RESEARCH ARTICLE OPEN ACCESS

# Experimental Study of the Flexural Behaviour of Damaged RC Beams Strengthened in Bending Moment Region with Basalt Fiber Reinforced Polymer (BFRP) Sheets

Akshay P. Gholkar*, H. S. Jadhav**
*(M. Tech (Structure) Student, Rajarambapu Institute of Technology, Rajaramnagar, Sakharale, Dist-Sangli (M. S.), India. 415414)
**(Head, Civil Department, Rajarambapu Institute of Technology, Rajaramnagar, Sakharale, Dist-Sangli (M. S.), India. 415414)

**Abstract**
This paper presents the flexural behaviour of basalt fiber reinforced polymer (BFRP) strengthened reinforced concrete (RC) beams. For flexural strengthening of reinforced concrete beams, total twenty-two beams were cast and tested over an effective span of 900 mm up to failure of the beam under two-point loading. The beams were designed as under-reinforced beams. The beams were bonded with BFRP sheets in single layer and double layers in the bending moment region at the bottom face of the beam. Out of the twenty-two beams two beams were control beams and remaining beams were strengthened after being damaged for various degrees of damage (0 %, 70 %, 80 %, 90% and 100 %). The experimental results show that the beams strengthened show high load carrying capacity.
**Keywords:** Basalt Fiber Reinforced Polymer (BFRP), Bending moment region, Control beam, Reinforced Concrete, Strengthened beam, Ultimate Load carrying capacity.

## I. INTRODUCTION

Much of our current infrastructure is constructed of concrete. As time passes, deterioration and change of use requirements facilitate the need for new structures. Demolition of existing and construction of new structures is a costly, time consuming and resource intensive operation. If existing structures could be reinforced to meet new requirements then the associated operating costs of our infrastructure would be reduced. [1] In recent years repair and retrofitting of existing structures such as buildings, bridges, etc., have been amongst the most important challenges in Civil Engineering. The main reason for strengthening of RC structures is to upgrade the resistance of the structure to withstand underestimated loads and increase the load carrying capacity for loads such as seismic loads. The maintenance and rehabilitation of structural members, is perhaps one of the most crucial problems in civil engineering applications. [2]

***Basalt fibers***

Basalt is a natural, hard, dense, dark brown to black volcanic igneous rock originating at a depth of hundreds of kilometres beneath the earth and resulting the surface as molten magma. And it's grey, dark in colour, formed from the molten lava after solidification. The production of basalt fiber consists of melt preparation, extrusion, fiber formation, application of lubricates and finally winding. This method is also known as spinning. A fiber is a material made into a long filament with a density generally in the order of 300g/cm$^2$ of 50 cm. [5]
Experimental studies conducted by David E. et.al. [3] focused on the flexural behaviour of RC beams strengthened using Carbon Fibre Plates. Esfahani M.R. et.al. [4] investigated the flexural behaviour of reinforced concrete beams strengthened using Carbon Fibre Reinforced Polymers (CFRP) sheets. Jadhav H.S. et.al. [5] presented the results of experimental studies carried out to investigate the effect of length, width and number of layers of Glass Fiber Reinforced Polymer strips. In my work, I have conducted tests on beams wrapped in the bending moment region.

## II. EXPERIMENTAL PROGRAM

The experimental programme consisted of casting reinforced concrete beams, damaging them to various degrees, applying the BFRP sheets and testing them under two point loading.

### 2.1 Details of the Beam Specimen

The experimental work consisted of a total of twenty-two rectangular beams under reinfor-ced concrete. All beams were of the same size 100 mm x 150 mm x 1200 mm, 2 -8 mm diameter bars were used for flexural reinforcement at the bottom of each beam, 2-8 mm at the top of each beam and 6 mm diameter stirrups spaced 150 mm center-to- center for shear reinforcement. Typical beam reinforcement details are illustrated in the Figure 1. The casting of beams was made as per IS code specification using M20 grade concrete with 20 mm maximum size of coarse aggregate, locally available sand and 53 grade ordinary Portland cement. These beams were cured for 28 days in pure.

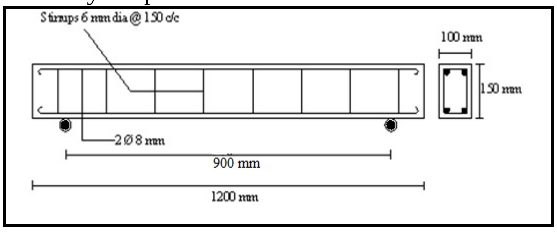

Fig. 1 reinforcement details of beam

### 2.2 Test beam preparation

The description of test specimens is summarized in Table 1. The tension surfaces of the beams were cleaned using polish paper to ensure a good bond between the BFRP strip and concrete surface. Each of these beams was externally bonded with GFRP strips and epoxy at the tension face of the beam as per the procedure given by the manufacturer. Physical properties of Basalt fiber are given in Table 2.

### 2.3 Test procedure and instrumentation

All beam specimens were instrumented and loaded and supported simply as shown in figure 2. The load was applied through Universal Testing Machine of capacity 600 kN. All beams were tested under two point loading. They were statically tested for failure at equal 2 kN increment of load. During loading the mid span deflection was measured using dial gauge having a least count of 0.01 mm. Deflections and the applied load were recorded at every load increment.

Table 1. Description of test specimens

| Specimen ID | Basalt fiber reinforced Polymer (BFRP) strip | |
|---|---|---|
| | **Length (mm)** | **Number of layers** |
| Control beam | NA | NA |
| 0% damaged | 850 | 1 |
| 0% damaged | 850 | 2 |
| 70% damaged | 850 | 1 |
| 70% damaged | 850 | 2 |
| 80% damaged | 850 | 1 |
| 80% damaged | 850 | 2 |
| 90% damaged | 850 | 1 |
| 90% damaged | 850 | 2 |
| 100% damaged | 850 | 1 |
| 100% damaged | 850 | 2 |

Table 2. Properties of basalt fiber

| **Properties** | **Values** |
|---|---|
| Tensile Strength (MPa) | 3000 – 4800 Mpa |
| Modulus of Elasticity (GPa) | 110 GPa |
| Strain at the failure | 2.56 % |
| Weight of the sheet per $m^2$ | 300 $g/m^2$ |
| Density | 1700 $g/cm^3$ |
| Thickness of the sheet | 0.2 mm |

Fig. 2 beam test setup

The beams were wrapped in the bending moment region as shown in figure 3.


Fig. 3 application of sheets

## III. RESULTS AND DISCUSSIONS

The control beam had a load at yielding of 40 kN and an ultimate load of 50 kN. All strengthened specimens exhibited limited deformation and cracks before yielding of reinforcement. The initial cracks were initiated at a load of 20 kN and progressed towards upward direction from bottom as shown in Figure 7.

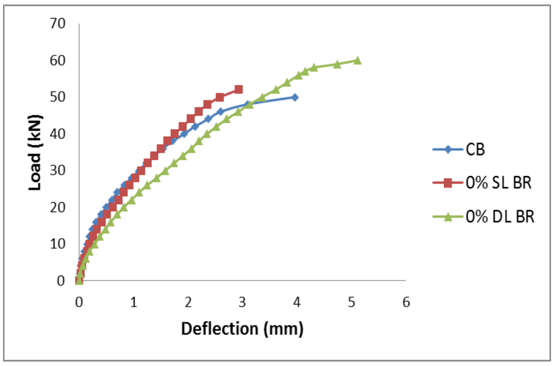


Fig. 4 load versus deflection curve (0% damage)

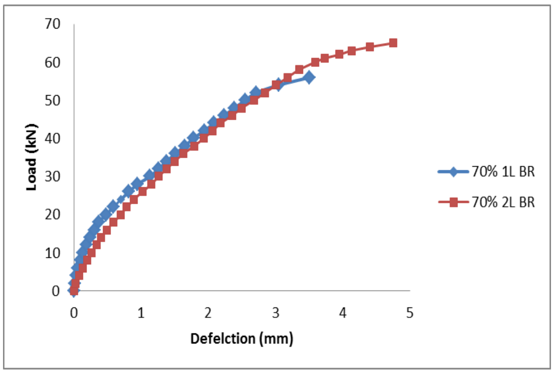


Fig. 5 load versus deflection curve (70% damaged)

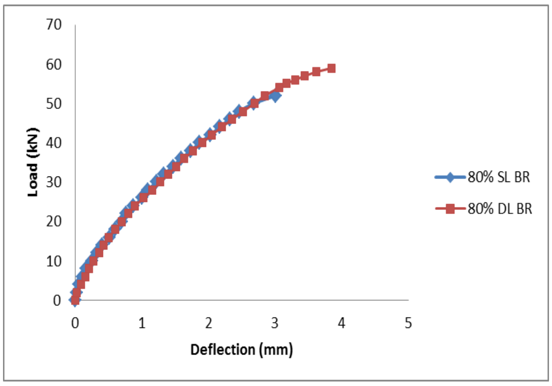


Fig. 6 load versus deflection curve (80% damaged)

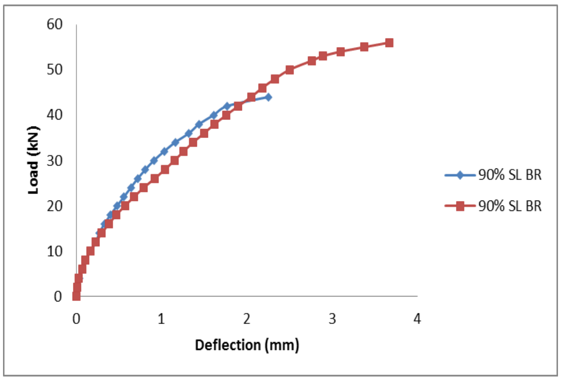


Fig. 7 load versus deflection curve (90% damaged)

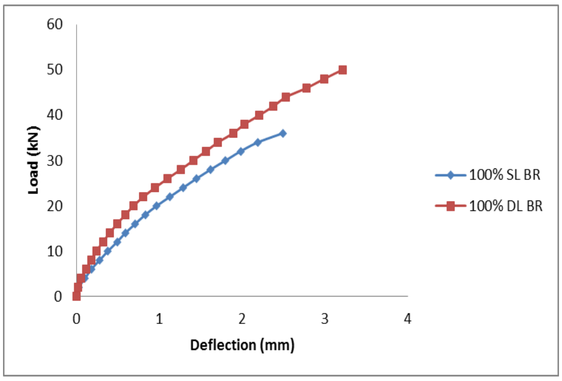


Fig. 8 load versus deflection curve (100% damaged)

Fig. 8 cracking pattern for the control beam

Beams strengthened by different number of layers of BFRP strip at bottom side of the beam, failure occurred by debonding and also due to bending. The debonding caused separation of BFRP strips from the concrete surface.

### 3.1 Effect of layers of BFRP on damaged beams

As compared to the load carrying capacity of 100% damaged beams wrapped in single and double layer, 0 % damaged beams show increase in load carrying capacity by 44 % and 20 % for single and double layer respectively.

70 % damaged beams show increase in load carrying capacity by 58 % and 30 % for single and double layer respectively. 80 % damaged beams show increase in load carrying capacity by 44 % and 18 % for single and double layer respectively. 90 % damaged beams show increase in load carrying capacity by 25 % and 12 % for single and double layer respectively.

From the above results, I conclude that, the percentage increase in load carrying capacity showed by the 70 % and 80 % damaged beams wrapped with single layer of BFRP is nearly same as that of 0 % damaged beam. 90 % damaged beams are deficient as compared to the 0 % damaged beam.

For 70% damaged beams wrapped with double layer of BFRP, the load carrying capacity is slightly less compared to 0 % damaged beams. 80 % and 90 % beams are deficient in load carrying capacity.

## IV. CONCLUSIONS

Based on the experimental investigation presented in this study, for the beams strengthened in flexure with sheets, it can be concluded that,

- 0%, 70% and 80% damaged degree beams showed higher performance in terms of load carrying capacity, while 90% and 100% damage degree beams did not show appreciable increase in load carrying capacity.
- On increasing the number of layers of BFRP strip, increase in yield and ultimate displacement are observed.
- Results of BFRP wrapping with 100mm wide in single and double layer showed increase in ultimate load carrying capacity by 44% and 20% respectively in 0% damaged beam.
- With increase in degree of damage, deflection at ultimate load is found to be decreasing.

## REFERENCES

[1] Lankinen C. W. and Soudki K. A. (2008). "*Behaviour of rectangular reinforced concrete members confined with GFRP sheets*", Fourth International Conference on FRP Composites in Civil Engineering (CICE2008) 22-24 July 2008, Zurich, Switzerland.

[2] Singaravadivelan R., Sakthieswaren N. and Dr. Muthuramu K. L. (2012). "*Experimental Investigation on the Behaviour of Flexural Strengthening of Beam Using Basalt Fiber*", International Conference on Automotive, Mechanical and Materials Engineering (ICAMME' 2012) Penang (Malaysia) May 19-20.

[3] David E., Ragneau E. and Buyle-Bodin F. (2003). "*Experimental analysis of flexural behavior of externally bonded CFRP reinforced concrete structures*", Materials and Structures, Vol. 36, pp.238-241.

[4] Esfahani M.R., Kianoush M.R., Tajari A.R. (2007). "*Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets*", Engineering Structures, Vol. 29, pp. 2428–2444.

[5] Jadhav H. S. and Shiyekar M. R. (2011). "*Performance of reinforced concrete beams strengthened with GFRP laminate configuration*", International Journal of 3R's, Vol. 1, No. 4, 2010, pp. 192-195.