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Study On Retrofitting of Reinforced Concrete Beams Using Fibrous Concrete

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Abstract

Reinforced concrete structures often require repairing and strengthening due to their degradation by various environmental factors, ageing or material damage under extreme loading conditions and also sometimes due to mistakes during construction period. Nowadays, many different techniques are being used to repair RC structures. One of the retrofitting techniques is the use of FRC. In this study, steel fiber reinforced concrete (SFRC) containing randomly distributed short discrete steel fibers which act as internal reinforcement so as to enhance the properties of the cementitious composite (concrete). The principal reason for incorporating short discrete fibres into a cement matrix is to reduce cracking in the elastic range, increase the tensile strength and deformation capacity and increase the toughness of the resultant composite. These properties of SFRC primarily depend upon length and volume of Steel fibers used in the concrete mixture. In India, the steel fiber reinforced concrete (SFRC) has seen limited applications in several structures due to the lack of awareness, design guidelines and construction specifications. Therefore there is a need to develop information on the role of steel fibers in the concrete mixture.

An experimental study was undertaken in which crimped Steel fibres of two different aspect ratios 30 and 60 with volume fractions (Vf) of 0.5%, 1% and 1.5% were used. The experimental work reported in this study includes the mechanical properties of concrete at different volume fractions of steel fibers. These mechanical properties include compressive strength, split tensile strength and flexural strength and to study the effect of volume fraction and aspect ratio of steel fibers on these mechanical properties. However, main aim of the study was significance of reinforced concrete beams strengthened with fiber reinforced concrete layer and to study the load deflection behaviour of these beams. The results obtained during investigation indicates that strengthening of beams using FRC improved structural performance measured in terms of ultimate load carrying capacity, crack pattern deflection and mode of failure. An increase in 13.1% in load carrying capacity of strengthened beam was observed where as an increase in 5.35% in load carrying capacity of retrofitted beams was observed. Further it was also observed that application of FRC delayed appearance and propagation of cracks.

Keywords: *Retrofitting; steel fibers;FRC; aspect ratio; mechanical properies.*

INTRODUCTION

Concrete is the most commonly used construction material worldwide used in the construction of variety of civil infrastructure applications including small and large buildings, houses, bridges, storage tanks, dams and numerous other types of structures. Reinforced Concrete structures are designed for particular life span and for particular service, with passage of time new design standards, deterioration of structure occur mainly due to aggressive environment, increase in load cycle, construction error, and contact with chemicals or saline water, catastrophic event like earthquake. Such structure can be made serviceable again either by retrofitting or complete replacement of the structure. A challenge in retrofitting of concrete structures is selection of strengthening material and method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations and economy. Each project has its own constraints and it is not possible to replace whole structure due to its high costs of construction and material and a stronger environmental impact so it is often better to repair structure by using retrofitting techniques. Improvement and modification in the performance of RC structures have attracted interest of researchers and varying organization to strengthen these structures to restore their performance.

Several methods for strengthening of structures have been developed. These incorporate addition of material to increase gross sectional area, post tensioning techniques, etc. In spite of the fact that these strategies can be practically used and effective sometimes, but sometimes uneconomical or insufficient to meet desired results. Traditionally externally epoxy-bonded steel plates are used to flexure and shear deficit structures. Although this technique is efficient, simple and cost effective but its biggest drawback is deterioration of bond at steel and concrete faces which reduces its effectiveness. Other techniques are U jacketing of beams with steel which result in increase of dead load and requires corrosion protection, increase overall cross-section and is not cost effective [1]. Other disadvantages of using steel for strengthening are: difficult to transport, limited length (which result in joint) and massive and heavy formwork. Other methods include chemical treatment, mechanical anchorage system [2] and external prestressing of member [3]. Use of short discrete fibers in concrete is one approach to mitigate the cracking and increasing the tensile straining capacity.

MATERIAL PROPERTIES

In this research, reinforced concrete beams of dimensions 1200mm X 150mm X 230 mm were used and were analyzed using the same materials and same reinforcements. The results of 28 days compressive strength were that the compressive strength of normal concrete was 38.6MPa whereas it was found to increase on the addition of steel fibers and maximum strength of 43.33Mpawas achieved when steel fibers of aspect ratio 60 at volume fraction of 1.5% were used [1-3]. Also, 28 days split tensile strength was found out to be 3.32Mpa and was increased to 3.98MPa for steel fibers of aspect ratio 60 at 1.5% volume. Flexural strength at 28 days was 4.21MPa for normal concrete which was increased to 5.08MPa for aspect ratio 60 steel fibers at 1.5%. For bending tensile reinforcement (at the bottom of the beam) reinforcement steel bars with yield stress, which was equal to 434 MPa was used and for Compressive bending reinforcement (at top of the beam) reinforcement steel bars with yield stress equal to 426 MPa was used.

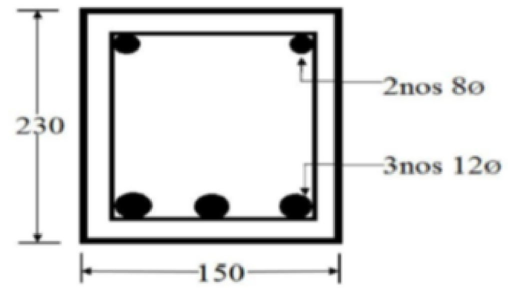

Fig.1. *Section details of beam*

Table I. *Mix design details of concrete*

Material	Water (liters)	Cement (kg)	Fine aggregates (kg)	Coarse aggregates (kg)
Qty/m³	160	380	711	1283

Ratio	0.42	1.00	1.87	3.37

Table II. *Compressive strengths of concrete*

S.No	Volume fraction	Normal concrete	FRC with aspect ratio 30	FRC with aspect ratio 60
1.	0.5%	38.6 MPa	38.86MPa	39.40MPa
2.	1.0%	38.6MPa	40.75MPa	41.55MPa
3.	1.5%	38.6MPa	39.20MPa	43.33MPa

Table III *Split tensile strengths of concrete*

S.No	Volume fraction	Normal concrete	FRC with aspect ratio 30	FRC with aspect ratio 60
1.	0.5%	3.32MPa	3.65MPa	3.71MPa
2.	1.0%	3.32MPa	3.92MPa	3.96MPa
3.	1.5%	3.32MPa	3.91MPa	3.98MPa

Table IV *Flexural strengths of concrete*

S.No	Volume fraction	Normal concrete	FRC with aspect ratio 30	FRC with aspect ratio 60
1.	0.5%	4.21MPa	4.38MPa	4.41MPa
2.	1.0%	4.21MPa	4.61MPa	4.94MPa
3.	1.5%	4.21MPa	4.95MPa	5.08MPa

Fig. 2. *Casting of specimens*

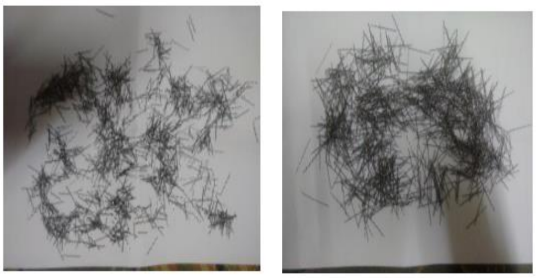

Fig. 3. *Steel fibers of aspect ratio 30 and 60*

CHARACTERISTICS OF BEAMS

All Specimens are made from above designed concrete mix. A total of 4 beams type test specimens of the same shape and size were casted keeping in a view the size and capacity of the loading frame and other facilities available in the laboratory These 4 beams specimen is divided into 3 sets.

The detailing of all the specimens was same. Set 1 consists of 2 reference beams BR1 and BR2. Set 2 consist of 1 beam BW1. In this set beam is wrapped with Fiber reinforced concrete of the configuration with the maximum flexural strength as calculated above. The layers of FRC were applied on the top and at the bottom. Set 3 consists of a beam BL1. In this set beam was loaded till crack appeared i.e. up to service load and after that beam BL1 was wrapped with layer of FRC both at the top and the bottom

The reinforced concrete beams were designed as a singly reinforced under reinforced sections as the recommended concrete stress block in IS: 456-2000. Three 12-mm diameter HYSD steel bars corresponding to 1% tension reinforcement with respect to the member were provided as main tension reinforcement at the bottom of the test specimen. The percentage of reinforcement used in all the specimens was same. Shear reinforcement provided in all the specimens was also same. Shear reinforcement in the test specimens was provided in the form of two-legged closed 8mm diameter bars at a center to center spacing of 160mm in all the test specimens. Two number of 8mm diameter bars, at the top were provided on the compression face of the beams to hold the stirrups in place. Two numbers 8mm diameter For steel lifting hooks were provided for handling and transporting the beams. Specimen details and configuration of the reinforced concrete beams is shown in table V.

Table V. *Specimen Details*

Beams	Designation of beams	Depth (mm)	Length (mm)	Fiber configuration
Standard beam	BR1	230	1200	-
Standard beam	BR2	230	1200	-
Beam Strengthened	BW1	230	1200	Layer at bottom
Beam Retrofitted	BL1	230	1200	Layer at bottom

EXPERIMENTAL PROGRAM

The beam specimens were subjected to static testing under monotonically increasing loads, which were applied using the test set-up. The plate shows the plan position of the specimen during the course of the test[1-3]. Two point loading arrangement was selected for the present investigation. As beam was studied for flexural strength it was best arrangement of loading. The specimen supporting arrangement allows for unhindered deflections of the members under the effect of the load applied at the center of member which is converted into two point load. Beams specimens are supported the arrangement which consist of two mild steel girders attached to two mild steel boxes. Occasionally, due to inadvertent of obliquity of the loading piston or due to slight difference the lever arm due to placing of beam on the arrangement or because of inadvertent imperfections in the formwork geometry, the symmetrical behavior of the two sides of beam was not always obtained.

Once the specimen was in the test position and the loading and instrumentation setup was ready, initial readings of the dial gauges, cylinder plant were recorded prior to the commencement of the experiment. Incremental load was increased and corresponding to that load deflection and slope values were noted down. Cracks propagation was measured with magnifying glass at various stages. Crack pattern of the specimen was marked with marker. Due to limitations of the loading system post peak response recording was hampered and also by nature of specimen. However, for all the specimens in plain concrete, prolonged investigation after ultimate loads have reached was severely compromised. It took around one hour to complete test on one specimen.

In set one beams ultimate load, deflection, slopes and crack pattern was studied. This set was reference set.

In second set of beam BW1 was wrapped with fiber reinforced concrete layer of 40mm bottom as discussed earlier. These were then cured for 28 days. After curing, testing was done in the same manner as was done on reference beams. Ultimate loads, deflection, slope and crack pattern was noted at regular interval of loads.

In third set of beams BL1 beams were retrofitted. In this set beams were loaded prior to wrapping up to service load. Beam BL1 was first loaded till first crack appeared on it. Processes of loading were same as that of earlier beams. After cracks appeared beam was retrofitted with fiber reinforced concrete layers on top and bottom. Epoxy resin was applied and then layers of FRC were applied on beam. These beams also cured for 28 days before testing. After curing beams were again given incremental load as given earlier. At equal interval of loads values of deflection, slopes and crack pattern was noted.

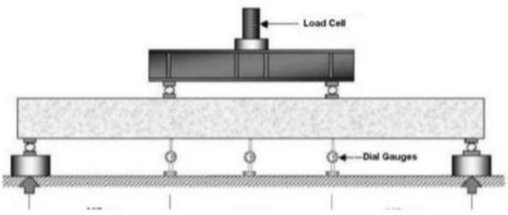

Fig. 4. *Two point loading of beams*

Fig. 5. *Loading arrangement of beam*

TEST RESULTS

A. Load-Deflection Behaviour

The load deflection behaviour of each set of beams is being shown in Figure 6 to 10. It can be seen from Figure 6 that for the reference beams (BR1) deflection increases with increase in load. The maximum deflection of 8.65mm was observed at a load of 168KN. Deflection was carefully noted with dial gauge.

For the second set of beam containing layer of FRC at the bottom load deflection behaviour is shown in Figure 7, and it was observed that deflection was decreased significantly after the application of FRC layer at the bottom of the beam. This behaviour may be attributed to the fact that fiber reinforced concrete shows better performance in flexure as compared to normal concrete. The use of FRC layer increased the stiffness of the beam due to increase in flexural rigidity of the beam and hence, a reduction in the value of deflection was observes at an increase load.

The load-deflection behaviour of reference and strengthened beams are shown in Figure 8. It is clear from the figure that the load deflection behaviour curve follows same pattern for both reference as well as strengthened beams. It was found that the deflection at ultimate load of BW1 was reduced by 10.9% as compared to the reference beam.

Comparison of the load deflection behaviour of reference beam and damaged reinforced concrete beam retrofitted with fiber reinforced concrete is shown in Figure 9. It was observed that the deflection in the retrofitted beam was more (i.e. 13.3%) as compared to the deflection of the reference beam. Figure 10 shows the comparison of reference beam, strengthened beam and retrofitted beam in terms of load deflection behaviour. It was observed that maximum increase in deflection was achieved in retrofitted beam and the maximum ultimate load was achieved in case of strengthened beam.

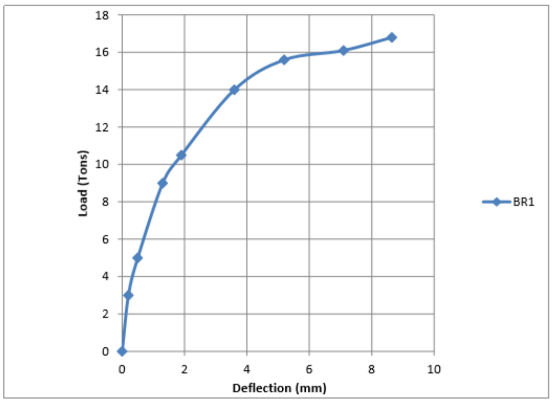

Fig. 6. *Load deflection behaviour of BR1*

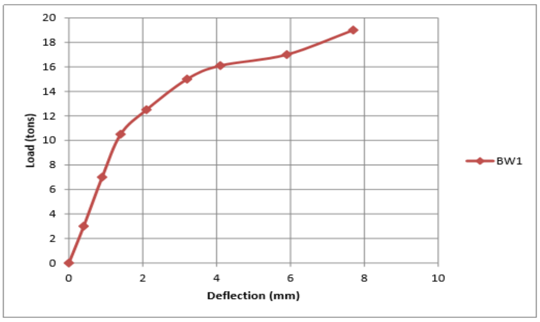

Fig. 7. *Load deflection behaviour of BW1*

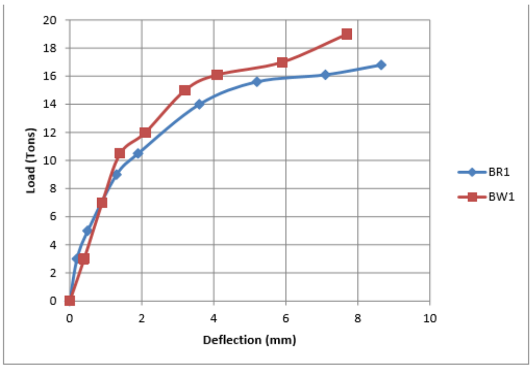

Fig. 7. Comparison of load deflection behaviour of BR1 and BW1 beams

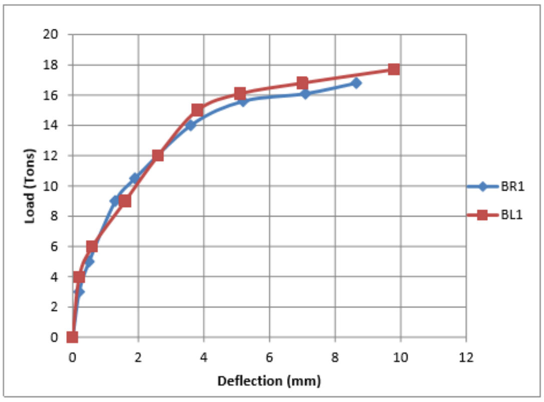

Fig. 8. Comparison of load deflection behaviour of BR1 and BL1 beams

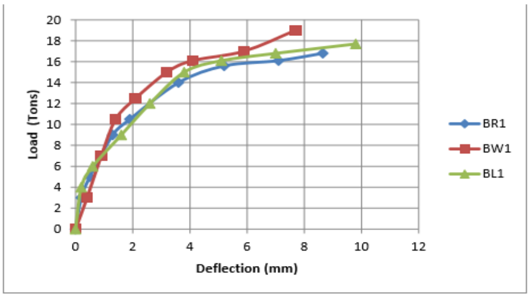

Fig. 9. *Comparison of load deflection behaviour of BR1, BW1 and BL1 beams*

B. ***Ultimate load carrying capacity***

The ultimate loads obtained from different sets of beams are shown in table VI. It was observed that the ultimate load increased when a layer of fibrous concrete is being applied at the bottom of the beams. An increase in 13.1% in ultimate load value was observed with application of layer of fiber reinforced concrete at the bottom of strengthened beam. This increase in load carrying capacity of the beam may be attributed to the fact that layer of FRC has increased the flexural rigidity of beam and it can be concluded that use of fibers in concrete can be suggested for increasing the ultimate load carrying capacity of beam.

The beams which were retrofitted with FRC layer also showed an increase in the ultimate load carrying capacity of beams by 5.35%. However the increase noted in case of retrofitted beam is lesser as compared to the strengthened beams. This decrease in load carrying capacity can be attributed to the fact that more of the stresses were transferred to the fibrous concrete layer in reference beams because of already developed cracks.

Fig.10. *Beam BR1 at ultimate load*

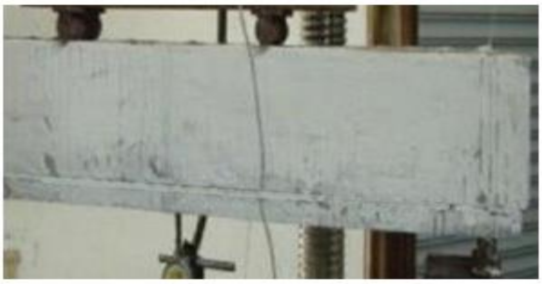

Fig.11. *Beam BW1 after application of layer*

C. Failure Mode

Ultimate failure pattern of beams at ultimate load was observed with the development of cracks and ultimate failure due to shear stress induced at terminal stage of loading. Figure 10 shows cracking pattern of reference beam at ultimate load. At a load of 90KN crack started appearing in the beams. Crack width recorded at 90KN was 0.1mm. As load was increased cracks started propagating and at 120KN there was development of shear cracks. Beam failed at 168KN and maximum crack width at this load was found to be 0.6mm.

The beam BW1 with layer of FRC at the bottom is shown in Figure 11. Crack started appearing at around 100 KN. Failure of BW1 occurred due to shear failure also. It was visualized that cracks started appearing when a load of 100KN was applied. Near the centre cracks were perpendicular to the length of the beam and the cracks were inclined at any angle approximately equal to 45º near the supports of the beam and the failure of beam BW1 at ultimate load was observes as a shear failure and there was no debonding between the FRC layer and the surface of the beam.

Figure 13 shows the retrofitted beam before the application of FRC layer and depicts the initial cracking pattern when subjected to loading. In this case, the propagation of cracks was similar to the other beams i.e. BR1 and BW1. The cracks started appearing at a load of 95KN and the failure of beam was occurred at ultimate load which was again due to induced shear stresses in the beam and hence in this case also shear failure was observed at ultimate load.

Fig. 12. *Cracking pattern in BR1 beam*

Fig. 13. *Initial cracking in BL1 beam*

Table VI. *Results*

S. No	Beam	Ultimate load (KN)	Layer of FRC	Centre point deflection (mm)	% increase in ultimate load	Failure pattern
1.	BR 1	168	No	8.65	-	Shear failure
2.	BR 2	161	No	8.3	-	Shear failure
3.	BW 1	190	At the bottom	7.7	13.1 %	Shear failure
4.	BL 1	177	At the bottom	9.4	5.35 %	Shear failure

CONCLUSION

In the present study, an increase in the mechanical properties of concrete was observed with the addition of steel fibers by volume fraction of concrete. The results at were compared in terms of compressive strength, split tensile strength and flexural strength respectively. Based on these results the effect of fiber reinforced concrete was investigated on RC beams and it was observed that there is an increase in ultimate load carrying capacity and decrease in deflection after the application of fiber reinforced concrete layer at the bottom of beams. Hence, fibrous concrete can be applied in layers to strengthen and retrofit reinforced concrete beams. The following conclusions can be drawn from the present study:

- Results showed that compressive strength was increased as high as 12.25% to that of normal concrete on addition of steel fibers and maximum strength was found for aspect ratio 60 at volume fraction of 1.5%. Thus, steel fibers can easily be used to increase the compressive strength of concrete.
- An increase in split tensile strength was also indicated by experimental test results. It was found to be varying for different aspect ratios at different volume fractions of steel fibers and the maximum variation was observed to be 19.8% for aspect ratio 60 at volume fraction of 1.5%.
- Due to addition of steel fibers in concrete, the flexural rigidity of beams was improved which resulted in an increased flexural capacity of beams. It was found out that maximum flexural strength was also obtained at 1.5% volume fraction of steel fibers at aspect ratio 60 and maximum increase in the strength was found to be 20.66% when compared with normal concrete specimen.
- The results obtained in the present investigation also showed that layers of steel fiber concrete can be reliably used for strengthening of reinforced concrete beams. An increase of 13.1% in the ultimate load carrying capacity of reinforced concrete beams was observed when it was strengthened with a layer of FRC at the bottom of the beam.
- The retrofitting of reinforced concrete beams with layer of steel fibers concrete resulted in improved structural behaviour of beam. An increase of 5.35% was observed when the reinforced concrete beams are retrofitted with layer of FRC.
- Cracking pattern was also observed during the testing of beams. It was seen that appearance and propagation of cracks was delayed when reinforced concrete beams were strengthened and retrofitted using steel fibrous concrete.

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