTM) and universal testing machine (UTM). Five 100x200 mm concrete cylinders were tested for every compressive strength test. Three 150x300 mm concrete cylinders were tested for each tensile splitting strength test. The results given in the various Figures and Tables are the mean of these values.

RESULTS AND DISCUSSIONS

Total Thirteen castings were done out of which twelve were geopolymer concrete. The results of GPC were compared with varying parameters. The results of GPC are tabulated as follows:

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>Compressive strength 7 days</th>
<th>Compressive strength 28 days</th>
<th>Split tensile strength 7 days</th>
<th>Split tensile strength 28 days</th>
<th>Flexural strength 7 days</th>
<th>Flexural strength 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 M</td>
<td>14.64</td>
<td>18.05</td>
<td>2.08</td>
<td>3.00</td>
<td>2.816</td>
<td>4.16</td>
</tr>
<tr>
<td>10 M</td>
<td>15.46</td>
<td>19.23</td>
<td>2.448</td>
<td>3.15</td>
<td>3.184</td>
<td>4.8</td>
</tr>
<tr>
<td>12M</td>
<td>15.58</td>
<td>19.40</td>
<td>2.80</td>
<td>3.60</td>
<td>3.440</td>
<td>5.28</td>
</tr>
<tr>
<td>14M</td>
<td>15.74</td>
<td>19.54</td>
<td>3.04</td>
<td>3.75</td>
<td>3.472</td>
<td>5.328</td>
</tr>
</tbody>
</table>

As is evident from above table, that the compressive, split tensile and flexural strength of GPC, all are greater than M25 grade OPC. Also, the increasing trend in strengths can be seen as as the molarity of KOH solution is increased from 8M to 14M. However, from 12M to 14M, the increase in strengths is not of much value. Thus, 12M can be considered as optimum molarity considering economy.

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>Compressive strength 7 days</th>
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<th>Split tensile strength 7 days</th>
<th>Split tensile strength 28 days</th>
<th>Flexural strength 7 days</th>
<th>Flexural strength 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>8M</td>
<td>16.74</td>
<td>20.15</td>
<td>2.21</td>
<td>3.20</td>
<td>2.92</td>
<td>4.2</td>
</tr>
<tr>
<td>10M</td>
<td>17.56</td>
<td>22.08</td>
<td>2.64</td>
<td>3.31</td>
<td>3.21</td>
<td>5.00</td>
</tr>
<tr>
<td>12M</td>
<td>19.25</td>
<td>24.65</td>
<td>3.01</td>
<td>3.83</td>
<td>3.54</td>
<td>5.43</td>
</tr>
<tr>
<td>14M</td>
<td>21.45</td>
<td>25.73</td>
<td>3.21</td>
<td>3.91</td>
<td>3.672</td>
<td>5.6</td>
</tr>
</tbody>
</table>
As is evident from above table, that the compressive, split tensile and flexural strength of GPC, all are greater or comparable to M25 grade OPC. Also, the increasing trend in strengths can be seen as as the molarity of NaOH solution (like KOH solution) is increased from 8M to 14M, However, from 12M to 14M, the increase in strengths is not of much value. Thus, 12M can be considered as optimum molarity considering economy.

Table 5.0: Results for GPC with (KOH + NaOH) as activator at 12M

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>Compressive strength 7 days</th>
<th>Compressive strength 28 days</th>
<th>Split tensile strength 7 days</th>
<th>Split tensile strength 28 days</th>
<th>Flexural strength 7 days</th>
<th>Flexural strength 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% NaOH + 80% KOH</td>
<td>14.43</td>
<td>18.18</td>
<td>2.826</td>
<td>3.62</td>
<td>2.42</td>
<td>5.31</td>
</tr>
<tr>
<td>40% NaOH + 60% KOH</td>
<td>16.30</td>
<td>20.43</td>
<td>2.852</td>
<td>3.63</td>
<td>3.48</td>
<td>5.33</td>
</tr>
<tr>
<td>60% NaOH + 40% KOH</td>
<td>17.65</td>
<td>22.36</td>
<td>2.87</td>
<td>3.65</td>
<td>3.5</td>
<td>5.37</td>
</tr>
<tr>
<td>80% NaOH + 20% KOH</td>
<td>19.178</td>
<td>24.54</td>
<td>2.90</td>
<td>3.67</td>
<td>3.52</td>
<td>5.46</td>
</tr>
</tbody>
</table>

As is evident from the above table that all of the three viz. compressive strength, split tensile strength, flexural strength increase as we increase the percentage of NaOH in the mix, thus depicting that the best alkali for the polymerization is NaOH. In the following section, the comparative variations have been made in same graphs from graphs (1-6).

COMPARATIVE GRAPHS

GRAPH 1:

Graph 1 shows the variation of comparative 7 day compression tests of the cubes.

The NaOH and KOH molarities have been varied from 8M to 14M, while as the combination of the two has been maintained with same molarity of 12M.

In the graph, it is evident that the NaOH line lies above both the KOH and (KOH + NaOH) line, thus depicting that the compressive strength in case of the former case is greater than both the cases. It can be clearly seen that the compressive strength in case of 12M of the (NaOH + KOH) chemical is well above the varied molarity lines of NaOH and KOH lines and hence, concludes that NaOH is the best suitable activator from the selected three cases of chemicals.
Graph 2 shows the comparison between the 28 day compressive strength of the cubes. The NaOH and KOH molarities have been varied from 8M to 14M, while as the combination of the two has been maintained with same molarity of 12M.

From the graph it is quite evident that like the case of 7 day strength variation, 28 day strength is larger in case of NaOH, when compared to other two cases, hence again supporting the suitability of NaOH as the best suitable activator among the three in consideration.

Graph 3 shows the variation between the 7 day split tensile strength of the cylinders.

There is very little variation in the strength in case of 12M (NaOH + KOH) solution. But the strength is higher than KOH and NaOH when molarity is below 10M and it is on the reverse side when molarity is greater than 10M.

Graph 4 shows the variation between 28 days split tensile strength of cylinders.
Like in previous case, there is very little variation in the strength in case of 12M (NaOH + KOH) solution. But the strength is higher than KOH and NaOH when molarity is below 10M and it is on the reverse side when molarity is greater than 10M.

**GRAPH 5:**

Graph 5 shows the variation of 7 day flexural strength of the beams.

This graph shows an unusual variation in case of (NaOH + KOH), but still at higher ends of molarities in two cases viz. NaOH and KOH, the strength is higher in case of NaOH than the other two cases in consideration.

**GRAPH 6:**

Graph 6 shows the variation of 28 day flexural strength of beams.

The graph shows clearly that the strength in case of NaOH is greater than other two cases but only when molarity is greater than 10M.

**CONCLUSION**

From the detailed study of the above parameters the general conclusions which can be drawn are as under:

1) In case of KOH, the compressive, split tensile and flexural strength of GPC, all are comparable to M25 grade OPC. Also, the increasing trend in strengths can be seen as as the molarity of KOH solution is increased from 8M to 14M. However, from 12M to 14M, the increase in strengths is not of much value. Thus, 12M can be considered as optimum molarity considering economy.
2) In case of NaOH, the compressive, split tensile and flexural strength of GPC, all are comparable to M25 grade OPC. Also, the increasing trend in strengths can be seen as the molarity of NaOH solution is increased from 8M to 14M. However, from 12M to 14M, the increase in strengths is not of much value. Thus, 12M can be considered as optimum molarity considering economy.

3) In case of mix of the two chemicals, the compressive strength, tensile and flexural strength all increase as we increase the percentage of the NaOH chemical in the mix.

4) The 7 day compressive strength in case of 12M of the (NaOH + KOH) chemical is well above the varied molarity lines of NaOH and KOH lines and hence, concludes that NaOH is the best suitable activator from the selected three cases of chemicals.

5) Like the case of 7 day strength variation, 28 day strength is also larger in case of NaOH, when compared to other two cases, hence again supporting the suitability of NaOH as the best suitable activator among the three in consideration.

6) There is very little variation in 7 day and 28 days' split tensile strength in case of 12M (NaOH + KOH) solution. But the strength is higher than KOH and NaOH when molarity is below 10M and it is on the reverse side when molarity is greater than 10M.

7) This 7 day flexural strength graph shows an unusual variation in case of (NaOH + KOH), but still at higher ends of Molarities of 10M and greater in two cases viz. NaOH and KOH, the strength is higher in case of NaOH than the other two cases in consideration.

8) The graph shows clearly that the strength in case of NaOH is greater than other two cases but only when molarity is greater than 10M

Thus, it can be stated from above observations that NaOH is the best suitable activator from the above three considerations, for polymerization reaction to take place.

REFERENCES


