GEOPOLYMER CONCRETE AN ECO-FRIENDLY ALTERNATIVE TO PORTLAND CEMENT PAVING GRADE CONCRETE

Girish M. G  
Assistant Professor, Department of Civil Engineering,  
Manipal Institute of Technology, Manipal University, Karnataka, India

Kiran K. Shetty  
Professor, Department of Civil Engineering,  
Manipal Institute of Technology, Manipal University, Karnataka, India

Raja Rao A  
PG Student, Department of Civil Engineering,  
Manipal Institute of Technology, Manipal University, Karnataka, India

ABSTRACT

The current generation of “Sustainable development” demands the new concrete which uses the less natural resource, energy as well as generates less CO₂, without compromising on strength and durability aspects. In this context research works on geopolymer concrete prepared from conventional alkali-activator solutions like sodium hydroxide and sodium silicate curable at ambient temperature is gaining momentum now-a-days. In this paper, the paste phase and solid phase properties of geopolymer concrete containing quarry dust and sand as fine aggregate, suitable for rigid pavement application, curable at ambient temperature are the points of discussion. The targeted compressive strength of 40MPa was achieved soon after seven days of air curing and maximum strength attained in 28 days is nearly 62MPa. Both the compressive strength and the flexural strength were within the acceptance limit of paving grade concrete.

Key words: Alkaline activators, Geopolymer concrete, Fly-ash, GGBS, Quarry dust

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=7

1. INTRODUCTION

Concrete is the most consumed material next to water in the world. To live, how water is essential, similarly for shelter concrete building is important in this era. The manufacture of cement is considered to be highly energy intensive next to steel and aluminium. The process
of manufacturing of 1000kg of Portland clinker directly generates over a 500kg of chemical-Carbon dioxides, and nearly another 500kg of Carbon dioxide comes from the combustion of carbon-fuel[1]. The only exceptions are so-called ‘blended cement’, using such ingredients as coal fly-ash, where the emissions of carbon dioxides are slightly suppressed, by a maximum of 10-15%[1].Geopolymer cement (GC) does not rely on calcium carbonate and generate a very minimal amount of CO₂ for its manufacture, i.e. a reduction in the range of 40% to 80-90% [1].

The geopolymer cement is formed by polymerization process which involves the reaction between an aluminosilicate source material such as fly-ash, GGBS, etc. with an alkaline activator solutions. The process results in the creation of a network of a tetrahedral chain of SiO₄ and AlO₄ to shared oxygen atoms alternatively [2]. Hardening of GC takes place through polycondensation of potassium oligo (sialate-siloxo) into potassium poly (sialate-siloxo) cross-linked network [1]. The GC, so formed binds the aggregates and inert materials to form a matrix called geopolymer concrete (GPC). Present days, lots of researches are being carried out on the utilisation of industrial by-product such as fly-ash, GGBS, silica fumes, metakaolin as an aluminosilicate precursor material for geopolymers[3]. The alkaline liquids used in the production of GC mainly are of soluble alkali metals that are usually sodium or potassium based. The most commonly used alkaline liquid is the combination of Sodium Hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) or Potassium Hydroxide (KOH) and Potassium Silicate (K₂SiO₃) [4].

The molarity and molar ratio of alkaline solution, water to binder ratio, plasticiser and curing temperature is found to have a profound effect on the fresh and hardened state of geopolymer concrete [5]. The increase in molarity of NaOH solution from 8M to 14M and molar ratio increases the strength and decreases the workability of the concrete respectively. The increase of super plasticizer content and the alkali concentration improves the interfacial transition zone (ITZ) and microstructure of GPC[6]. The presence of additional water exceeding 15% causes bleeding, segregation and reduced the compressive strength of the concrete[7].

The geopolymer concrete, in future, can become a viable alternative to OPC as a binding material in mass concreting applications. In recent times researches have been carried out across many locations of the world to investigate the potentials of GPC for structural applications. However, little is known as for as its applications in the field of the highway pavements are concerned. In this paper, attempts are made to explore the possibilities of using GPC as a paving grade concrete. The production of GPC is carried out using the OPC concrete production technology methods.

2. MATERIALS AND THEIR PROPERTIES

2.1. Fly-ash
Fly ash from Raichur Thermal Power Station (RTPS) located in Karnataka, India is used as one of the precursors. According to IS: 3812-2000 [8], it is classified as Class-F fly ash. Specific gravity is measured as 2.05 according to IS:1727-1967[9]. Pozzolanic activity index with Portland cement is 74.22% and Blaine’s surface area of 3225 cm²/gm.

2.2. Aggregates
Locally available clean river sand and quarry dust were used as fine aggregates. The F.A belongs to grading Zone II as per IS: 383-1970[10],with the specific gravity,of 2.64 and fineness modulus of 2.935.
The quarry dust with specific gravity 2.62 and fineness modulus 2.84 obtained in the vicinity is used in the current study. Crushed aggregate of 20 mm down size having specific gravity 2.68 and fineness modulus 6.96 is utilised as coarse aggregate.

2.3. Alkaline Solution
The commonly used alkaline activators in Geopolymer concrete are sodium hydroxide and sodium silicate solutions. Sodium silicate solution (A53) is obtained from a local factory, and it is composed of Na2O- 13.54%, SiO2- 32.46% and H2O- 54.0%. Sodium hydroxide used is of analytical grade and is of 97% purity.

2.4. Water
Potable water conforming to IS: 456-2000 [11] is used in all mixes. And it is free from salts and other organic impurities. The water content in GPC is the combined water present in the alkali solution. The amount of water in Silicate solution is found out by chemical analysis.

2.5. Ground Granulated Blast Furnace Slag (GGBS)
GGBS was obtained from Jindal Steel Works (JSW) Bellary, Karnataka. The specific gravity of GGBS was found to be 2.88.

2.6. Super Plasticizer
Conplast SP500 conforming to IS: 9103-1999, is based on Sulphonated Napthalene Polymers and is supplied as a brown liquid instantly dispersible in water. The specific gravity was found to be 1.26.

3. MIX DESIGNS
The composition of the geopolymer mixes used in the present investigation is given in Table 1. The NaOH solution of 12M concentration is preferred in this study. The NaOH solution was prepared 24 hours before the mixing. Mix M1 and M2 are more or less identical in composition except that, in mix M2, sand is replaced by quarry dust by same amount. Mix M3 also has quarry dust in place of sand as fine aggregate. The quantity of coarse aggregate used in M3 is slightly higher than M1 and M2.

<table>
<thead>
<tr>
<th>Materials</th>
<th>M1 (kg/m³)</th>
<th>M2 (kg/m³)</th>
<th>M3 (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash</td>
<td>330</td>
<td>330</td>
<td>237</td>
</tr>
<tr>
<td>GGBS</td>
<td>220</td>
<td>220</td>
<td>158</td>
</tr>
<tr>
<td>NaOH soln. (L/m³)</td>
<td>45.15</td>
<td>45.15</td>
<td>45.15</td>
</tr>
<tr>
<td>Na₂SiO₃ soln. (L/m³)</td>
<td>112.88</td>
<td>112.88</td>
<td>112.88</td>
</tr>
<tr>
<td>S.P (L/m³)</td>
<td>16.5</td>
<td>16.5</td>
<td>11.85</td>
</tr>
<tr>
<td>F.A (quarry dust)</td>
<td>-</td>
<td>735</td>
<td>555</td>
</tr>
<tr>
<td>F.A (river sand)</td>
<td>735</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>C.A</td>
<td>870</td>
<td>870</td>
<td>1290</td>
</tr>
<tr>
<td>Water (L/m³)</td>
<td>24.75</td>
<td>41.8</td>
<td>39.5</td>
</tr>
<tr>
<td>Na₂SiO₃/NaOH</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Water to GPS ratio</td>
<td>0.19</td>
<td>0.213</td>
<td>0.28</td>
</tr>
<tr>
<td>Alkaline to Binder ratio</td>
<td>0.29</td>
<td>0.29</td>
<td>0.40</td>
</tr>
</tbody>
</table>
4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Fresh Properties for Paving Grade Concrete

The target slump in the range 6 to 8 inches, spread in the range 11 to 13 inches and compaction factor > 95% was recognised as standard to define the fresh state properties of paving grade geopolymer concrete. Figure 1 represents the slump test and Figure 2 represents the spread test. The results of the slump test, compaction factor test and spread test are presented in Table 2. The compaction factor values of all the mixes were comparable to the set standards. The slump and spread values of mixes M1 and M2 were close to adopted standards. However, slump and spread values of mix M3 are found to be not within the range. This is due to slightly increase in quantity of coarse aggregate and reduction quarry of dust which caused stiffening of the paste and loss of mobility.

<table>
<thead>
<tr>
<th>Mixes</th>
<th>Slump (inches)</th>
<th>Spread (inches)</th>
<th>Compaction Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>9.0</td>
<td>16.5</td>
<td>98</td>
</tr>
<tr>
<td>M2</td>
<td>8.5</td>
<td>15.5</td>
<td>96.5</td>
</tr>
<tr>
<td>M3</td>
<td>5.0</td>
<td>9.0</td>
<td>95.6</td>
</tr>
</tbody>
</table>

4.2. Density

The density values of GPC mixes were in the range of 2300 to 2500 kg/m³ which is found to be similar to the density of OPC concrete.

4.3. Compressive Strength

The compression strength test values of GPC cube specimens of size 100x100x100 mm of three mixes, when tested under compression load as per IS: 516-1959 [13] is presented in Table 3, and same is graphically depicted in Figure 3.

<table>
<thead>
<tr>
<th>Mix</th>
<th>7 days (MPa)</th>
<th>14 days (MPa)</th>
<th>28 days (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>54.71</td>
<td>58.17</td>
<td>62.15</td>
</tr>
<tr>
<td>M2</td>
<td>45.23</td>
<td>46.89</td>
<td>49.91</td>
</tr>
<tr>
<td>M3</td>
<td>40.01</td>
<td>40.82</td>
<td>55.03</td>
</tr>
</tbody>
</table>

Compressive strength values of all the mixes indicates, an incremental increase in the strength over three ambient curing frequencies. This is because of the pozzolanic activity of fly ash which supplies Si and Al, GGBS rich in Ca supplies enough Ca for the reaction and the alkaline solution which binds the binder contents. All the three mixes achieved an average compressive strength of more than 40MPa in 7 days. As per Indian Road Congress code specification [14, 15], a 28days compressive strength of 40MPa is viewed as min.
compressive strength requirement of cement concrete for rigid pavement. This phenomenon of early age strength gain is known to be beneficial since this can facilitate early opening of pavement to vehicular traffic. The complete replacement of sand by quarry dust resulted in decreasing the compressive strength of GPC. On the other hand, the excess coarse aggregate content improved the compressive strength of GPC.

![Figure 3 Compressive strength of GPC mixes](image)

### 4.4. Flexural Strength

To measure flexural strength, beams of size 100x100x500 mm were used and tested as per IS: 516-1959 specifications [13]. Results of average flexural strength test of different mixes at the age of 28 days are given in Table 4 and shown pictorially in Figure 4. The combined stresses due to wheel load and temperature developed in the rigid pavement should be less than flexural strength of cement concrete used in rigid pavements [15]. Therefore the flexural strength of concrete is known to be of prime importance. The test results show that all the three mixes possessed a flexural strength higher than min. required i.e. 4.42MPa for paving grade concrete of compressive strength 40MPa. Mix M1 had the highest flexural strength then followed by M3 and M2 being the least.

<table>
<thead>
<tr>
<th>Mix</th>
<th>28 days (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>5.30</td>
</tr>
<tr>
<td>M2</td>
<td>4.92</td>
</tr>
<tr>
<td>M3</td>
<td>5.10</td>
</tr>
</tbody>
</table>

![Table 4 Flexural strength test results.](image)

![Figure 4 Flexural strength of GPC mixes](image)
5. CONCLUSIONS
The study aimed at developing a geopolymer concrete suitable for rigid pavement application. The study comprised of examining the fresh and hardened state behaviour of three different mixes of geopolymer concrete. Among the mixes; mix M1 contained sand as fine aggregate, mix M2 had quarry dust as fine aggregate and mix M3 was having more coarse aggregate content along with quarry dust when compare to other two mixes.

The following conclusions are arrived from the studies:-

- The fresh state properties of the GPC indicated that the slump and spread values were in the close proximity of assumed standards except for the mix M3. Thus it can be concluded that the developed GPC can be adopted for fixed form paving.

- The compressive strength of GPC obtained was in the range of 40-60MPa which is more than the target strength. The mixes gained strength gradually over the period of times of curing. This is due to the pozzolanic action of fly ash. All the three mixes acquired a target strength of 40MPa in 7 days of curing. Thus it can be concluded the GPC may facilitate the early opening of road to traffic. The complete replacement of sand by quarry dust resulted in a reduction of compressive strength of GPC. Whereas the GPC containing a combination of more quantity of coarse aggregate and the quarry dust produced better compressive strength.

- The flexural strength of GPC is found to be significantly more than the target strength. Hence, it can be concluded that the GPC can become a practicable alternative to conventional cement concrete pavement.

REFERENCES
Geopolymer Concrete an Eco-Friendly Alternative to Portland Cement Paving Grade Concrete


http://www.iaeme.com/IJCIET/index.asp 892 editor@iaeme.com