Suitability of Incinerated Sewage Sludge Ash to Produce Geopolymer Concrete

R.C.M. Paulnath¹, A.M.M.Askhi¹, F.Hamsath¹, S.Jasekan¹ and C.K.Pathirana¹
¹Department of Civil Engineering
Faculty of Engineering
University of Peradeniya
Peradeniya
SRI LANKA
E-mail: chin@civil.pdn.ac.lk

Abstract: Geopolymer concrete (GPC) has been developed as an alternative material to conventional Portland cement concrete. This was developed to reduce the emission of carbon dioxide. So far, materials such as fly ash, blast furnace slag and metakaolin have been used as geopolymer solids to produce the GPC. Aim of this research is to study the suitability of Incinerated Sewage Sludge Ash (ISSA) to be used as geopolymer solid. Mix design for GPC was carried out using the G-graphs which were developed for fly ash based-geopolymer concrete. Initially GPC test cubes were cast using fly ash and ISSA alone. Thereafter fly ash was replaced by ISSA in certain percentages (5, 10, 15 and 20) to make geopolymer concrete. XRF and heavy metal analysis tests were carried out for raw Sewage Sludge (SS) as well as ISSA. Compressive strength of GPC was also observed in acidic environment.

XRF test revealed that SiO₂ and Al₂O₃ are mostly present in all samples tested. Heavy metal analysis for Hanthana sample showed that Zn is the most prominent heavy metal exists in both SS sample as well as ISSA sample. The compressive strength developed was not significant when using ISSA alone to make GPC. When fly ash was partially replaced by ISSA, the strength of GPC showed decreasing pattern as the ISSA percentage was increased. Similar strength results were observed in acidic environment too. According to the Concrete Society Board recommendations, all GPC specimens with different fly ash replacements, can be considered as average in absorption rating as well as concrete quality. Therefore ISSA could be used as a partial replacement for fly ash, for specific applications which would require less strength characteristics.

Keywords: Geopolymer concrete, incinerated sewage sludge ash, fly ash

1. INTRODUCTION

GPC is OPC free concrete. It is made by binding aggregates with geopolymer binder. Geopolymer binder is made by mixing source material and alkaline solution. Alkaline solution triggers the geopolymerisation (Davidovits, 1994). So far, slag based-geopolymer concrete and fly ash based-geopolymer concrete have been developed and used in the construction industry.

Increase in sewage sludge causes too many environmental problems. The presence of harmful heavy metals in Incinerated sewage sludge ash (ISSA) causes disposal problems. By trapping these heavy metals in the chain of polymers it may achieve the immobilization. This research study mainly focuses on the application of ISSA in GPC.

1.1. Geopolymers

The two main constituents of geopolymers are source materials and alkaline liquids. The source materials for geopolymers based on alumina–silicate should be rich in silicon (Si) and aluminum (Al). These could be natural minerals such as kaolinite and clays. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash and red mud could be used as source materials. The alkaline liquids are obtained from soluble alkali metals that are usually sodium or potassium based.
1.2. Incinerated Sewage Sludge Ash (ISSA)

Sewage sludge (SS) is a waste material obtained from wastewater treatment plants. Large amount of heavy metals which exist in wastewater tends to accumulate in SS. The composition of SS and its content of heavy metals vary widely depending on the sludge origins and treatment options. In the past decades, SS was primarily disposed to landfills and seawaters. ISSA is obtained by incinerating the wastewater sludge.

2. LITERATURE REVIEW

Incineration of sewage sludge ash must be optimized at 800°C to preserve the pozzolanic activity of the resultant ash (Tantaway et al., 2012). Shankar and Khadiraikar (2012) have studied the performance of fly ash based geopolymer concrete and Portland cement concrete under severe environment (10% H2SO4). They have observed better performance of geopolymer concrete (GPC) than that of Portland cement concrete (PCC). In addition, they also observed that the strength of geopolymer concrete and Portland cement concrete gradually decreases as the day of exposure increases.

3. METHODOLOGY

3.1. Preparation of ISSA

The samples of SS were collected from selected treatment plants in Sri Lanka such as Zoysapura (Colombo), Raddolugama (Katunayaka), General hospital (Peradeniya) and Hantana housing scheme (Hantana). The SS samples were incinerated at 800°C for 3 hours. Ash particles which passed through 150 µm sieve were used for experiments.

3.2. XRF and heavy metal analyses

XRF test was performed for both SS and ISSA samples of all locations and heavy metal analysis was performed only on Hantana sample with the available facilities.

3.3. Mix design based on G-graph, and specimen preparation

Based on G-graph (Talha et al., 2015) which is used for designing of fly ash based GPC, mix was designed and specimens were cast. The following criteria were adopted in the process.

- Target strength 30 MPa, Curing temperature - 80°C, Curing time- 48 hours,
- Concentration of NaOH – 12M, Na2SiO3/ NaOH- 2.5, W/GPS – 0.29, Al/FA ratio is 0.4.

  - Test cubes were cast for both fly ash-based geopolymer concrete (0% ISSA) and ISSA-based geopolymer concrete (100% ISSA). These cubes were cured at 80°C.
  - Four more mixtures were prepared by replacing fly ash with ISSA in the percentages of 5%, 10%, 15% and 20%. These cubes were cured at ambient temperature (not at 80°C).

To prepare the GPC, alkaline solution was prepared by using 12M Sodium Hydroxide and 2.5M Sodium Silicate. Concrete cubes were cast in 50 mm x 50 mm x 50 mm moulds. Three specimens were cast from each mix. Each cube was cast in three layers and each layer was tamped 25 times by the standard compaction rod. Aftercasting the specimens, they were kept in room temperature for 24 hours.

Curing of specimens prepared with four types of mixtures was done in the room temperature for 7 days.
3.4. Specific gravity

Specific gravity of the sample collected from Hanthana wastewater treatment plant was measured according to ASTM C188-95 test method. Also the specific gravity of fly ash, fine aggregates and coarse aggregates was determined using ASTM C188 – 95, ASTM C128 – 07a and ASTM C127 – 07 test methods respectively.

3.5. Porosity

To determine the porosity or relative permeability characteristic of concretes, absorption study was carried out.

3.6. Acid attack

GPC specimens were soaked in 3% of Sulphuric acid and the acid attack was estimated by determining the compressive strength in a period of 0, 7, 14 and 21 days from the date of immersion.

4. RESULTS AND DISCUSSION

4.1. Specific gravity

Table 1 shows the values obtained for specific gravity of ingredients used in making GPC with the sample collected from Hanthana waste water treatment plant.

<table>
<thead>
<tr>
<th></th>
<th>ISSA</th>
<th>Fine Aggregate</th>
<th>Coarse Aggregate</th>
<th>Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.69</td>
<td>2.67</td>
<td>2.65</td>
<td>2.1</td>
</tr>
</tbody>
</table>

4.2. XRF test and Heavy metal analysis

XRF test was conducted on all samples to determine the chemical composition of SSA and fly ash. Table 2 shows the chemical composition of SSA and fly ash obtained from XRF test. The results shows that SiO2 and Al2O3 are mostly present in all the tested samples and Fe2O3 and CaO are also present in considerable amount and the sequence was obtained as:

SiO2 > Al2O3 > Fe2O3 > CaO > MgO > K2O

<table>
<thead>
<tr>
<th>Location</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>K2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hantana</td>
<td>53.02</td>
<td>13.57</td>
<td>13.28</td>
<td>2.4</td>
<td>1.37</td>
<td>0.96</td>
</tr>
<tr>
<td>Peradeniya Hospital</td>
<td>32.71</td>
<td>23.11</td>
<td>17.45</td>
<td>5.21</td>
<td>3.01</td>
<td>0.58</td>
</tr>
<tr>
<td>Zoysapura</td>
<td>34.23</td>
<td>24.44</td>
<td>12.71</td>
<td>6.82</td>
<td>1.80</td>
<td>1.13</td>
</tr>
<tr>
<td>Raddolugama</td>
<td>43.19</td>
<td>21.27</td>
<td>9.87</td>
<td>7.54</td>
<td>1.95</td>
<td>0.64</td>
</tr>
<tr>
<td>Fly ash</td>
<td>52.03</td>
<td>32.31</td>
<td>7.04</td>
<td>5.55</td>
<td>1.3</td>
<td>-</td>
</tr>
</tbody>
</table>

The amounts of heavy metals in SS and ISSA samples were determined for Hanthana sample and the results in ppm are shown in Table 3. The results of the analysis show the following sequence:

Zn > Mn > Cu > Pb > Cr > Ni > Cd
4.3. Water absorption

In order to classify the GPC by relative porosity or permeability characteristics, the water absorption studies have been done. The results of the study are given in Table 3. From the recommendation given by the Concrete Society Board (CEB-FIP 1989) it can be noted that all GPC specimens are in average of concrete quality as well as absorption rating.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Absorption %</th>
<th>Absorption Rating</th>
<th>Concrete quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>3.96</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>5%SSA</td>
<td>4.91</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>10%SSA</td>
<td>4.67</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>15%SSA</td>
<td>4.58</td>
<td>Average</td>
<td>Average</td>
</tr>
</tbody>
</table>

4.4. Acid attack study

Compressive strength variation of ISSA based GPC with different combinations, exposed for a period of 0, 7, 14 and 21 days in 3% Sulphuric acid are shown in figure 1. As the percentage of ISSA increases up to 15%, the compressive strength of GPC decreases, and the strength of GPC gradually decreases as the number of days increases in acidic exposure. The reduction in compressive strength observed for 0%, 5%, 10% and 15% ISSA based GPC were 27%, 47%, 58% and 58% respectively during 21 days of exposure.

![Figure 1 Variation of compressive strength with time](image)

4.5. Strength characteristics

Appearance of the ISSA based geopolymer concrete showed brownish in colour. When it was used as a filler material to fly ash with increasing percentage of ISSA content, colour of the specimens changed from gray to brown. The 7 day compressive strength of fly ash alone GPC was 30.25 N/mm² with 80°C curing, and ISSA based GPC showed no strength development.

Compressive strength developed by the GPC when fly ash was partially replaced by ISSA is shown in figure 2 below. Note that these were cured at ambient temperature. If the curing temperature could be kept at 80 °C, higher strength would have been expected.
5. CONCLUSIONS

XRF results of all ISSA samples show that SiO$_2$ and Al$_2$O$_3$ are present in high concentration and Fe$_2$O$_3$ and CaO are present in significant amount. Chemical composition of all ISSA samples show that it is almost equal to the composition of fly ash. Heavy metal analysis for Hantana raw sewage sludge sample shows that Zn is prominent in that among other metals. Mn and Cu are also present in a higher range. It may affect the geopolymerization.

The compressive strength of ISSA-based GPC shows that as the percentage of ISSA increases the compressive strength decreases. There is no significant strength reduction up to 5% replacement of fly ash with ISSA. But 20% replacement of fly ash with ISSA shows 40% of strength reduction.

Influence of temperature can be observed from the compressive strength variation of fly ash based GPC. It was cured at both ambient and elevated temperature. It shows that in elevated temperature, the strength development of GPC concrete is significantly high (nearly 5 times higher) for 7 day compressive strength.

G-graph method was adopted to design the proportion of mixtures. Compressive strength of fly ash alone GPC shows the conformity of G-graph method.

All GPC specimens are average in concrete quality as well as absorption rating. According to the results obtained from the acid attack study, the loss of compressive strength for the specimens exposed in sulphuric acid is comparatively higher in (ISSA+FA)-based GPC than fly ash alone-based geopolymer concrete. Compressive strength reduces as the acidic exposure increases in all combination of ISSA-based GPC. Though the compressive strength of ISSA-based GPC is not equally good as fly ash alone-based GPC, still this ISSA-based GPC could be used for specific applications which require less compressive strength.

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REFERENCES


