Experimental Approach To Study The Properties Of Fiber Reinforced Fly Ash Based Geopolymer Concrete

Abstract

The fly ash content influences on the strength parameters, the compressive strength, split, tensile and flexure strength increases with increase in fly ash content to certain extent and decrease with further increases. The optimal flyash content found at 27% for 130 litres of water content. The incorporation of steel fiber in Geopolymer concrete found moderate reduction in compressive strength but significantly increases the split tensile strength and flexure capacity. The cracking moment capacity and ultimate load capacity of the beams were increased with increase in fiber fraction to certain extent which is as expected in ordinary Portland cement concrete. The fiber fractions ranging from 0.6% to 1.0 % with an aspect ratio of 75 have significant influence to increase flexure strength up to 11.5 %.
1. Introduction
The fibers are commonly used to improve the mechanical properties of concretes such as tensile strength, flexure capacity and fracture toughness. Generally steel, carbon, glass fibers are used to increase the fracture toughness and flexure capacity of the structural element, for the present study steel fibers are incorporated with fly ash based Geopolymer concrete. An experimental program is conducted to study the properties of fiber reinforced fly ash based Geopolymer concrete. The effect of fly ash and fiber content on cube compressive strength, split tensile strength and on flexure behavior is undertaken in the present study.

The structural application of Geopolymer concrete provides effective durability and strength over conventional Portland cements concrete. The behavior of the concrete depends upon the source materials or pozzolanas and activator solution or alkaline solution. From past one decade the effective research works are being carried in France, America, Australia and India about Geopolymer binders and still lot of works are yet to be carried to establish the engineering properties of Geopolymer under structural applications.

Since this is a new era concrete and limited experimental investigations are carried in structural applications, the efforts are taken to conduct the experimental investigation on Geopolymer concrete particularly about flexural behavior. This work is planned to conduct the experiment and present the behavior of “low calcium fly ash based tensile reinforced Geopolymer concrete with steel fibers.”

2. Materials Used

I. Fly ash
In the present experimental work, low calcium, Class F (American Society for Testing and Materials 2001) fly ash is used and it is obtained from the silos of Raichur thermal Power station, RTPCL, Southern India. The physical and chemical properties of the fly ash presented in Table 1

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Description</th>
<th>Values</th>
<th>Requirement as per IS:3812:2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>2.05</td>
<td>-----</td>
</tr>
<tr>
<td>2</td>
<td>Fineness (Blain’s air permeability- m²/kg)</td>
<td>333</td>
<td>320</td>
</tr>
<tr>
<td>3</td>
<td>SiO₂ (% by mass)</td>
<td>62.92</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>Al₂O₃ (% by mass)</td>
<td>30.96</td>
<td>------</td>
</tr>
<tr>
<td>5</td>
<td>SiO₂ + Al₂O₃ + Fe₂O₃ (% by mass)</td>
<td>93.88</td>
<td>70</td>
</tr>
<tr>
<td>6</td>
<td>MgO (% by mass)</td>
<td>0.74</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Total sulphur as sulphur trioxide S O₃(% by mass)</td>
<td>0.23</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Loss of ignition (% by mass)</td>
<td>0.59</td>
<td>5</td>
</tr>
</tbody>
</table>
Aggregates
- **Coarse aggregate**
  - Locally available crushed (angular) granite of maximum size 12.5 mm is used as coarse aggregate confirming to IS 383. The Specific gravity of coarse aggregate is 2.62 and Water absorption is 0.3 %
- **Fine aggregate**
  - Locally available river sand is used as fine aggregate confirming to IS 383. Fineness modules of fine aggregate is 2.64 and Specific gravity is 2.61.

II. **Alkaline Solution**
A combination of sodium silicate solution and sodium hydroxide solution was used to react with the aluminium and the silica in the fly ash. Flake form sodium hydroxide with 97% purity and sodium silicate from local supplier was used for the present study. The chemical composition of sodium silicate solution are Na$_2$O=14.74%, SiO$_2$=31.45%, and water content= 33.75% by mass. The molarity of the solution is kept 16M for thought experimental work.

III. **Steel fiber**
The plain rounded steel wires are used as fiber. The properties of steel fibers are presented in the table 2

Table 2: Properties of steel fiber

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>45 mm</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>7.85</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>200 GPA</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>75</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>0%</td>
</tr>
</tbody>
</table>

IV. **Water**
Clean potable water is used for solution preparation. The total water in the solution is considered as added water plus the water content in the sodium silicate

V. **Super plasticizers**:
Poly carboxylic ether based high performance super plasticizers of the brand name GleniumB233 confirmed with IS 9103: 1999, from BASF construction chemicals was used for all the experimental mix. The dosage applied in the range of 1% to 2% of cementitious material (fly ash) by mass for better workability.

VI. **Mix proportioning**
The mixtures named as FGC-M (Fly ash based Geopolymer concrete mixture) were prepared by varying fly ash content from 15% to 31% of total particulate matter with increments of 2%. The ratio of sodium silicate to sodium hydroxide kept constant at 2.5 for all series of mixture. The mixtures were prepared with water content of 135 litres per cubic meter of concrete. The detail of mixture proportions are presented in table 3.

Table 3: Details of mixture proportion.

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Fly ash %</th>
<th>Fly ash kg/m$^3$</th>
<th>Coarse aggregate kg/m$^3$</th>
<th>Fine aggregate kg/m$^3$</th>
<th>NaOH kg/m$^3$</th>
<th>Na$_2$SiO$_3$ kg/m$^3$</th>
<th>Plasticizer kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGC-M1</td>
<td>15</td>
<td>312.86</td>
<td>992.82</td>
<td>780.08</td>
<td>89.78</td>
<td>224.46</td>
<td>3.13</td>
</tr>
<tr>
<td>FGC-M2</td>
<td>17</td>
<td>354.58</td>
<td>969.46</td>
<td>761.72</td>
<td>89.77</td>
<td>224.45</td>
<td>3.54</td>
</tr>
<tr>
<td>FGC-M3</td>
<td>19</td>
<td>396.29</td>
<td>946.10</td>
<td>743.37</td>
<td>89.77</td>
<td>224.45</td>
<td>3.96</td>
</tr>
</tbody>
</table>
3. Compressive Strength Of The Concrete

3.1: Compressive Strength Test
The compressive strength test is conducted 150x150x150 mm concrete cubes. Three number of cubes prepared on each mixtures specified in table 2 and tested through compressive testing machine. Table 4 shows the compressive strength of the specimens.

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>% of fly ash</th>
<th>Density (KN/m$^3$)</th>
<th>Load (kN)</th>
<th>Compressive strength $f_c$ (N/mm$^2$)</th>
<th>Average compressive strength (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGC-M4</td>
<td>21</td>
<td>438.01</td>
<td>922.74</td>
<td>725.01</td>
<td>89.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.45</td>
</tr>
<tr>
<td>FGC-M5</td>
<td>23</td>
<td>479.73</td>
<td>899.38</td>
<td>706.66</td>
<td>89.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.45</td>
</tr>
<tr>
<td>FGC-M6</td>
<td>25</td>
<td>521.44</td>
<td>876.02</td>
<td>688.30</td>
<td>89.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.44</td>
</tr>
<tr>
<td>FGC-M7</td>
<td>27</td>
<td>563.16</td>
<td>852.66</td>
<td>669.94</td>
<td>89.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.44</td>
</tr>
<tr>
<td>FGC-M8</td>
<td>29</td>
<td>604.87</td>
<td>829.30</td>
<td>651.59</td>
<td>89.76</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.44</td>
</tr>
<tr>
<td>FGC-M9</td>
<td>31</td>
<td>646.59</td>
<td>805.94</td>
<td>633.23</td>
<td>89.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>224.43</td>
</tr>
</tbody>
</table>

Table 4: Compressive strength of cube specimen
3.2: Flexural Strength Test

The Geopolymer concrete mixtures FGC-M6, FGC-M7 and FGC-M8 (Optimal compressive strength mixtures) were used for the flexural strength. Tests carried on 100 X 100 X 500 mm specimens according to IS: 516-1959, the tests results are shown in Table 5

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Load P (kN)</th>
<th>Distance From fracture to nearer support (mm)</th>
<th>Flexural strength ( f_{cr} = \frac{PL}{bd^2} ) (N/mm²)</th>
<th>Average Flexural strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGC-M6</td>
<td>10</td>
<td>178</td>
<td>4.0</td>
<td>4.26</td>
</tr>
<tr>
<td></td>
<td>11.5</td>
<td>135</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.5</td>
<td>183</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>FGC-M7</td>
<td>11</td>
<td>165</td>
<td>4.4</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>178</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>174</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.5</td>
<td>166</td>
<td>4.2</td>
<td>4.13</td>
</tr>
<tr>
<td>FGC-M8</td>
<td>10.5</td>
<td>166</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>

The fibres were mixed by weight fractions of 0.2 % to 1.2% of fly ash with Mix composition of FGC-M7 Mixture, selected based on the optimized compressive strength and flexural strength, shown in table 4&5. The fibre reinforced mixture are named here as FFGC Mixtures (Fibre reinforced Fly ash based Geopolymer Concrete mixture)

4. Tests on FFGC-Mixtures and Specimens

4.1: Work ability test of FFGC-Mixtures

Slump test, Vee-Bee tests were conducted in similar way as FGC-Mixture and the value presented in the table 6

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Fiber (%)</th>
<th>Slump (mm)</th>
<th>Vee -Bee test (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFGC-M1</td>
<td>0.2</td>
<td>198</td>
<td>33</td>
</tr>
<tr>
<td>FFGC-M2</td>
<td>0.4</td>
<td>165</td>
<td>36</td>
</tr>
<tr>
<td>FFGC-M3</td>
<td>0.6</td>
<td>115</td>
<td>40</td>
</tr>
<tr>
<td>FFGC-M3</td>
<td>0.8</td>
<td>109</td>
<td>43</td>
</tr>
<tr>
<td>FFGC-M4</td>
<td>1.0</td>
<td>105</td>
<td>45</td>
</tr>
<tr>
<td>FFGC-M5</td>
<td>1.2</td>
<td>84</td>
<td>47</td>
</tr>
<tr>
<td>FFGC-M6</td>
<td>1.4</td>
<td>75</td>
<td>52</td>
</tr>
</tbody>
</table>
Table 6, Fig. 1 and 2 shows the slump and Vee-Bee cosistometer test results. As the fiber volume fraction increases the flow ability of concrete or subsidence of concrete decreases because of internal friction with matrix and fiber. The duration to collapse conical shape of the concrete in Vee-Bee cosistometer was increased with increase in fiber volume fraction. The work ability is quite important aspect along with the strength parameter. While selection of mixture both strength and considerable workability parameters were observed.
4.2: FFGC Compression Strength Test

Table 7: FFGC 7th day Compressive strength results

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>% of fiber</th>
<th>Density (KN/m³)</th>
<th>Load (kN)</th>
<th>Compressive strength $f_{ck}$ (N/mm²)</th>
<th>Average compressive strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFGC-M1</td>
<td>0.2</td>
<td>23.53</td>
<td>800</td>
<td>35.55</td>
<td>35.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.37</td>
<td>805</td>
<td>35.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.45</td>
<td>785</td>
<td>34.88</td>
<td></td>
</tr>
<tr>
<td>FFGC-M2</td>
<td>0.4</td>
<td>23.49</td>
<td>765</td>
<td>34.00</td>
<td>33.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.37</td>
<td>775</td>
<td>34.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.33</td>
<td>750</td>
<td>33.33</td>
<td></td>
</tr>
<tr>
<td>FFGC-M3</td>
<td>0.6</td>
<td>23.46</td>
<td>735</td>
<td>32.66</td>
<td>32.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.57</td>
<td>715</td>
<td>31.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.54</td>
<td>715</td>
<td>31.77</td>
<td></td>
</tr>
<tr>
<td>FFGC-M4</td>
<td>0.8</td>
<td>23.58</td>
<td>755</td>
<td>33.53</td>
<td>33.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.66</td>
<td>765</td>
<td>33.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.64</td>
<td>750</td>
<td>33.33</td>
<td></td>
</tr>
<tr>
<td>FFGC-M5</td>
<td>1.0</td>
<td>23.67</td>
<td>710</td>
<td>31.55</td>
<td>30.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.63</td>
<td>685</td>
<td>30.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.59</td>
<td>695</td>
<td>30.88</td>
<td></td>
</tr>
<tr>
<td>FFGC-M6</td>
<td>1.2</td>
<td>23.67</td>
<td>680</td>
<td>30.22</td>
<td>30.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.59</td>
<td>710</td>
<td>31.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.53</td>
<td>680</td>
<td>30.22</td>
<td></td>
</tr>
<tr>
<td>FFGC-M7</td>
<td>1.4</td>
<td>23.63</td>
<td>680</td>
<td>30.22</td>
<td>30.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.56</td>
<td>700</td>
<td>31.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.69</td>
<td>685</td>
<td>30.44</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Effect of fiber content on compressive strength
Table 6.8 and Fig. 6.13 show the decrease in compressive strength with increase in fiber content up to 0.6% and at 0.8% there slight increment in compressive strength was observed. This trend is some time may similar with fiber reinforced OPC concrete; it may be due to the void between fiber and matrix.

![Figure 4: Comparison of compressive strength](image)

**4.3: FFGC Flexure Test**

The specimens with varying percent of fiber from 0.6% (FFGC-M3) to 1.2% (FFGC-M7) were tested to study the effect of flexure with respect to fiber content.

**Table 8: FFGC 7th day Flexure test Results**

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>Load P (kN)</th>
<th>Distance From fracture to nearer support (mm)</th>
<th>Flexural strength $f_{cr}=PL/bd^2$ (N/mm²)</th>
<th>Average Flexural strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFGC-M3</td>
<td>13</td>
<td>163</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>116</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>183</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>FFGC-M4</td>
<td>13</td>
<td>165</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.5</td>
<td>167</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>178</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>FFGC-M5</td>
<td>13.5</td>
<td>174</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.5</td>
<td>166</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.0</td>
<td>168</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>FFGC-M6</td>
<td>12.5</td>
<td>174</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>166</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>168</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>FFGC-M7</td>
<td>10.5</td>
<td>174</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>166</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>168</td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>
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Table 7 and Fig 5 present the effect of fiber on flexure strength. The flexure value of 5.06, 5.13, and 5.33 N/mm² were found for the fiber content of 0.6%, 0.8%, 1.0% respectively. The trend shows the rise in the flexure capacity from 0.6% to 1% of fiber content and then the decrement in strength observed on further addition. Fig 6 shows the increasing flexure of FFGC-Mixture to FGC-M7, through addition of fibers. The percentage of increment in flexure observed is 13.3%, 15% and 19.5% with fiber content of 0.66%, 0.8%, and 1.0% respectively over the FGC-M7 flexure strength.

Figure 5: Effect of fiber content on flexure strength

Figure 6: Comparison of flexure strength
4.4: FFGC Split tensile strength test

Table 9: FFGC split tensile test Results

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Load P (kN)</th>
<th>Split tensile strength ( f_{st} = \frac{2P}{\pi ld} ) (N/mm(^2))</th>
<th>Average split tensile strength (N/mm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFGC-M3</td>
<td>210</td>
<td>2.97</td>
<td>2.99</td>
</tr>
<tr>
<td></td>
<td>220</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>205</td>
<td>2.89</td>
<td></td>
</tr>
<tr>
<td>FFGC-M4</td>
<td>235</td>
<td>3.32</td>
<td>3.32</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>3.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>FFGC-M5</td>
<td>235</td>
<td>3.32</td>
<td>3.34</td>
</tr>
<tr>
<td></td>
<td>245</td>
<td>3.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>235</td>
<td>3.32</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Comparison of split tensile strength

Table 9 and Fig 7 present the split tensile strength results. The higher value of split tensile strength observed for the FFGC-M5 with fiber content of 1.0%. The trend shows the split strength increases with flexure strength.

Fig 6 shows the increasing flexure of FFGC-Mixture to FGC-M7, through addition of fibers. The percentage of increment in split tensile were observed is 1.7%, 9.52% and 13.5% with fiber content of 0.6%, 0.8%, and 1.0% respectively over the FGC-M7 split tensile strength.

Based on these test parameters three mixtures were selected with optimal percentage of fiber and higher strength. The mixture FFGC-3, FFGC-4, FFGC-5, with fiber content of 0.6%, 0.8% and 1% respectively were selected for manufacturing of beam specimens.

5. Conclusion

I. The increase in fiber volume fraction with same fly ash and water content in the mixture decreases the workability. The work ability can be improved by adding super plasticizer
with the dosage of 1% to 2%. The mix becomes very stiff and incompatible to handle with further addition of fiber beyond 1.4%

II. Fiber reinforced Geopolymer concrete shows decrease in compressive strength compared to concrete without fibers for the same mixture proportion.

III. Fiber reinforced Geopolymer concrete shows increase in flexure and split tensile strength compared to concrete without fibers for the same mixture proportion.

IV. FGC-Mixture shows the proportional increase in flexure with compressive strength as expected in OPC-Concrete, but the FFGC-Mixture shows decrease in compressive strength and increase in flexure and split tensile strength. Due to this property of the FFGC-Mixture it could be important to investigate the compressive strength with respect to required flexure strength for design of structural elements.

V. The fiber volume fraction found effective and give optimal compressive strength at 0.8% with the aspect ratio of 75 for the specified fiber used in the investigation.

VI. FFGC-Beams shows increase in cracking moment and flexure capacity with increase in fiber content of the mixture compared to FGC-Beams.

References


