Performance Evaluation of Fly-ash based Self-compacting geopolymer concrete mixes

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Abstract: In this paper, an attempt has been made to develop Fly ash based self-compacting geopolymer concrete mixes with varying volume of pastes using conventionally available river sand as fine aggregate and crushed granite chips as coarse aggregate. These mixes were developed using Fly ash as the only major source material in the production of SCC mixes. Different amounts of Sodium silicate solutions, with specified amounts of Sodium Hydroxide flakes dissolved in them, are used as alkaline solutions. The total of four mixes were developed with varying volume of pastes in the range of 0.40 – 0.52 (within an interval of 0.04). These mixes were evaluated for their flow ability characteristics as per the relevant EFNARC guidelines. Further the mixes were evaluated for their mechanical properties in terms of compressive strength, splitting tensile strength and water absorption characteristics. Durability tests by means of subjecting to acidic and sulphate environments, along with their resistances to sustained elevated temperatures for a sustained period of 2 hours upto 800ºC were carried out for all these mixes. The test results indicate better flow ability characteristics, along with their mechanical and durability properties.

Keywords: Fly ash; Self-compacting; Geo polymer concrete; Durability; Elevated temperatures.

1. Introduction

1.1 General

The infrastructure development has increased exponentially due to the rapid increase in population. Large demands for the new infrastructure are causing greater requirements in the production of ordinary Portland cement which is the main source of binding material for producing concrete. The present global demand for OPC is around 4 billion tons [1, 2] being the second largely consumed material after water and it is also expected to increase by 8–10% in the future years [3]. Every tonne Production of one tonne of cement approximately releases one-tonne of carbon dioxide (CO2) during its entire production[4]. Development of substitute binder materials has been reported by many researchers in order to overcome these challenges. Geopolymer Concrete (GPC) generally produced by the alkali activation of silica and alumina rich compounds is one such material that has taken forward in the current research[5]. Lower cost, reduced emission of CO2 and usage of environmentally friendly materials are the major advantages in the GPC[6,7] with the effectively utilizing industrial wastes such as fly ash, slag, rice husk ash etc. [8,9]. GPC mixes cured at elevated temperatures out-performs conventional OPC concrete in terms of strength and durability aspects[10]. The present paper reports on the efforts being made for developing fly ash based self-compacting geopolymer concrete mixes. In order to develop these mixes, varying volume of pastes were considered namely 0.40, 0.44, 0.48 and 0.52 as the major variable, along with conventionally available natural river sand as fine aggregate and 12.5mm downsize granite chips as coarse aggregate.
In the present investigation, Class F - Fly ash, obtained from Raichur Thermal Power Corporation, Raichur, India, conforming to IS: 3812 - 2003 was used. The Fly ash had a specific gravity of 2.12 and Blaine's fineness of about 436 m²/kg.

2.2 Alkaline Solution

In the present study, mixtures of sodium hydroxide and sodium silicate solutions with the ratio of Sodium Silicate/Sodium Hydroxide (SS/SH) being kept as 1.0, maintaining a constant molarity of 8M are used as alkaline solutions. The alkaline solution prepared is allowed to cool and mature for 24 hours prior to mixing, in order to reduce the heat liberated during the time of mixing.

2.3 Aggregates

In the present study, natural river sand was used as fine aggregate and 12.5mm downsize granite chips, was used as the coarse aggregate fraction in all these geopolymer concrete mixes. The river sand and jelly were locally. The fine aggregate and coarse aggregate used were having a specific gravity of 2.60 and 2.62. Both the fine aggregates and coarse aggregates used in the present study conform to the specifications of IS: 383-1970 based on the results obtained from sieve analysis.

3. Mixture Proportioning, Preparation and Casting of Mixtures

An initial set of only four trial mixes were formulated using a constant ratio of SS/SH as 1, maintaining a molarity of 8M and the performance of these mixes were tested in the laboratory. The details of proportions of concrete mixtures are shown in Table 1. The design of trial GPC mixes used here in, were proportioned on the basis of absolute volume method, due to the absence of any national code or general guidelines. The ratio of proportions of fine to coarse aggregates in all the mixes was maintained constant at 50:50. The cube specimens were then cast using 100mmx100mmx100mm moulds; for evaluating both the mechanical and durability characteristics. Cylindrical specimens of size 100mm x 200mm dia was cast for evaluating the splitting tensile strength for all these mixes. These cast specimens were kept in oven along with the mould at 60°C for 24 hours for heat curing. All the test specimens could be de-moulded after completion of heat curing and were then subjected to ambient curing under the lab-environment. Sufficient numbers of specimens were cast for facilitating these tests at the age of 28-days. In each case, the averages of test results for three test specimens were considered.

### Table 1. Details of Trial Self Compacting GPC Mixes Tested with their quantities in kg/m³

| SL No. | Volume of Paste (Vp) | Fly Ash | NaOH Solution | Sodium Silicate Solution | River Sand | Jelly 12.5mm |
|--------|----------------------|---------|--------------|--------------------------|------------|--------------|
| 1      | 0.40                 | 276     | 194          | 194                      | 869        | 867          |
| 2      | 0.44                 | 361     | 194          | 194                      | 827        | 827          |
| 3      | 0.48                 | 446     | 194          | 194                      | 784        | 784          |
| 4      | 0.52                 | 530     | 194          | 194                      | 742        | 742          |

4. Results and discussions

4.1 Tests on Fresh Fly ash based Self-compacting GPC mixes

Flow ability tests such as Slump flow, V- funnel and L-box, generally prescribed for flow-able mixes were performed on all the four geopolymer concrete mixes as per relevant EFNARC guidelines. The slump flow tests were carried out using the Abram’s cone, to evaluate the filling ability of the different GP concrete mixes as shown in Figure 1. The volume of paste varying in the range 0.40-0.52 has shown a slump flow value ranging between 600mm – 630mm as shown in Table 2. Increase in the volume of paste has shown an increase in the flow upto paste volume of 0.48. Further increase in the volume of paste has slight caused a decrease in flow. However the wider range of decrease or increase in the flow characteristics has not been observed in any of the trial mixes tested herein. This slight decrease or increase in the flow with the increase in the volume of paste may be possible due to the slight variations in the volume of aggregates which has affected the flow ability performance of these mixes.
mixes. The obtained results can be attributed as that the increase in the volume of powder content by means of increasing the volume of paste beyond certain limit, does not cause an increase in the flow characteristics.

![Figure 1. Variation of slump flow for different volume of pastes](image)

V – Funnel tests were also carried out on all these GPC mixes. It is observed from Table 2, the times taken for emptying the V – Funnel are in the range of 12sec – 29sec, slightly greater than the specified guidelines for V- Funnel test as per the EFNARC guidelines. Based on V- funnel test results, it can be concluded again that the mixes did not show any greater resistance to its passing ability towards filling the areas with larger congestion of rebar’s leading to better structural conditions.

The Fly ash based GPC mixes were also tested for their passing ability by conducting the L–Box tests. It was observed that that increase in the volume of paste showed an increase in their passing ability in term of their blocking ratio being in the range of 0.63 – 0.89. This behaviour can be attributed due to the increase in the paste volume, which in turn decreases the volume of aggregates leading to a better blocking ratio for all the GPC mixestested herein. However all the fly ash based self-compacting GPC mixes tested herein are quite stable with no signs of segregation or bleeding, due to the viscous nature of the alkaline solution.

4.2 Mechanical Properties of Fly ash based Self compacting GPC mixes
All the GPC mixes tested herein have shown compressive strength and splitting tensile strength values on testing as per IS 516:1959 and IS 5816:1999 as shown in Table 2. It can be observed that lower compressive strengths and splitting tensile strength in the range of 8MPa – 25 MPa and 0.6MPa – 2MPa were obtained at the age of 28days. As generally observed in any case of fly ash based geopolymer concrete system, lower strengths have been obtained at the early ages and the geopolymerisation process in case of fly ash based systems takes place at a later ages. The amount of reactive silica and alumina availablein the fly ash also plays a major role in the geopolymerisation processresponsible for enhancing strength properties.

| MIX ID | Volume of Paste V_p | Slump Flow mm | V- Funnel in sec | L-Box Test | Compressive Strength @ 28 Days MPa | Split Tensile Strength @ 28 Days MPa | Water absorption @ 28 Days % |
|--------|---------------------|---------------|-----------------|------------|-----------------------------------|--------------------------------------|-------------------------------|
| FA0.40VP | 0.40                | 615           | 23              | 0.63       | 9                                 | 0.6                                  | 5.6                            |
| FA0.44VP | 0.44                | 610           | 12              | 0.67       | 16                                | 1.2                                  | 5.2                            |
| FA0.48VP | 0.48                | 630           | 15              | 0.72       | 24                                | 1.6                                  | 4.9                            |
| FA0.52VP | 0.52                | 600           | 29              | 0.89       | 25                                | 2.0                                  | 4.3                            |

Legend: FA 0.4 VP - FA indicates Fly Ash, 0.40 VP indicates volume of paste of 0.40

Water absorption test were performed on all the four GPC mixes in order to have a general idea on the amount of pores present in the concrete microstructure. The water absorption values were in the range of 4.3% - 5.6%. Increase in the volume of paste has slightly shown a decrease in the water absorption values. This may be due to the filling of some amount of pores by the geopolymerisation products and
All the Fly ash based Self compacting GPC mixes were exposed to concentrated sulphuric acid solution for 4 weeks after 28 days of curing with their concentration being maintained at 5%. It was observed that all the specimens after the exposure to the acidic environment maintained their structural integrity without causing a major distress on the surface of the specimens. Further no significant change in colour of the specimens was observed for any of the specimens tested herein. The residual compressive strength of all the mixes was in the range of 0% - 40% as shown in Table 3. Increase in the volume of paste showed an increase in the residual strength values. However the specimens with paste volume of 0.52 did not show any reduction in strength values, which in turn is reflected by means of showing no signs of deterioration. This behaviour may be due to the polymerisation products formed by means of sialate linkages are more resistant to acidic environment as compared to normal C-S-H gels formed in case of OPC concrete mixes.

4.3.2 Resistance to Magnesium Sulphate attack

The test results of magnesium sulfate attack on the compressive strength of various GPC mixes, subjected to 5% magnesium sulfate solutions up to an duration of 4 weeks is shown in Table 3. All the fly ash based self-compacting GPC mixes maintained their structural stability without showing any major cracks on the surface of the specimens. The colour on the surface of the specimens were slightly changed to whitish, due to the formation of reaction product mainly gypsum. The residual compressive strength of all the specimens subjected to sulphate environment was in the range of 0% – 30%. Similar behaviour was observed as in case of the specimens subjected to acidic environments. Increase in the volume of paste showed a decrease in the strength reduction values. Further the specimens having paste volume of 0.52 did not show any strength reduction which in turn is reflected by means of showing no signs of deterioration. This behaviour may be due to the crystalline phases present in the polymerisation reaction products which inhibits the formation of more amounts of expansive reaction products mainly M-S-H and gypsum.

4.4 Elevated Temperature performance of Fly ash based Self compacting GPC mixes

In order to evaluate the elevated temperature performance of all the GPC mixes, the specimens after 28 days of curing were placed in muffle furnace. These mixes were subjected to different increase in temperatures namely 200°C, 400°C, 600°C and 800°C for a sustained duration of 2 hours, after reaching the target temperature. The visual observation of the specimens did not show any change in the colour with the structural integrity of the specimens being maintained even after subjecting 800°C for such a longer soaking period of 2 hours. Further the specimens also did not show any signs of spalling when subjected to higher temperatures. However minor surface cracks may be observed on the surface of specimens exposed to temperature of about 800°C. The percentage reduction of compressive strength of all the mixes tested herein was in the range of 23% - 43% for a temperature of 800°C. It can be observed as shown in Figure 2, that slightly higher percentage of strength loss has been observed with the increase in temperature from 200°C – 400°C. This behaviour may be attributed to the loss of majority of the pore water present in the capillary pores, providing a path along the

4.3 Durability studies on Fly ash based Self compacting GPC mixes

4.3.1 Resistance to Sulphuric acid attack

Increase in the volume of paste showed a decrease in the residual strength values. However the specimens with paste volume of 0.52 did not show any reduction in strength values, which in turn is reflected by means of showing no signs of deterioration. This behaviour may be due to the polymerisation products formed by means of sialate linkages are more resistant to acidic environment as compared to normal C-S-H gels formed in case of OPC concrete mixes.

| MIX ID    | Volume of Paste V_p | Sulphuric Acid Resistance | Magnesium Sulphate Resistance |
|-----------|---------------------|---------------------------|-----------------------------|
|           |                     | Actual Comp. Strength MPa | Residual Comp. Strength MPa | Strength Reduction % | Actual Comp. Strength MPa | Residual Comp. Strength MPa | Strength Reduction % |
| FA0.40VP  | 0.40                | 9                          | 5.3                          | 41                   | 9                          | 6.3                          | 30                   |
| FA0.44VP  | 0.44                | 16                         | 10.5                         | 34                   | 16                         | 12.3                         | 23                   |
| FA0.48VP  | 0.48                | 24                         | 18.2                         | 24                   | 24                         | 19.3                         | 19.6                 |
| FA0.52VP  | 0.52                | 25                         | 25                           | 0                    | 25                         | 25                           | 0                    |
empty pores leading to failure channel at the early stages. Increase in the volume of paste has showed a better resistance, along with the increase in temperature upto 800°C. This may possible due to some unreacted fly ash grains may have further extended the process of geopolymerisation at these temperatures.

Figure 2. Variation of Residual Compressive Strength for different volume pastes

5. Conclusions
1. Fly-ash based Self-compacting geopolymer concrete mixes can be prepared with 8M of Sodium Hydroxide solution having the ratio of Sodium Silicate to Sodium Hydroxide as 1.
2. Based on the workability tests such as Slump flow, V-Funnel and L-Box carried out for assessing the SCC properties for Fly-ash based geopolymer concrete shows an acceptable values for volume of pastes ranging between 0.44 -0.48. However the volume of paste 0.48 is having more optimum value.
3. Fly-ash based Self-compacting geopolymer concrete mixes recorded a compressive strength greater than 20 MPa and tensile strength of about 1.6 MPa for the volume of paste 0.48. However further increase in strength can be obtained by increasing the powder content.
4. The limited durability studies carried out onFly-ash based self-compacting geopolymer concrete mixes showed a greater resistances to acidic, sulphate and sustained elevated temperatures for the volume of pastes 0.48 and 0.52.

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