BEHAVIOR OF HIGH STRENGTH HYBRID REINFORCEMENT CONCRETE BEAMS

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Introduction

1. Objectives

2. Finite Elements Modeling

3. Results

4. Conclusion

Out line
High-strength fiber reinforced concrete

The need of a cement-based material production having high tensile, high compressive strength, outstanding energy absorption capacity with homogeneous and isotropic merits, led to a quick expand of High-strength fiber reinforced concrete, thus becoming more extensive in modern structural materials with a high potential.

Fiber reinforced polymer (FRP)

Fiber reinforced polymer (FRP) rebars with its many types of Glass FRP (GFRP), Basalt FRP (BFRP), and Carbon FRP (CFRP), have advantages of high strength, lightweight and excellent corrosion resistance. They are therefore considered as alternatives to steel reinforcements in concrete structures. In the past decades, many researchers have investigated the structural performance of FRP reinforced components. However, FRP rebars have not been widely used in structures. The reason lies in that FRP rebars usually have low elastic modulus, which leads to the larger components deflection and the more cracks. Moreover, FRP rebars are linear elastic material, which is prone to brittle failure of structures.
Beams

Beams are used as links in the transfer of loads from slabs to columns or walls, and as such, there are several types of cross-sections of beams to meet their required functions, taking into account the requirements of construction and architecture. The most common cross-sections are rectangular and T-section, but other cross-sections can be used, such as trapezoidal, tapered, and haunch beams. The concept of reinforced beams resisting loads is that they resist compressive stress by using a concrete compression zone and the steel bars carry tension stress in the tension zone.
The main objective of this study is to develop a non-ferrous hybrid reinforcing system for concrete beams by employing continuous FRP reinforced bars incorporated with short discontinuous randomly distributed steel fiber, as well as utilizing a trapezoidal cross-section. This hybrid system has the potential to terminate problems related to steel reinforcement corrosion, while providing required strength, stiffness, and coveted ductility, which are drawbacks associated with conventional concrete structures constructed with FRP reinforcement system.
A total of six simply supported HS-SFRC beams proposed models were numerically tested in this research. These test beams are divided into two groups depending on their cross section shape. Group A consist of four trapezoidal cross section beams with dimensions of (bottom width of 125mm, top width of 250 mm, and total height of 200 mm), while Group B consist of two rectangular beam with proposed dimensions of (125×200) mm. All beams have same total length of 1500 mm, and they are supposed to be contained 1% of steel fiber having length of 35 mm and aspect ratio of 64. The proposed compressive strength $f'_{c}$ was 60 MPa for all test beams. Different types and diameters of FRP (GFRP, and BFRP) rebars were used to reinforce these proposed beams in tension zone.
### Nomenclature of the tested beams

Refer to beam cross section. (T) for Trapezoidal (R) for Rectangular

Refer to diameter and type of longitudinal reinforcement. (G10) for Ø10 mm GFRP  (G12) for Ø12 mm GFRP  (B10) for Ø10 mm BFRP  (B6) for Ø6 mm BFRP

### Table - Details of proposed beams

<table>
<thead>
<tr>
<th>Group design</th>
<th>Beam designation</th>
<th>Steel fiber</th>
<th>Main rebar details</th>
<th>Main rebar type</th>
<th>Total length</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>TG10</td>
<td>1%</td>
<td>2 Ø10 mm</td>
<td>GFRP</td>
<td>1500 mm</td>
</tr>
<tr>
<td></td>
<td>TG12</td>
<td>1%</td>
<td>2 Ø12 mm</td>
<td>GFRP</td>
<td>1500 mm</td>
</tr>
<tr>
<td></td>
<td>TB10</td>
<td>1%</td>
<td>2 Ø10 mm</td>
<td>BFRP</td>
<td>1500 mm</td>
</tr>
<tr>
<td></td>
<td>TB6</td>
<td>1%</td>
<td>2 Ø6 mm</td>
<td>BFRP</td>
<td>1500 mm</td>
</tr>
<tr>
<td>B</td>
<td>RG10</td>
<td>1%</td>
<td>2 Ø10 mm</td>
<td>GFRP</td>
<td>1500 mm</td>
</tr>
<tr>
<td></td>
<td>RB6</td>
<td>1%</td>
<td>2 Ø6 mm</td>
<td>BFRP</td>
<td>1500 mm</td>
</tr>
</tbody>
</table>
The layout details and finite element modeling of the proposed beams.

Notes: *Main rebars = Variable; 2@10 GFRP, 2@12 GFRP, 2@10 BFRP, 2@6 BFRP

The proposed trapezoidal beams
The proposed rectangular beams

Notes; *Main rebars = Variable; 2Ø10 GFRP, 2Ø6 BFRP.
General Behavior

As expected, the flexural behavior can be determined based on the ratio and type of reinforcement bars provided for the beam, as well as based on the shape and dimensions of the beam section. It is obvious from the test results in the following Table and chart that the different FRP reinforcement ratios and types and the beam cross section shape had some notable effects on the first cracking load and ultimate load capacity. However, on the other hand the shape of the beam cross-section exhibited rather significant influence on the ultimate load capacity.

<table>
<thead>
<tr>
<th>Group design</th>
<th>Beam I.D.</th>
<th>Reinforcement ratio %</th>
<th>First crack</th>
<th>Peak state</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( \rho f^* ) %</td>
<td>( P_{cr}^* ) (kN)</td>
<td>( \Delta cr^* ) (mm)</td>
<td>( P_{u}^* ) (kN)</td>
</tr>
<tr>
<td>A</td>
<td>TG10</td>
<td>0.4787</td>
<td>48.4</td>
<td>0.46</td>
<td>78.5</td>
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<tr>
<td></td>
<td>TG12</td>
<td>0.6933</td>
<td>56.6</td>
<td>0.54</td>
<td>82.1</td>
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<tr>
<td></td>
<td>TB10</td>
<td>0.4787</td>
<td>56.4</td>
<td>0.54</td>
<td>80.7</td>
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<td></td>
<td>TB6</td>
<td>0.1703</td>
<td>54.7</td>
<td>0.54</td>
<td>75.2</td>
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<tr>
<td>B</td>
<td>RG10</td>
<td>0.7180</td>
<td>41.7</td>
<td>0.57</td>
<td>57.8</td>
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<td></td>
<td>RB6</td>
<td>0.2555</td>
<td>41.3</td>
<td>0.57</td>
<td>55.5</td>
</tr>
</tbody>
</table>

Notes: *C.C = Concrete crushing, \( P_{cr}^* \) = First crack load, \( \Delta cr^* \) = Mid span deflection at first crack load, \( P_{u}^* \) = Ultimate load (peak load), \( \Delta u^* \) = Mid span deflection at ultimate load.
The load carrying capacity of all tested beams
1. Load-deflection Response

At the beginning before any observation of cracking, the relationship of load-deflection was identical and almost linear for all beams as it depends on the beam stiffness.

However, SFRC beams including FRP rebars exhibit a different behavior in terms of showing a significant enhancement in flexural stiffness throughout the post-crack stage up to peak load, and showing a behavior of a gradual reduction (softening) in strength and higher residual strength in the post-peak stage, in other words behaving in a ductile way compared to conventional concrete beams. This behavior is attributed to steel fibers ability and role in bridging the cracks with their high elastic and shear modulus.
In general the load-deflection curve of plain FRP concrete beams keeps almost linear until failure, however the flexural stiffness significantly decreases quickly right away after the first crack formation due to the low elastic modulus of FRP rebars and inadequate tensile load carrying capacity of concrete. Afterwards, the flexural stiffness gradually decreases with a steep increase in the cracks number and fast increase in crack width, and each beam behaves differently depending on the reinforcement type and ratio. The Fig shown here to the side depict such behavior of load-deflection of plain concrete reinforced with different types of FRP bars and the behavior of the curve is valid to be considered as a typical behavior regardless of the obtained data values that significantly differ from one research to another depending on many influential factors.
2. Effect of FRP Reinforcement Type

The load deflection response plotted in the displayed figure shows that the behavior of the GFRP and BFRP reinforced beams are almost similar, however some improvement can be observed in the stiffness of the post cracking response of BFRP reinforced beam and an increase in the first crack load and ultimate load capacity of approximately 14.5% and 2.8% respectively with higher residual strength in the post-peak stage. These observed improvements are mostly owing to the higher Young’s modulus of the BFRP rebars and the higher rupture stress than the GFRP rebars.
3. Effect of Reinforcement Ratio

Higher GFRP and BFRP reinforcement ratios resulted in higher first cracking load and peak loads, which were found to be increased by 16.9% and 4.6% respectively, for 44.8% increase in GFRP reinforcement ratio, and by 3% and 7.3% respectively, for 181% increase in BFRP reinforcement ratio. For the higher reinforcement ratio a slightly stiffer post-cracking flexural behavior were observed. However the effect of increasing the reinforcement ratio manifested clearly on a more gradual reduction in strength and higher residual strength in post-peak stage for both cases shown in figures here.
4. Effect of Cross-section Shape

The results show that the trapezoidal cross section beams exhibited higher stiffness at post-cracking stage, which refer to a better fracture toughness, also the results indicate that the ultimate load capacity has increased by 35.5 to 35.8% when the top width of the beams increased from 125 mm to 250 mm, i.e. converting the beams from having a rectangular cross section to trapezoidal cross section.
These improvements may be attributed to the compression area in the cross-section becoming bigger with any increase in the top width, causing the depth of the equivalent rectangular compression zone to be smaller, which lead to an increase in the moment arm from \((d - a/2)\) in rectangular cross-section case to \((d - y)\) in trapezoidal case.
5. Crack Patterns at Final Loading Stage

Cracks generated from initializing the stress field at the pure bending region by applying the two symmetrical point loads on each side of the test beams.

After reviewing cracking patterns of models at failure, it became clear that the cracks appear as a green region and initiate from the center then propagated upward toward the compression zone.

A major two facts reported from conducting this study are that all model beams were governed by concrete crushing failure mode with no widening of a flexural crack in the tension zones, also The cracks did not propagate rapidly in concrete beams due to combining the effects of HSC material, steel fiber, with FRP reinforcing bars regardless of whether the cross section of the beam is trapezoidal or rectangular.
Conclusions

The deflections were similar and were approximately 1.07–1.54 mm for all test beams. Because of its fiber bridging capacity on the crack surfaces, all the HS-SFRC beams exhibited stiff load–deflection curves at post-cracking stage and a gradual decrease in strength as well as a high residual strength in post-peak stage.

When GFRP rebars replace by BFRP, the beam behaved almost similarly. However, an increase in the first crack load and ultimate load capacity of approximately 14.5% and 2.8% respectively were observed. The BFRP reinforced beam showed higher residual strength in the post-peak stage, also a slight improvement in the stiffness in the post cracking stage was noticed.

Higher post-cracking stiffness was observed with higher reinforcement ratio of FRP bars. The increases in the first crack load and ultimate load were found to be approximately 16.9 % and 4.6% respectively, for 44.8% increase in GFRP reinforcement ratio, and approximately 3% and 7.3% for 181% increase in the BFRP reinforcement ratio.
Converting the beam from having a rectangular cross section to trapezoidal by increasing the top width from 125 mm to 250 mm resulted in increasing the first crack load by 16 to 32.4%. The increase in ultimate load capacity was approximately 35.5 to 35.8% with higher post-cracking stiffness exhibition, which certainly refers to a better fracture toughness.

All test beams were governed by concrete crushing failure mode and the cracks did not propagate rapidly or deeply in concrete beams due to combining the effects of HSC material, steel fiber, and trapezoidal cross section with FRP rebars.
THANK YOU