AN ANALYTICAL AND EXPERIMENTAL STUDY ON REINFORCED CONCRETE BEAM WITH CARBON FIBER FABRIC WRAP

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INTRODUCTION

1. To compare the difference in critical load, ultimate load and flexural strength of beam specimens retrofitted with carbon fiber fabric wrap \(B_{u30}, B_{u25}, B_{u20}\) at different widths, i.e., 30 cm, 25 cm and 20 cm respectively.

2. To compare the experimental values of retrofitted beam specimens with conventional beam specimen’s \(B_{con}\) test results.

3. To analyze the specimens tested experimentally in ANSYS software and to compare the analytical results with the experimental results.

4. To find the beam specimen with highest flexural strength and to compare its analytical values with the experimental values.

5. To check the shear stress distribution in the specimens using ANSYS software and find the maximum shear values of the specimens and the points at which shear concentration is higher.

METHODOLOGY

Use of carbon fiber based retrofitting sheets or mats has been in use for the past decade. Even though sufficient studies has to be carried out to optimize the cost involved in retrofitting since carbon fiber compounds are expensive. Carbon fiber fabric is bi-directional anisotropic compound. Retrofitting using carbon fiber fabric mat requires proper binding using epoxy resins. Epoxy resin plays a key role in the experiment by avoiding debonding failure during the experimental tests. The carbon fiber fabric as compared to carbon fiber woven sheets are very thin loosely arranged, minimum of five layer is required for adequate strength (Murali and Pannirselvam, 2011; Norris, et al., 1997; Antonopoulos and Triantafillou, 2002). In this study, carbon fiber fabric retrofits...
mats having three different widths [30, 25, 20] cm are u - wrapped constant intermediate gap of 10 cm to the beam specimens (Fig. 1).

MIX DESIGN
The specified strength of the concrete is 35 mpa in 28 days. The specific gravity of cement, coarse aggregate and fine aggregate are 3.15, 2.884 and 2.29 respectively. Grade of the cement used for the casting is opc 53. The water cement ratio adopted is 0.45. The mix proportion of the concrete has been obtained by the code [IS 10262-1982]. The mix proportion obtained has been showed in Table 1.

The compression test of the concrete at 28 days has been carried out to check the average compressive strength of the concrete. The values obtained is as tabulated in the Table 2 and (Fig. 2). From the test results, the average compressive strength of the concrete is found to be 34.56 N/mm².

EXPERIMENTAL STUDY
Total number of four beam specimens has been casted for the experimental studies. Beam specimens casted have been cured for 28 days before testing. Size of the beams are 1500 mm × 200 mm × 250 mm. Nomenclature of the beam specimens are as given in Table 3. Excellent bonding between the carbon fiber fabric mat and the surface of the beam specimen is required for the efficient increase in flexural strength of the specimen. Epoxyresin provides the adequate bonding strength to avoid debonding failure and the carbon fiber fabric mat act uniformly as the specimen under the loading condition (Fig. 3 and 4).

TESTING OF BEAM SPECIMENS
All the beam specimens are being tested under two point loading condition. The conventional beam (B_{con}) is tested first to find out the critical and ultimate loads. The flexural strength is found out using the formula,

\[ \sigma = \frac{F \times L}{b \times d^2} \]  \hspace{1cm} (1)

Where \( \sigma \) is the flexural stress or the bending stress of the beam; \( F \) is the ultimate load exerted on the beam specimen; \( L \) is the effective length of the beam specimen; \( b \) is the breadth of the beam; \( d \) is the depth of the beam (Fig. 5).

Similarly, the retrofitted test beams, B_{u30}, B_{u25}, B_{u20} are also tested respectively. The experimental test results of each beams which has been recorded are tabulated in Table 4. which is as follows:

EXPERIMENTAL TEST RESULTS
The experimental test results shows that there is an increase in the flexural stress or the bending stress as the width of the carbon fiber fabric wrap is increased. The load bearing capacity of the beam is increased as the width of the wrapping is increased. As compared

Table 1. Mix proportion

<table>
<thead>
<tr>
<th>Water (Liter)</th>
<th>Cement (kg)</th>
<th>Fine aggregate (kg)</th>
<th>Coarse aggregate (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.40</td>
<td>186</td>
<td>132</td>
<td>232.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>410.83</td>
</tr>
<tr>
<td>1.40</td>
<td>1</td>
<td>1.76</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Table 2. Compression test results of concrete cubes (150 × 150) mm

<table>
<thead>
<tr>
<th>S. No</th>
<th>Mould Number</th>
<th>Fresh Concrete Density in Kg</th>
<th>Hardened Concrete Density in Kg</th>
<th>Compressive Strength In N/Mm²</th>
<th>Avg. Compressive Strength in N/Mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CC 1</td>
<td>2666.66</td>
<td>2400</td>
<td>34.6</td>
<td>34.56</td>
</tr>
<tr>
<td>2</td>
<td>CC 2</td>
<td>2577.77</td>
<td>2429.63</td>
<td>36.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CC 3</td>
<td>2607.41</td>
<td>2459.25</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>
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with the conventional beam, the percentage increase in flexural strength of $B_{u20}$, $B_{u25}$ and $B_{u30}$ are 27.27%, 36.36% and 54.55%.

The graphical representation of difference in ultimate load and flexural strength in test beams are showed in (Fig. 6 and Fig. 7) respectively (Yoganathan and Mahendran, 2014; Kharatmol, et al., 2014; Yasmeen, 2010).

The deflection at the right, left and the center portion

with the ultimate load of conventional beam, the percentage increase in $B_{u20}$, $B_{u25}$ and $B_{u30}$ are 28.57%, 35.71% and 50% respectively. Similarly, as compared

Table 3. Nomenclature of test beam specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Critical load (KN)</th>
<th>Ultimate load (KN)</th>
<th>Flexural stress (KN/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{conv}$</td>
<td>56</td>
<td>112</td>
<td>0.011</td>
</tr>
<tr>
<td>$B_{u20}$</td>
<td>64</td>
<td>144</td>
<td>0.014</td>
</tr>
<tr>
<td>$B_{u25}$</td>
<td>68</td>
<td>152</td>
<td>0.015</td>
</tr>
<tr>
<td>$B_{u30}$</td>
<td>76</td>
<td>168</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Table 4. Experimental test results

Fig. 2 Compression test of cube specimen CC2.

Fig. 3 Cracks formed during the test of $B_{conv}$.

Fig. 4 Test setup of $B_{u20}$.

Fig. 5 Test setup of $B_{u30}$.

Fig. 6 Ultimate load chart of specimens.

Fig. 7 Flexural strength of specimens.
of the beam specimen is during two point loading is found out and tabulated using strain gauges. Since the procedure is a progressive loading the range of loading was adopted to be 4 KN (Venkatesha, et al., 2012). The load vs deflection graph is showed in the following figures (Fig. 8-11).

From the experimental test results, among the retrofitted test beams $B_{U30}$ has the maximum deflection when $B_{U20}$ has the minimum deflection. $B_{U30}$ has the maximum ultimate load value while $B_{U20}$ has the minimum ultimate load value (Table 5).

**ANALYTICAL STUDY**

The analytical part mainly consist of three stages, they are modeling, meshing and analysis. The modeling of the beam is carries out by creating the exact model of the test specimens. Meshing is the part where the choice of fine meshing or coarse meshing is made. This study is carried out under fine mesh condition. As the mesh gets finer the time taken for the analysis also increases.

Exact conditions where the experiments has been carried out is stimulated in ANSYS Workbench. The loads, Loading distances and support distances are provided exactly as the experimental setup. The physical and mechanical properties of the materials such as concrete, steel and carbon fiber is provided to the models.

### Analytical Results of Specimens Loaded Under Ultimate Load of Conventional Beam

Analysis is done in two stages. First, by providing the ultimate load of conventional beam to the retrofitted beam in order to study the change in deformation and equivalent shear value in retrofitted beamsunder the ultimate load value condition of conventional beam. The analytical results under this condition is provided in Table 6.

As the results shows, the least deformation is showed by $B_{U20}$ among retrofitted beam specimens as the maximum deformation is observed in $B_{U30}$. The equivalent shear stress value is highest in $B_{U25}$ as it is least in $B_{U20}$ (Fig. 12-16).

### Analytical Test Results of Specimens Tested Under Respective Ultimate Loads

The second stage of analysis is that the specimens are analyzed using the experimental values of their own. The results thus obtained has been tabulated in Table 7.
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Table 6. Change in deformation and equivalent shear value in retrofitted beams under the ultimate load value condition of conventional beam

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Load (KN)</th>
<th>Total deformation (mm)</th>
<th>Equivalent stress (mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B$_{conv}$</td>
<td>112</td>
<td>0.662</td>
<td>113.56</td>
</tr>
<tr>
<td>B$_{U20}$</td>
<td>112</td>
<td>0.5209</td>
<td>110.34</td>
</tr>
<tr>
<td>B$_{U25}$</td>
<td>112</td>
<td>0.4955</td>
<td>329.63</td>
</tr>
<tr>
<td>B$_{U30}$</td>
<td>112</td>
<td>0.6095</td>
<td>105.52</td>
</tr>
</tbody>
</table>

Fig. 12 B$_{conv}$ under loading.

Fig. 13 B$_{U20}$ under ultimate load of conventional beam.

Here the least deformation among retrofitted test beams was observed in B$_{U20}$ when the maximum deformation is found in B$_{U30}$. The least equivalent shear among retrofitted test beams was observed in B$_{U30}$ where the maximum equivalent stress was observed in B$_{U25}$ (Fig. 17 and Fig. 18).
Fig. 14 $B_{u20}$ under ultimate load of conventional beam.

Fig. 15 $B_{u30}$ under ultimate load of conventional beam.

Fig. 16 $B_{U20}$ under loading.
Table 7. Analytical test results of specimens tested under respective ultimate loads

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Load (KN)</th>
<th>Total Deformation (mm)</th>
<th>Equivalent stress(mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{conv}</td>
<td>112</td>
<td>0.662</td>
<td>113.56</td>
</tr>
<tr>
<td>B_{U20}</td>
<td>114</td>
<td>0.669</td>
<td>142.5</td>
</tr>
<tr>
<td>B_{U25}</td>
<td>152</td>
<td>0.672</td>
<td>447.36</td>
</tr>
<tr>
<td>B_{U30}</td>
<td>168</td>
<td>0.914</td>
<td>158.29</td>
</tr>
</tbody>
</table>

Fig. 17 B_{U25} under loading.

CONCLUSION

Based on the experimental and analytical results the following conclusions has been made.

- The total deformation was highest for BU30 both in experimental as well as analytical results. Thus the beam wrapped with 300 mm wide strips has the largest deflection among the three retrofitted beams.

- Beam wrapped with 300m wide strips has the maximum flexural value (0.017 KN/mm²). While the beam retrofitted with 20 mm wide strips has the least value for flexural stress (0.014 KN/mm²).

- The maximum equivalent stress value was observed in beam wrapped with 250 mm wide strips. While the least equivalent stress value was observed in beam retrofitted with 200 mm wide strips.

- The experimental values and the analytical values of deflection has slight variation. This might be caused by the quality of materials, quality of casting, errors occurred during testing.
As compared with the ultimate load of conventional beam, the percentage increase in \( B_{U20}, B_{U25} \) and \( B_{U30} \) are 28.57%, 35.71% and 50% respectively. Similarly, as compared with the conventional beam, the percentage increase in flexural strength of \( B_{U20}, B_{U25} \) and \( B_{U30} \) are 27.27%, 36.36% and 54.55%. Thus the most effective mode of retrofitting is clearly with 30 cm wide strips at 100 mm spacing.

This results are and conclusion is based on the experimental as well as analytical study of 4 beams. The air bubble or the void formed between the beam and the wrap is a phenomenon which cause variation in test results. Exact and 100% efficient bonding is not practically possible. This will cause variation in analytical and experimental results. Experiments with more number of beams can be done with more number of wrapping and varied width.

REFERENCES


