FLEXURAL RESPONSE OF REINFORCED CONCRETE BEAMS LAMINATED WITH BASALT FIBER REINFORCED POLYMER (BFRP)

KESAVAN S¹ & RAJASEKARAN A²

¹Scholar, Department of Civil & Structural Engineering, Annamalai University, Chidambaram, Tamil Nadu, India
²Professor of Civil & Structural Engineering, Annamalai University, Chidambaram, Tamil Nadu, India

ABSTRACT

Many researchers studied the flexural behavior of reinforced concrete beams strengthened with near surface mounted fiber reinforced polymers of glass, carbon and aramid fibers with different configurations. The present study enumerates the flexural response of reinforced concrete beams strengthened with Near Surface Mounted (NSM) Basalt Fiber Reinforced Polymers (BFRP). To investigate the flexural response 3 reinforced concrete beams were cast and tested. One beam served as reference beam and other two beams were strengthened with 2layered BFRP and 4layered BFRP laminates. All the beams were tested under four point bending and the results were compared with reference beam and presented. The experimental results concluded that reinforced concrete beams strengthened with 4 layered BFRP laminates at the tension zone exhibit an increase in load carrying capacity of about 17.95% when compared to that of reference beam.

KEYWORDS: Basalt Fiber, Fiber Reinforced Polymers, Flexural Rigidity, Epoxy Resin & Load Carrying Capacity

Received: Jun 10, 2020; Accepted: Jun 30, 2020; Published: Jul 28, 2020; PaperId.: IJMPERDJUN2020507

1. INTRODUCTION

In last few decades, many researchers conducted experimental study on Reinforced concrete (RC) beams strengthened with different types Fibre Reinforced Polymers (FRP) having different configurations (Attari et al., 2012, Ceroni 2010 and Jiangfeng Dong et al., 2013). Toutanjiet et al., 2006, studied the flexural performance of RC beams strengthened with near surface mounted carbon fiber reinforced polymer (CFRP) sheets. All the beam specimens were tested under two-point loading. The test results concluded that CFRP strengthened RC beams exhibit an increase of about 170% in load carrying capacity when compared to that of control beam. The CFRP strengthened RC beam showed enhanced ductility than that of control beam. Hashemi et al. examined the flexural response of reinforced high strength concrete (HSC) beams strengthened with CFRP sheets. The test results of strengthened beams under four point bending concluded that the energy ductility got increased twice than that of displacement ductility values.

Muktar Nuhu Danrakaet al., 2017, reported that FRP strengthened RC beams show sign of increase in load carrying capacity, stiffness, ductility and control development of cracks.

In contrast to the artificial fibers, now-a-days natural fibers such as jute and basalt fibers are getting popularity in the structural strengthening and repair. Panuwat et al., 2019, investigated the flexural strengthening of RC beams using natural fibers Jute Fiber Reinforced Polymer Composites (JFRP) and Basalt Fiber Reinforced
Polymer (BFRP) composites. The authors adopted two types of strengthening technique, one at the tension zone and the second one is U shaped wrapping. The experimental study concluded that second type of strengthening technique proved to be effective technique to enhance the flexural strength. The authors also reported that de-bonding failure mode occurred which should be avoided.

Practical application of external strengthening fiber reinforced polymer laminates or sheets to concrete may not be as perfect as carried out in the laboratory. The bonding defects cannot be avoided. An experimental program including two-point loading test on reinforced concrete (RC) beams strengthened with and without FRP was conducted. Test results concluded that FRP sheets / laminates with 10% concrete pulled off. On tested beams, cracks have a 2 sided effect on bond-slip relationship which resulted in degradation of the bond slip relationship when crack width is large Wan et al., 2018.

The present study is planned to investigate the flexural response of reinforced concrete beams strengthened using natural basalt fiber laminates.

2. EXPERIMENTAL PROGRAM

2.1 Test Specimens

To study the flexural response a total of three beams were cast and tested. One beam served as reference beam and remaining two were strengthened with 2-layered and 4-layered BFRP laminates. The details of the test specimens with designation are presented in table 1.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Beam Designation</th>
<th>Strengthening Type</th>
<th>Thickness of Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0BFRP</td>
<td>0</td>
<td>0-layered BFRP</td>
</tr>
<tr>
<td>2</td>
<td>2BFRP</td>
<td>2</td>
<td>2-layered BFRP</td>
</tr>
<tr>
<td>3</td>
<td>4BFRP</td>
<td>4</td>
<td>4-layered BFRP</td>
</tr>
</tbody>
</table>

2.2 Materials Used

Concrete mix of M20 grade, with Ordinary Portland Cement (OPC) of 53 grade satisfying the requirements of IS12269-1987, Fine Aggregate (FA) confirming to zone II, Coarse Aggregate (CA) of maximum size 20mm and potable water was used in this study. Fe500 grade steel confirming IS1786-2008 was used as reinforcement. The basalt fibers of diameter 1.2mm are fabricated together to form 1-layered BFRP laminate of thickness 0.41mm. The epoxy resin (1kg of Corocreteresin) mixed up with 200gms of hardener was used to bond the BFRP laminate at the soffit of the beam specimens.

2.3 Casting of Beams

Three reinforced concrete beams of width 150mm, depth 250mm and 3000mm length was cast with 2 numbers of 12mm diameter bars as tension reinforcement and 2 numbers of 10mm diameter bars as hanger bars with 8mm diameter bars as transverse reinforcement placed at 125mm center to center distance. All beams were cast with M20 grade concrete mix ratio 1:1.5:3. The details of reinforced concrete beam is presented in figure 1.
2.4 Strengthening and Testing of Beams

One beam served as reference beam and the other two beams were strengthened with 2-layered and 4-layered BFRP laminates at the soffit of the beams using epoxy resin and kept cured for 7 days at room temperature. All the beams were tested under four-point bending until failure. The BFRP strengthening process is shown in figures 2 to 5. The experimental test set-up of RC beam under four-point bending is shown in figure 6.
3. RESULTS AND DISCUSSIONS

3.1 Effect of BFRP Laminates on Strength

Four-point bending test was carried with load increment of 1kN and its corresponding deflections are noted. It is observed that all the beams exhibit flexure mode of failure. The load-deflection graph is plotted for all the beam specimens and the results were compared with reference beam. The values of ultimate load and maximum deflection for all the beam specimens are tabulated in table 2 and the load-defection graph is presented in figure 7.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Beam ID</th>
<th>Load (kN)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0BFRP</td>
<td>39</td>
<td>24.60</td>
</tr>
<tr>
<td>2</td>
<td>2BFRP</td>
<td>40</td>
<td>24.20</td>
</tr>
<tr>
<td>3</td>
<td>4BFRP</td>
<td>46</td>
<td>22.20</td>
</tr>
</tbody>
</table>

Figure 7: Load-Deflection Plot for the Test Specimens.
Flexural Response of Reinforced Concrete Beams Laminated with Basalt Fiber Reinforced Polymer (Bfrp)

The figure 7 inferred that, the ultimate strength of 2-layered, and 4-layered BFRP strengthened beams enhanced by 2.56% and 17.95 % respectively when compared to that of reference beam. Also, the reference beam has a deflection of 24.6mm and it got reduced by 1.63% and 9.76% by external strengthening of 2-layered and 4-layered BFRP laminates respectively. The maximum load carrying capacity of 4-layered BFRP strengthened beam was 46kN, which is 13.04% higher than that of 2-layered BFRP strengthened beam. Similarly, the central deflection of 4-layered beam is 22.2mm, which is 8.26% lesser than that of 2-layered BFRP strengthened beam. The load-deflection behavior is found to be typical in the initial stage for reference beam and 2-layered BFRP beam.

3.2 Moment – Curvature Relationship

Moment-Curvature represents the variation of moment of resistance with respect to the curvature. Moment is caused due to the load on the beam and its curvature is the resistance to rotation about its central point. The experimental values of load deflection are used to determine the moment curvature relationship. The moment-curvature for all beam specimens are tabulated in Table 3 and the graphs are pictured from figure 8.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Beam ID</th>
<th>Moment (kNm)</th>
<th>Curvature (rad/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0BFRP</td>
<td>18.20</td>
<td>0.438</td>
</tr>
<tr>
<td>2</td>
<td>2BFRP</td>
<td>18.67</td>
<td>0.431</td>
</tr>
<tr>
<td>3</td>
<td>4BFRP</td>
<td>21.47</td>
<td>0.395</td>
</tr>
</tbody>
</table>

Figure 8: Moment – Curvature Plot for the Test Specimens.

The table 3 and figure 8 inferred that the moment carrying capacity of 4-layered BFRP beam is 21.47kNm, which got increased by 17.96% and 15% for the controlled and 2-layered beams respectively. On the other hand, the curvature got decreased by strengthening of beam using BFRP laminates. The resistance to rotation was decreased by 9.81% by the external reinforcement of 4-layered BFRP laminate.

3.3 Flexural Rigidity

Flexural rigidity is the resistance offered by the beam under flexure. Mathematically, it is defined as the product of modulus of elasticity (E) and moment of inertia (I) of the beam. The value for flexural rigidity can be obtained from the
relationship between the maximum central deflection ($\Delta$) and flexural rigidity (EI). The maximum deflection for a simply supported beam carrying two-point load is given by,

$$\Delta = \frac{P a}{24 E I} (3L^2 - 4a^2) \ldots \ldots$$  \hspace{1cm} (1)

Where,

$\Delta$ = Maximum deflection  
$P$ = Ultimate load  
$L$ = Beam span  
$a$ = Span from support to the loading point  
$EI$ = Flexural rigidity

By using the above equation (1), the values are calculated and tabulated in table 4.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Beam ID</th>
<th>Load (kN)</th>
<th>Deflection (mm)</th>
<th>Flexural Rigidity (kN m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0BFRP</td>
<td>39</td>
<td>24.60</td>
<td>1235.09</td>
</tr>
<tr>
<td>2</td>
<td>2BFRP</td>
<td>40</td>
<td>24.20</td>
<td>1287.69</td>
</tr>
<tr>
<td>3</td>
<td>4BFRP</td>
<td>46</td>
<td>22.20</td>
<td>1614.26</td>
</tr>
</tbody>
</table>

Table 4 inferred that the flexural rigidity of 2-layered and 4-layered BFRP beam got increased by 4.26% and 30.70% respectively when compared with controlled beam specimen. The 4-layered BFRP beam has a rigidity of 1614.26 kNm$^2$ which was 25.36% greater than 2-layered BFRP strengthened beam.

### 3.4 Failure Mode of Test Specimens

All the beams were tested under four-point bending and it was observed that all the beams are failed under flexure mode. Flexure cracks are observed in all beams. The following figures show the less number of shear cracks due to the close spacing of stirrups. As the load is applied over the span of the beam, the first hairline cracks are noticed and its corresponding load as first crack load. The first crack load is increased for the retrofitted beam by comparing with the controlled concrete beam. For a controlled specimen, the flexural crack starts from the bottom of the beam and propagates vertically towards the top phase till the concrete rupture. For the 2 layered BFRP strengthened beam, controls the deflection, thus propagation of cracks is more which results in the rupture of BFRP plates. For the 4-layered retrofitted beam, increased cracks and the BFRP plates get failed from the beam specimen. This kind of failure of BFRP plates gives prior warning to failure. The crack pattern observed on 0-layered, 2-layered, and 4-layered BFRP strengthened beams are shown in figures 9 to 11 respectively.

Figure 9: Crack Pattern Observed in 0-Layered BFRP Beam.
4. CONCLUSIONS

This study presents an experimental investigation on the use of BFRP laminates on flexural strengthening of reinforced concrete beams. Based on experimental investigation following conclusions are made:

- The application of BFRP laminates at the soffit of the RC beams proved to be an effective strengthening to enhance the ultimate load carrying capacity of RC beams.
- The 4-layered BFRP strengthened RC beams exhibit a maximum increase in load carrying capacity of 13.04% and 17.5% compared to that of 2-layered BFRP strengthened beam and reference beam respectively.
- Near surface mounted BFRP laminate strengthening techniques are found effective to enhance load carrying capacity and controlled deflection of RC beams.
- Increasing the number of layers of BFRP plates in strengthening of beams decreases the deflection thereby increasing the flexural rigidity.

REFERENCES


