An Experimental Investigation on Basalt Reinforced Beam using Steel Fibers

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Abstract. The concrete construction field has shown a growing interest in the advantages of introduction of fiber reinforcement in structural elements. Among the different fibers available, e.g. steel, synthetic, glass, and natural fibers, the steel fiber is probably the most investigated and most commonly used. Addition of short, discontinuous fibers plays an important role in the improvement of the mechanical properties of concrete. Some of the potential benefits of fibers in concrete are improved crack control and more strength than plain concrete, and the possibility of designing more slender structures. However, the extent of the crack control depends to a large extent on the type and amount of fibers added. From the durability point of view it is essential to control the cracking process and, moreover, being able to predict crack widths and crack pattern as well as to design a structure that exhibits the desired behavior. This project deals with the experimental investigation for enhancing the flexural strength capacities of steel fiber reinforced concrete (RC) beams using BFRP rods. A control specimen is prepared without adding steel fiber and BFRP rod. RC beam reinforced with BFRP rod alone is then casted and cured, after that three beam specimens with different lengths of steel fibers is casted. The ultimate loads, load-deflection curves, cracking and crushing patterns of BFRP reinforced concrete beam have been compared with that of steel fiber RC beam using BFRP rods.

Keywords-- Steel fibers, BFRP reinforced concrete beam.

I. INTRODUCTION

Durability of building structures is one of the most important features of present design. Standard steel bars do not have corrosion resistance, hence traditional reinforced concrete (RC) structures are very sensitive to damage in aggressive environment. This problem does not affect fiber-reinforced polymer (FRP) bars, which exhibit such properties as corrosion resistance, electromagnetic neutrality and high cuttability. As a result it can have many applications – in structures used in marine environments, in chemical plants, when electromagnetic neutrality is needed, or in temporary structures. FRP bars (especially in the case of glass FRP) have low modulus of elasticity as well as high tensile and low shear strength. Moreover, they do not exhibit any yielding before failure and they behave almost linearly up to tensile rupture. Due to their mechanical properties, deflections and cracking in FRP RC beams are larger than those found in traditional RC members. Consequently, the design of FRP RC beams is often governed by the serviceability limit states. The use of fiber reinforced polymer tendons (FRP bars) as a substitute for steel bars in concrete structures is an effective method. This method can be used to resolve the problem of concrete durability caused by the corrosion of steel bars and meet the requirement of special structures which need protection from electromagnetic interference. Currently, the performance of FRP bars and concrete structures reinforced with FRP bars is an important area of research in civil engineering and this new structure is widely being used in coastal engineering and subway engineering. But FRP bars have characteristics of high tensile strength, low elastic modulus, and linear deformation. These characteristics lead to behaviors of brittle failure, larger crack widths, and larger deflection, which have been obstructing FRP structure from being widely used in civil engineering. Basalt fiber has the advantage of high temperature resistance, chemical stability, corrosion resistance, thermal conductivity, and insulation. Continuous basalt fiber has wide application. It not only used to produce reinforced plastics for making fiber reinforced cement and fiber reinforced plastic but also used to resolve many other problems because of its acid resistance, alkali resistance, high strength, high temperature resistance, low temperature resistance, smoothness, softness, scratch-resistance, and insulation.

In the recent years, various fibers developed and used in the construction industries all over the world. Many problems that faces in construction industries can be overcome by reinforcing with short discontinuous fibers. The concept of using fibers as reinforcement is not new. Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. Different types of fibers are available today. Low cost high performance fibers offer potential to solve cracking and structural failure of concrete. earlier results shows that the addition of non-metallic fibers such as glass, polyester, polypropylene etc. results in good fresh concrete properties and reduced early age cracking. Some non-metallic fibers also helps to improve mechanical properties of concrete. Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular, triangular or flat in cross-section. The fire is often described by a convenient parameter called —aspect ratio—. The aspect ratio of the fiber is the ratio of its length to its diameter.
The principle reason for incorporating fibers into a cement matrix is to increase the toughness and tensile strength and improve the cracking deformation characteristics of the resultant composite. For FRC to be a viable construction material, it must be able to compete economically with existing reinforcing system. FRC composite properties, such as crack resistance, reinforcement and increase in toughness are dependent on the mechanical properties of the fiber, bonding properties of the fiber and matrix, as well as the quantity and distribution within the matrix of the fibers. Fibers are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produced greater impact, abrasion and shatter resistance in concrete. Generally fibers do not increase the flexural strength of concrete and so cannot replace moment resisting or structural steel reinforcement. Indeed, some fibers actually reduce the strength of concrete.

II. LITERATURE REVIEW

Abbass et al, (2018) [1]. They studied about the effect of adding steel fibers with different lengths and diameters on the mechanical properties of concrete for three values of concrete strength. In this study, hooked ended fibers of three lengths and two diameters were used with three water-to-cement ratios. Steel fibers were added with three volume fractions, 0.5%, 1.0%, and 1.5%. Thirty concrete mixes were prepared and investigated. They concluded that the addition of different content and lengths of steel fibers with increasing water-to-cement ratios caused significant change in the mechanical properties of concrete, with an increase of about 10–25% in compressive strength and about 31–47% in direct tensile strength. The increase in the fiber content from 0.5% to 1.5% increased the flexural strength from 3% to 124% for fiber with the smaller aspect ratio of 65, whereas, for the higher aspect ratio of 80, a 140% increase in the flexural strength was observed compared to the concrete without any fibers.

Mary et al, (2017) [2]. They studied about the flexural performance of concrete beams of grade M30 reinforced with hooked end steel fibers by conducting three point loading test. The steel fiber content was varied by 0.25%, 0.50%, 0.75% and 1.0% by weight of cement. The load was applied at midpoint of the beam specimen, increased at a uniform rate till the ultimate failure. The specimens were arranged with simply supported conditions. They concluded that the ultimate load was found to be increasing with the increase in the steel fiber reinforcement up to an optimum value. In comparison with the control beam, the ultimate load was found to be increased by 26.78% for the steel fiber reinforced beam at the optimum fiber reinforcement.

Jagdeesh et al, (2016) [3]. The study was carried out to determine flexural toughness and toughness indices of steel fiber reinforced concrete (SFRC). The variables used in investigation were: reinforcement, steel fiber percentage by volume. The aim of this project is to present the findings of the investigation and equations obtained for predicting the desired flexural toughness and in turn the toughness indices for SFRC. The experimental program consisted of casting and testing of 3 beams with steel fibers to compare the results with the steel fiber reinforced concrete. The fiber reinforced concrete beam contains steel fibers in at the rate of 0%, 0.5%, 1%, 1.5% volume fraction of the beams. They concluded that compressive strength, split tensile strength and flexural strength are on higher side for 1.5% fibers as compared to that produced from 0%, 0.5% 1% and 1.5 fibers. They also found that compressive strength of M25 grade concrete increases from 0.24% to 11.9% with addition of steel fibers.

III. STUDY OF FLEXURAL STRENGTH OF BEAM

Flexural capacity of the RC beam specimen is obtained by means of two point loading, beams are tested for determining flexural strength after 28 days of curing in the loading frame. Dial gauges are placed just below the centre of the mid span of the beam i.e. just below the load point for recording the deflection of the beams. After setting and reading all gauges, the load will be increased incrementally up to the calculated working load, with loads and deflections recorded at each stage. Loads will then normally be increased again in similar increments up to failure. Cracking and failure mode was checked visually, and a load/deflection plot was prepared. Test consist of testing 5 RC beam specimens.

1. Control beam (CB)
2. Basalt Reinforced Concrete Beam (BRB)
3) Basalt Reinforced Concrete beam with steel fibers of length 20 mm (BRBSF 1)

4) Basalt Reinforced Concrete beam with steel fibers of length 30 mm (BRBSF2)

5) Basalt Reinforced Concrete beam with steel fibers of length 40 mm (BRBSF3)

A. Material Properties

The materials used in the study are Ordinary Portland cement of grade 53, the average yield stress of main steel bars used in the experiment is 500 MPa and an elastic modulus of 200 GPa. Fine aggregate used is M sand, coarse aggregate used is of size 20mm. Steel fibers of length 20 mm, 30mm and 40mm is used (fig. 1). Basalt rod of 8 mm diameter is used as shown in fig. 2. Superplastisizer used is MasterRheobuild 924KL. It is composed of synthetic polymers specially designed to impart rheoplastic qualities to concrete. A rheoplastic concrete is a fluid concrete with a slump of at least 200mm but at the same time free from segregation and having the same water cement ratio as that of a no slump concrete (25mm) with admixture.

Fig. 1 Steel Fibers                  Fig. 2  Basalt rods

B. Optimization of Steel Fiber

Water quantity, cement, fine aggregate and coarse aggregate required for design mix of M30 were calculated based on the procedure given in IS code method in IS: 10262-1982. The final mix ratio was 1:1.68:2.93 with water cement ratio of 0.45. Amount of super plasticizers varies from the control beam mix. The measurement of materials was done by weight using electronic weighing machine. Water was measured in volume. Optimization of steel fibers was done in moulds of size 10cm x 10cm, in layers. The casted specimens were removed from the moulds after 24 hours and the specimens were kept or water curing. Six cubes of different percentage of steel fibers are casted for each three different lengths of steel fibers i.e. 20mm, 30mm and 40mm. The steel fibers were added at the rate of 0.5%, 1%, 1.5% and 2% of total volume. Total 72 cubes are casted. As shown in the fig. 3, it is clear that optimum percentage of steel fiber of length 20mm, 30mm and 40mm obtained is 1.5% as shown in the figure 3.

Fig. 3 Optimization of steel fiber

C. Details of specimens

A beam of size 150 x 200 x 1000 mm is casted with the addition of basalt reinforcement as specimen 1. Two main bars of diameter 8mm is used with a nominal cover of 30mm and 2 legged 6mm stirrup is placed at 120 mm spacing. Minimum clear cover to reinforcements depends on the exposure criteria and this is specified in IS: 456-2000. Superplasticizer is added at 1:3 (cement: superplasticizer) ratio. In specimen 2- BRBSF1, in addition to the basalt reinforcement steel fibers of length 20 mm is used. The fiber content used is 1.5% of the total volume of concrete which is obtained as the optimum quantity. Steel fibers are mixed to the dry mix uniformly without any balling. It is expected that incorporating steel fibers will hold the micro cracks effectively. In specimen 3, in addition to the basalt reinforcement steel fibers of length 30 mm is used. The fiber content used is 1.5% of the total volume of concrete which is obtained as the optimum quantity. Steel fibers are mixed to the dry mix uniformly without any balling. In specimen 4- BRBSF3, in addition to the basalt reinforcement steel fibers of length 40 mm is used.

D. Testing procedure

The control beam and other specimen were whitened for better observation of the development of cracks. The specimens were simply supported and subjected to two point load. Linear Variable Differential Transducers (LVDT) were placed at centre bottom and at support in point of the beam bottom. LVDTs are used to measure the displacement of the test specimen. The measured displacement will be displayed in the digital indicator and further it is connected to Data Acquisition System (DAQ). To measure strain, strain gauges were attached to the specimens. Strain gauges were glued to the specimen. The load is applied to the specimen, compression type load cell was used. The load cell is a strain gauge based device which will give proportional output in electrical parameters under the given load. The failure load was defined as a load that caused to fail in flexure or that caused failure at the interface between the substrate and overlay. Mid – span
deflections, deflection at a distance l/3 and strain values for the same were recorded for every load increment.

IV. RESULT AND DISCUSSION

According to the loading scheme, the control beam started to show flexural cracks at the middle part of the span and with further loading, flexural cracks began to be distributed around the middle part and increased in their lengths and widths as shown in the figure 4. In the sequel, flexural shear cracks were developed and finally shear cracks were formed. All beams were failed by flexural mode of failure. The control beam started to crack due to flexure at a length of l/3 at a vertical load of about 23.4 kN which is about 42.01% of the failure load. Proceeding with loading, the flexural cracks spread at the tension side till a vertical load of about 55.7 kN, then shear cracks began to appear.

The specimen 1- BRB was failed by concrete crushing as shown in the figure 5. The beam started to crack due to flexure at a length of l/3 at a vertical load of about 23.5 kN which is about 33.19% of the failure load. Proceeding with loading, the flexural cracks spread at the tension side till a vertical load of about 70.8 kN, then shear cracks began to appear. Initial cracks are developed in the beam at a load of 23.5 kN.

Basalt reinforced beam is incorporated with hooked end steel fibers of length 20 mm. The optimum concentration of the steel fibers is 1.5% of the total volume of concrete. The failure load in which the specimen failed was 84 kN. The beam started to show cracks at a load of 38.8 kN which is about 46.1% of the failure load. Initial cracks are developed in the specimen BRBSF1 as shown in the figure 6 at a load of 38.8 kN which indicates the higher load withstanding capacity of specimen 2.

The failure load of specimen 3 was 90 kN. The beam started to show the cracks at a load of 32.8 kN which is about 36.4% of the failure load (fig. 7).

Basalt reinforced beam is incorporated with hooked end steel fibers of length 40mm. Initial cracks are developed in the specimen BRBSF3 at a load of 23.6 kN. This load is much same as that of control beam. The behavior of crack pattern is such that they tend to move towards the top center of the beam as shown in the figure 8.

From fig. 9, it is clear that central deflection of the specimens BRB, BRBSF2 and BRBSF3 is very higher than that of control beam due to the lower modulus of elasticity of basalt bars. The highest deflection is in specimen BRBSF3. For basalt reinforced beams BRB, BRBSF2 and BRBSF3 the average deflection is 4-5 times greater compared to the control beam. Beam reinforced with basalt bars without steel fibers showed higher central deflection (51.32) than control beam (10.75). This is due to the low modulus of elasticity of BFRP bar. As the length of the steel fiber increases, the deflections corresponding to the ultimate load also increases. This may be due to balling effect of the larger length fibers. The maximum central deflection was exhibited in BRBSF3 i.e. 65.7 mm.

Strain corresponding to the specimen BRB is much higher compared to all other specimens. Because, basalt bars have low modulus of elasticity and causes larger deflection. But in the case of other specimens, steel fibers are used with basalt bars. Steel fibers have the capacity to hold the micro cracks effectively. BRBSF1, BRBSF2 and BRBSF3 showed almost same value of stress hence the strength of the three specimens are under a range of 14-15 N/mm² as shown in the figure 10.

Specimen BRBSF1 and BRBSF2 showed higher cracking load (38.8). As the length of the steel fibers increases, the magnitude of the cracking load decreases i.e. the initial generation of cracks increases or the ability to prevent the
growth of cracks decreases. In the case of cracking load, control beam, BRB and BRBSF3 showed initial cracks at almost same loads as shown in the figure 11.

Ultimate load is higher in BRBSF2, i.e. comparing with the control beam, BRBSF2 showed 61.57% increase in ultimate load. The three specimens added with steel fibers of different length (BRBSF1, BRBSF2, BRBSF3) showed a greater value of ultimate load so it have greater capacity to withstand load. Beam reinforced with basalt bar only (BRB) showed 27.1% increase in the ultimate load compared with the control beam as shown in the figure 12.

![Comparison of load Vs. deflection graph](image1)

![Comparison of ultimate load](image2)

The flexural strength of the specimens is highly enhanced by the use of BFRP bars and steel fibers. Highest flexural strength is obtained for the specimen 3 as shown in the table 1.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Flexural strength (N/mm²)</th>
<th>% increase in Flexural strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRB</td>
<td>11.8</td>
<td>27.1</td>
</tr>
<tr>
<td>BRBSF1</td>
<td>14</td>
<td>50.8</td>
</tr>
<tr>
<td>BRBSF2</td>
<td>15</td>
<td>56.19</td>
</tr>
<tr>
<td>BRBSF3</td>
<td>14.5</td>
<td>61.5</td>
</tr>
</tbody>
</table>

V. CONCLUSIONS
1. The critical load for tested beams reinforced with BFRP bars was much greater than the carrying capacity of beams with conventional steel reinforcement.
2. In comparison with the control beam, the ultimate load was found to be increased by 27.1% for the basalt reinforced beam.

3. It is observed that ultimate loads of beam increases from 50.8% to 61.5% for basalt reinforced beam with steel fibers.

4. Basalt reinforced beam with steel fibers of length 30mm showed greater ultimate load value up to 61.5% increase.

5. The fiber length has a significant effect on the flexural behavior of BFRP RC beams. An optimum value of 30mm of the fiber length is obtained from the experiment.

6. The central deflection of basalt reinforced beam is 4.7 times greater than control beam.

7. As the length of the steel fiber increases, the deflections corresponding to the ultimate load also increases.

8. A decrement of 7.08% central deflection is observed in basalt reinforced beam with steel fibers of length 20mm (BRBSF1). The central deflection of the specimen BRBSF2 is 3.3 times higher than that of control beam and the central deflection of the specimen BRBSF3 is 6.1 times greater than that of control beam.

9. Increment of 28.02% deflection is observed in basalt reinforced beam with steel fibers of length 40 mm (BRBSF3) compared with basalt reinforced beam (BRB).

10. Central deformation of the reinforcement of beams with basalt reinforcement were considerably higher (average of 4 to 5 times) than the beams with steel reinforcement. Deflections of beams with BFRP reinforcement were significantly higher than the reference beam deflection, due to the much lower modulus of BFRP bars compared to steel bars.

11. Flexural strength of all the specimens is increased. Specimen 1 showed 27.1% increase in flexural strength compared with control beam. specimen 2, 3 and 4 showed 50.8%, 56.19% and 61.5% increase in the flexural strength value when compared with the control beam.

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