Flexural and Punching Performances of FRP and Fiber Reinforced Concrete on Impact Loading

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ABSTRACT: In this study, in order to observe the behaviors of fiber reinforced polymer (FRP) strengthened and steel fiber reinforced concrete specimens for impact and static loads, flexural and punching tests were performed. For the one-way flexural and two-way punching tests, concrete specimens with the dimensions of 50×100×350 mm and 50×350×350 mm were fabricated. The steel fiber reinforced concrete specimens showed much enhanced resistance on two-way punching of static and impact loads. Also, the FRP strengthening system provided the outstanding performance under punching resistance. Because of large tensile strength and toughness of ultra high performance concrete (UHPC) in itself, the UHPC specimens retrofitted with FRP showed marginally enhanced strength and energy dissipating capacity.

1 INTRODUCTION

The addition of fiber reinforcement is one of the most effective methods for enhancing the performances of concrete (Bindganavile et al., 2002; Rao et al., 2010; Sukontajukkul et al., 2001). Conventional fiber reinforced concrete was developed in the 1960s and has been improved with the addition of high performance fiber reinforced cementitious composites. However, the required properties of fiber reinforced cementitious composites are not provided by the simple method of merely adding the fibers to concrete matrices. Today, construction structures demand higher resistances to impacts, blasts, earthquakes, and extreme fires. Because of the significant benefits with high strain rate loads, many researchers are paying attention to fiber reinforced polymers (FRPs) for the reinforcement of construction structures (Chen & Li, 2005; Min et al., 2009). Apart from the cost, the most essential problem in the FRP system is the “bond” between the FRP and concrete.

Hence, in this study, in order to assess the performances of FRP strengthened and steel fiber reinforced concrete specimens for impact and static loads, one-way flexural and two-way punching tests were carried out.

Table 1. Mix proportions of concrete.

<table>
<thead>
<tr>
<th>W/C</th>
<th>S/C</th>
<th>Water</th>
<th>Cement</th>
<th>Fine agg.</th>
<th>Coarse agg.</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0</td>
<td>50.4</td>
<td>204</td>
<td>408</td>
<td>876</td>
<td>863</td>
<td>2.04</td>
</tr>
</tbody>
</table>

Table 2. Test variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Details</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Normal concrete</td>
<td>NC</td>
</tr>
<tr>
<td></td>
<td>Steel fiber reinforced concrete</td>
<td>SFRC</td>
</tr>
<tr>
<td></td>
<td>Ultra high performance concrete</td>
<td>UHPC</td>
</tr>
<tr>
<td>FRP</td>
<td>Not retrofitted</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>GFRP</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>CFRP</td>
<td>C</td>
</tr>
<tr>
<td>Angle of fabrics</td>
<td>±45°</td>
<td>0/90°</td>
</tr>
</tbody>
</table>
### 3 EXPERIMENTAL PROGRAM

For the one-way flexural tests and two-way punching tests, concrete specimens with the dimensions of 50×100×350 mm and 50×350×350 mm were made, respectively. The casted specimens were stored in water at 20±3°C until tested. 14 days after casting, the FRPs were adhered and then cured for 14 days more at 50% relative humidity and at a temperature of 20°C.

The restrain conditions of flexural and punching tests were illustrated in Figures 1 and 2. The span of each specimen was 300 mm and the point loads were applied in the center of specimens. For flexural specimens, the loading was applied gradually using a 2,700kN capacity UTM (universal testing machine) under displacement control at a loading rate of 0.01 mm/s. The deflection at the center and a fourth of span were measured with LVDTs (linear variable differential transformers).

### RESULTS AND DISCUSSIONS

#### 4.1 One-way flexural tests

The results of the one-way static and impact flexural tests are summarized in Table 4 and 5, respectively. Figure 3 show the load-deflection relationships of specimens in the static tests. Also, Figure 4 shows the load-deflection relationships of specimens in the impact tests.

While the maximum load of SFRC specimens were marginally more improved than the NC specimens, the toughness of SFRC increased significantly. The FRP strengthening in the NC and SFRC series increase the resistance of static and impact loads. Because large tensile strength and toughness of UHPC in itself, the UHPC specimens retrofitted with FRP showed marginally enhanced strength and energy dissipating capacity.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Maximum load (kN)</th>
<th>Defl. at max load (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-N</td>
<td>6.32</td>
<td>0.83</td>
</tr>
<tr>
<td>NC-G-45</td>
<td>8.24</td>
<td>3.22</td>
</tr>
<tr>
<td>NC-G-0/90</td>
<td>13.21</td>
<td>1.22</td>
</tr>
<tr>
<td>C-C-45</td>
<td>9.27</td>
<td>2.94</td>
</tr>
<tr>
<td>NC-C-0/90</td>
<td>10.31</td>
<td>2.43</td>
</tr>
<tr>
<td>SFRC-N</td>
<td>8.75</td>
<td>6.68</td>
</tr>
<tr>
<td>SFRC-C-45</td>
<td>16.92</td>
<td>6.28</td>
</tr>
<tr>
<td>SFRC-C-0/90</td>
<td>17.17</td>
<td>1.70</td>
</tr>
<tr>
<td>UHPC-N</td>
<td>27.90</td>
<td>10.07</td>
</tr>
<tr>
<td>UHPC-C-45</td>
<td>33.34</td>
<td>5.31</td>
</tr>
<tr>
<td>UHPC-C-0/90</td>
<td>40.79</td>
<td>4.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Max. load (kN)</th>
<th>Defl. at max load (mm)</th>
<th>Total energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-N</td>
<td>38.63</td>
<td>1.77</td>
<td>77.76</td>
</tr>
<tr>
<td>NC-G-45</td>
<td>47.23</td>
<td>2.27</td>
<td>114.44</td>
</tr>
<tr>
<td>NC-G-0/90</td>
<td>49.23</td>
<td>2.33</td>
<td>162.60</td>
</tr>
<tr>
<td>NC-C-45</td>
<td>46.49</td>
<td>2.27</td>
<td>98.79</td>
</tr>
<tr>
<td>NC-C-0/90</td>
<td>45.39</td>
<td>2.35</td>
<td>154.07</td>
</tr>
<tr>
<td>SFRC-N</td>
<td>44.93</td>
<td>1.83</td>
<td>87.35</td>
</tr>
<tr>
<td>SFRC-C-45</td>
<td>50.16</td>
<td>2.33</td>
<td>212.84</td>
</tr>
<tr>
<td>SFRC-G-0/90</td>
<td>52.49</td>
<td>2.86</td>
<td>168.75</td>
</tr>
<tr>
<td>UHPC-N</td>
<td>69.99</td>
<td>1.39</td>
<td>643.89</td>
</tr>
<tr>
<td>UHPC-C-45</td>
<td>72.46</td>
<td>1.55</td>
<td>694.38</td>
</tr>
<tr>
<td>UHPC-C-0/90</td>
<td>72.82</td>
<td>1.61</td>
<td>671.89</td>
</tr>
</tbody>
</table>

Impact tests were carried out with a drop weight test machine that has a maximum capacity of about 800 Joules. Considering the high energy dissipation ability of reinforced specimens, a 33.62 kg weight was dropped with air pressure along a 0.7 m clear height. The load cell in the tub, with the attached speedometer, measured the impact load and velocity. Then the computer calculated the impact velocity and load, impact energy, and displacement, etc.
4.2 Two-way punching tests

The results of the two-way punching tests are summarized in Tables 6 and 7. Figures 5 and 6 show the load-deflection relationships of specimens in the static and impact tests, respectively. Also, Figure 7 shows the representative failure patterns of two-way specimens under impact punching tests.

The SFRC specimens showed much enhanced resistance on static and impact loads of two-way punching. Also, the FRP strengthening system provided the outstanding performances under two-way punching loads. The UHPC, FRP reinforced SFRC and UHPC members did not fail by one blow.

Table 6. Test results of two-way static punching.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Maximum load (kN)</th>
<th>Defl. at max load (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-N</td>
<td>14.90</td>
<td>0.29</td>
</tr>
<tr>
<td>NC-G-±45</td>
<td>43.05</td>
<td>1.14</td>
</tr>
<tr>
<td>NC-G-0/90</td>
<td>45.18</td>
<td>1.33</td>
</tr>
<tr>
<td>NC-C-±45</td>
<td>39.48</td>
<td>1.11</td>
</tr>
<tr>
<td>NC-C-0/90</td>
<td>44.66</td>
<td>1.36</td>
</tr>
<tr>
<td>SFRC-N</td>
<td>22.24</td>
<td>5.74</td>
</tr>
<tr>
<td>SFRC-C-±45</td>
<td>63.13</td>
<td>1.25</td>
</tr>
<tr>
<td>UHPC-N</td>
<td>64.70</td>
<td>4.28</td>
</tr>
<tr>
<td>UHPC-C-±45</td>
<td>97.05</td>
<td>2.03</td>
</tr>
<tr>
<td>UHPC-C-0/90</td>
<td>98.42</td>
<td>1.41</td>
</tr>
</tbody>
</table>

Table 7. Test results of two-way impact punching.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Max. load (kN)</th>
<th>Defl. at max. load (mm)</th>
<th>Total energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-N</td>
<td>53.23</td>
<td>2.54</td>
<td>128.08</td>
</tr>
<tr>
<td>NC-C-0/90</td>
<td>71.19</td>
<td>4.55</td>
<td>522.52</td>
</tr>
<tr>
<td>SFRC-C-±45</td>
<td>70.30</td>
<td>3.61</td>
<td>534.07</td>
</tr>
<tr>
<td>SFRC-C-0/90</td>
<td>70.13</td>
<td>4.53</td>
<td>653.28</td>
</tr>
<tr>
<td>UHPC-N</td>
<td>63.48</td>
<td>2.09</td>
<td>405.85</td>
</tr>
<tr>
<td>UHPC-C-±45</td>
<td>73.40</td>
<td>3.16</td>
<td>767.33</td>
</tr>
<tr>
<td>UHPC-C-0/90</td>
<td>45.69</td>
<td>9.23</td>
<td>106.99</td>
</tr>
</tbody>
</table>

* Acquired data are not available.
5 CONCLUSIONS

To observe the behaviors of FRP strengthened and steel fiber reinforced concrete specimens for impact and static loads, flexural and punching tests were performed. The one-way flexural capacity of SFRC specimens were marginally more improved than the NC specimens, however the FRP strengthening in the one-way specimens of NC and SFRC series increase the resistance on static and impact loads. The strength and toughness of the FRP retrofitted UHPC specimens showed marginally enhanced. The SFRC specimens showed much enhanced resistance on two-way punching on static and impact loads. Also, the FRP strengthening system provided the outstanding performances under punching loads.

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REFERENCES


