An Investigation towards the Effects of Using Fiber Reinforced Polymers in the Enhancement of Shear Strength of Reinforced Concrete Beams

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An Investigation towards the Effects of Using Fiber Reinforced Polymers in the Enhancement of Shear Strength of Reinforced Concrete Beams

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Abstract: *The primary concern of this paper is to experimentally investigate the shear capacity enhancement of reinforced concrete beams using Carbon Fiber Reinforced Polymers (CFRP) and Jute Fiber Reinforced Polymers (JFRP) sheets without using any web reinforcement to it. A total of ten beams, five of which were made of brick aggregate and other five were made of stone aggregate, were prepared. Two of these beams were taken as control beams whereas, others were confined with different arrangements of CFRP and JFRP sheets. In both cases, shear capacity of reinforced concrete beams (RC Beams) increased significantly compared with the control ones. In particular, for beams of brick aggregate, JFRP and CFRP sheets proved to be more efficient to enhance shear capacity (about 154% and 151% respectively) than for beams with stone aggregates (about 45% and 40% respectively).*

Keywords: RC (Reinforced Concrete) Beams, CFRP & JFRP sheets, Shear Capacity, Polymer Confinement patterns.

1. INTRODUCTION

Post strengthening of existing concrete structures has been in the limelight since many years as it helps to increase the durability of structures as well as helps to cut the cost of reconstruction through a complete demolition. With the arrival of FRP materials and powerful epoxy adhesives, a modern strengthening method has been introduced in response to the growing need for repairing and strengthening steel and concrete structure [1, 2, 3, 4, 5]. In addition, due to having several advantages such as high strength-to-weight ratio, ease of installation (considering architectural positions, projects, environmental conditions) corrosion resistance, versatility, and durability of the FRP composites [6, 7, 8, 9, 10], they are preferable over many other available strengthening techniques. Moreover, this strengthening technique increases beam performance under service loads, reduces the displacements and cracks, and increases ultimate flexural strength. [11, 12, 13, 14, 15,]. Several experiments have already been performed to investigate shear strengthening of RC structures using FRP laminates [16, 17, 18, 19, 20, and 21]

However, there are many factors such as beam geometry, strengthening material, strengthening scheme, shear span to depth ratio (a/d), concrete compressive strength, flexural reinforcement ratio, loading type, and layout method (wet or dry) [22, 23, 24], that affects the shear capacity enhancement.

In general, in three ways the FRP sheets can be bonded to RC beams to strengthen them in shear. They are Side-bonded, where the FRP sheets are bonded to the vertical sides of the beam; U-wrapped, where the FRP sheets are bonded to the sides of the beam as well as the tension face in a U-shaped approach and completely wrapped where the FRP sheets are bonded around the beam. Considering geometrical impediments, wrapping techniques, enduring strain debonding U-wrapped approach is most feasible among them [7. 25].

In this investigation, three parameters have been inspected to better understand the consequences due to FRP addition to the beams in shear. They are the load-deflection behavior of the controlled and FRP confined beams, the ultimate load carrying capacities and the cognitive analysis of the probable reasons of disparities and the patterns of failures of the subjected beams to better understand the upshots of omitting shear reinforcements to the specimens.

2. EXPERIMENTAL BACKGROUND

This experimental work was performed to identify the effects of Carbon fibers and Jute fibers as a shear reinforcement to improve shear capacity of RC beams. The strategy of omitting shear reinforcements was applied to estimate the shear capacity increment solely due to adding Carbon Fibers Polymers and Jute Fiber Polymers in the shear zone of the RC beams.

2.1 Specimens preparation

To execute this experiment, ten 101.6mm×101.6 mm (4"×4") Concrete beams were reinforced with 2-8 mm rebar on the tension side and left unsupported in shear zone.

At first, ten 4/4 inch molds (figure 1) out of steel sheets were prepared for casting RC beams shown in figure 1.

Fig. 1. Steel molds to cast beams

Here, M15 grade concrete was used. To support beams in tension Grade 60 (420 MPa) steel rebar were used.

Among the ten beams, five were prepared using stone aggregates and the rests were constructed out of brick chips following mixed design (Table 1).

Table 1. Mix Design

Cement type	OPC (ordinary Portland cement)
Coarse Aggregate Size	1 in passing and ¾ in retain (50%) ¾ in passing and ½ in retain (50%)
C: FA: CA	1:2:4
W/C	0.45
Type of coarse aggregate	Stone, Brick

After casting, all of the ten specimens were soaked in water for 28 days in a curing tank in submerged condition and were air dried for another one week. From each type, one specimen was taken as a controlled specimen and the rests were glued with epoxy resins [26] in order to appoint polymer fibers with different arrangements. Out of them three were bonded with 2 layers, 2 layer and 1 wrap and 3 layers and 2 wraps of Carbon fiber polymers. On the other hand, one brick and one stone beam were confined by 1 layer and 1 wrap of Jute fiber polymer (Figure 2)

Fig. 2. Carbon and Jute fiber polymers confinements to the beams

Once the beams were prepared, they were subjected to two-point loadings (Figure 3). Digital Universal Testing Machine (UTM) of capacity 1000 KN was used to perform compressive, tensile, and bending test of this experiment. This is a displacement controlled machine. Load and displacement (0.5 mm per minute) values were measured from load cell of UTM.
The loads were gradually increased in order to make the beams fail and expose failure patterns. The test results were presented in the form of graphs and tables. Detailed discussions were depicted on the outcomes with the help of graphs and tables considering all the associated parameters. Failure patterns were also observed to better understand the implications of not using the stirrups along the beams.

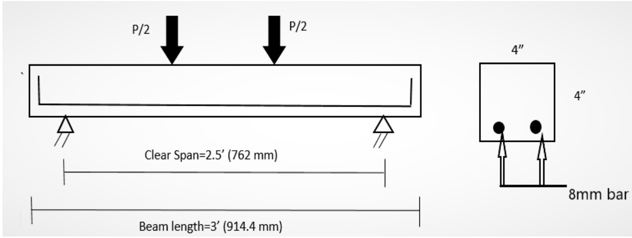


Fig. 3. Cross Section of a typical beam used in experiments and loading pattern.

2.2 Specimen designations and legends

This section introduces with the legends (Figure 4) which are important to understand the later parts of this investigation. C and J stands for Carbon and Jute fiber polymer sheets, L and W are the abbreviated forms of Layer and Wrapping. For example, BBC3L2W, BBC2L1W, BBC2L mean 3 Layers, 2 Wrappings. 2 layers 1 wrapping and only 2 layers of Carbon fiber polymer sheets on Brick Beams respectively.
Similarly, SBC3L2W, SBC2L1W, SBC2L mean 3 Layers, 2 Wrappings. 2 layers 1 wrapping and only 2 layers of Carbon fiber polymer sheets on Stone Beams correspondingly. Again, BBJ1L1W and SBJ1L1W mean, 1 Layer 1 Wrap of Jute fiber on Brick and Stone beams accordingly. BBCON and SBCON means the control specimens of both brick and stone beams respectively.

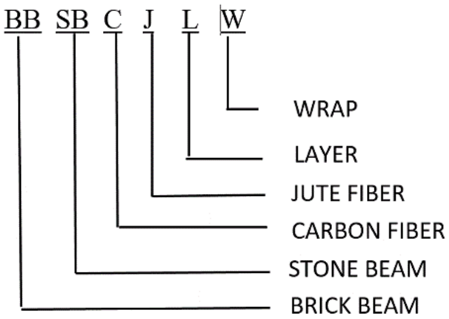


Fig. 4. Legends to identify specimen designations.

3. RESULTS AND DISCUSSION

Table 2 provides a summary of the test results and failure modes observed for the beams tested in this experimental program. The provided results include ultimate load, first crack load and first shear crack load for each of the beams tested.

Table 2. Summary of Test Results

Specimen Name	1st Crack load (N)	1st Shear Crack Load (N)	Ultimate Load (N)
BBCON	12000	18500	19845
BBC2L	16000	20000	22412
BBC2L1W	22000	26000	32417
BBC3L2W	35000	42000	49749
BBJ1L1W	33000	41500	49034

SBCON	24000	32000	35521
SBC2L	20000	23000	33530
SBC2L1W	43000	45000	49451
SBC3L2W	38000	48000	51203
SBJ1L1W	33000	43000	50905

3.1 Effect on bending capacity due to FRP confinement and wrapping strategies

Figure 5 and 6 represent the effect on load and bending capacity of beams due to using different materials (brick and stone aggregates) in concrete, FRPs with various layout and wrapping techniques.

Figure 5 elucidates the ultimate load carrying capacities as well as strains of BBCON, BBC2L, BBC2L1W, BBC3L2W, BBJ1L1W specimens, which were 19500 N and (deflection is 3.2 mm) and 22000 N (deflection is 3.7 mm), 42000 N (deflection is 5.9 mm), 49500 N (deflection is 6.2 mm), 49000 N (deflection is 8.5 mm) respectively.

The load carrying capacity of BBC2L was 13% higher than BBCON. The peak loading of BBC2L1W was 64% higher than BBCON.

The ultimate loading of BBC3L2W was significantly 154% higher than BBCON.

Again, the zenith of loading of BBJ1L1W and the load capacity was 151% higher than BBCON.

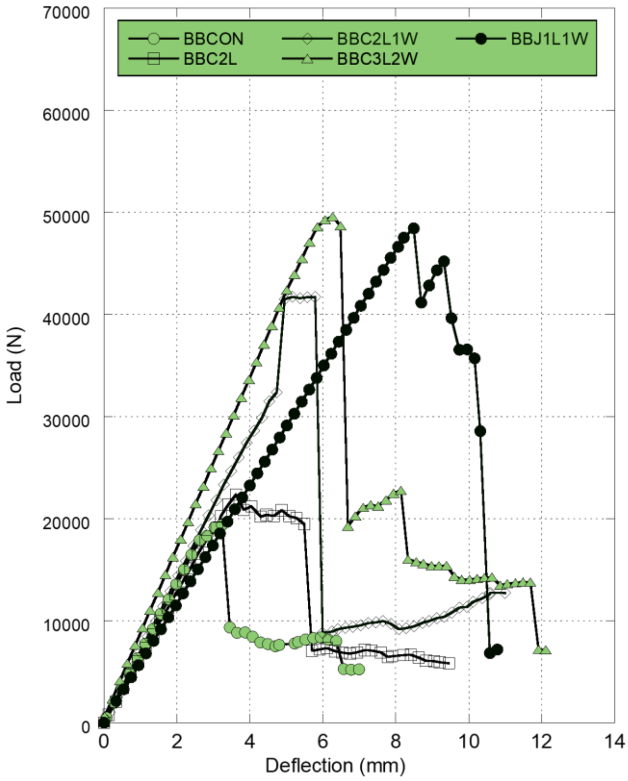


Fig. 5. Brick beam of with various confinements.

Similarly, Figure 6 explicates load capacities along with deflections due to gradual loading on SBCON, SBC2L, SBC2L1W, SBC3L2W, SBJ1L1W specimens till they indicated failure patterns.

The corresponding values of loads and deflections were 35500 (deflection 6 mm) and 33500 N (deflection 5 mm), 49000N (deflection 5.7 mm), 51000 N (deflection is 5.8 mm), 50500 N (deflection 3.9 mm).

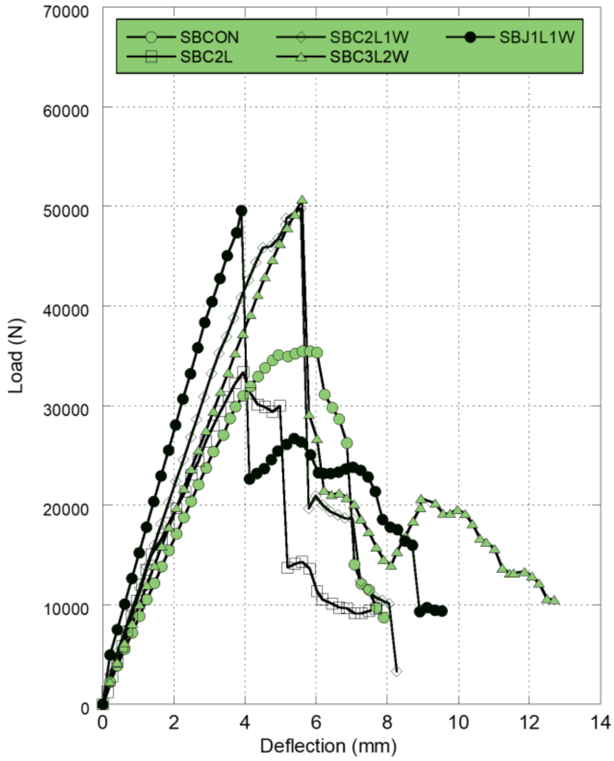


Fig. 6. Stone beams with various confinements.

Evidently the highest loading of SBC2L1W was 40 % higher than SBCON. Again, the ultimate loading of SBC3L2W, SBC2L1W was 45%, 38% higher than SBCON accordingly. For SBJ1L1W it was 40% more than SBCON. However, the load capacity of SBC2L was 5% lower than SBCON which may occur due to any imperfection happening in casting of the specimen.

3.2 Distinctions due to variation in aggregates

Figure 7 to figure 10 illustrate the variabilities emerged with identical confinements of the FRP sheets on the specimens of Brick and Stone aggregates.

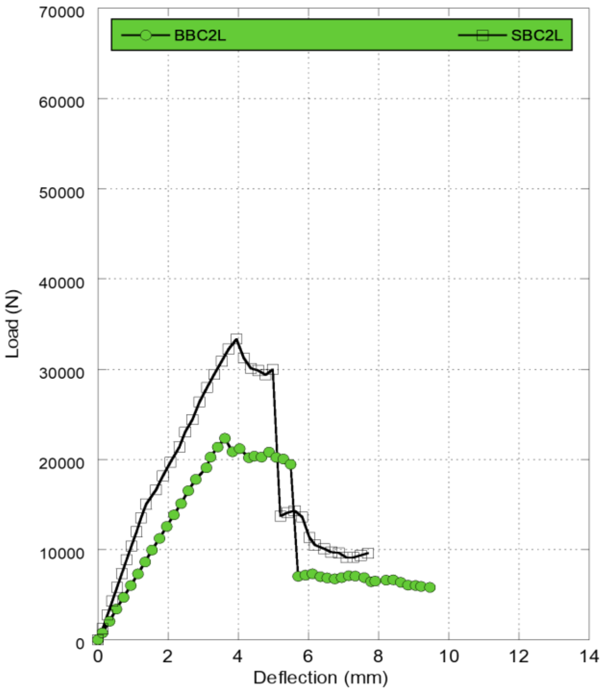


Fig. 7. BBC2L vs. SBC2L

Due to using stone aggregates, SBCON is usually stronger than BBCON as it carries 80% more load than brick beams. (From figures 7 and 8)

Figure 7 indicates that stone beams with two layers of CFRP can withstand approximately 53% more load than brick beams and go through more deflection before it exposes sign of failure.

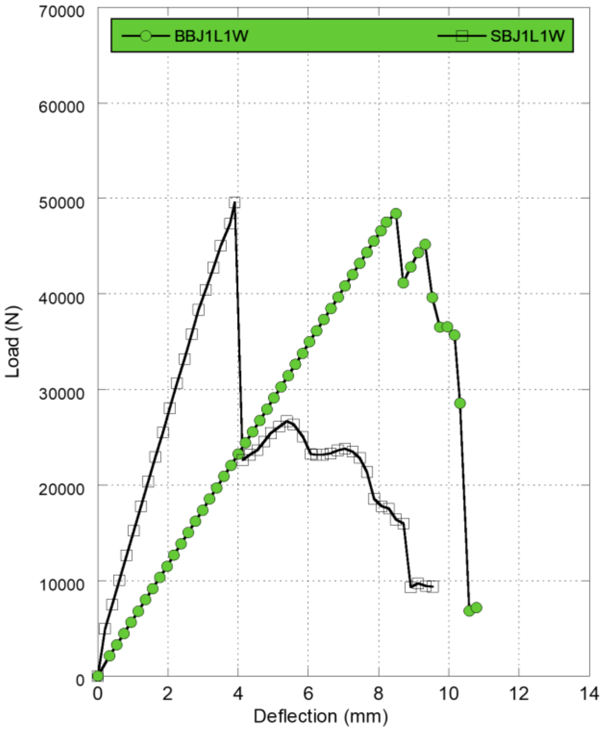
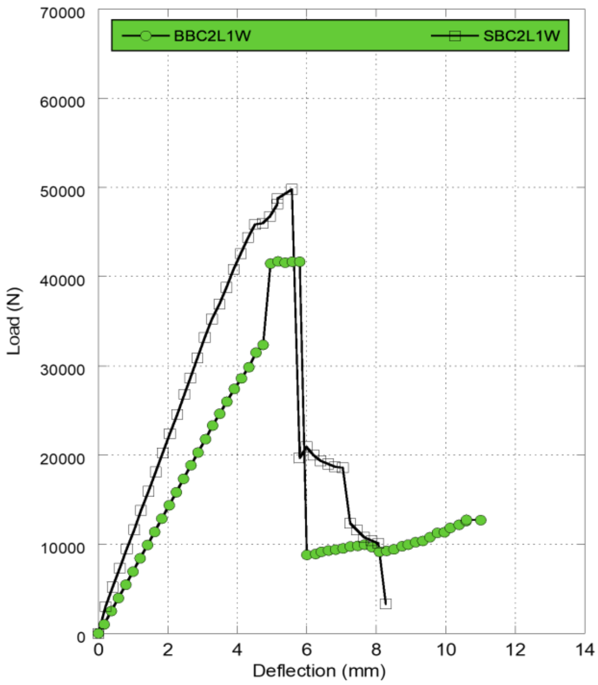


Fig. 8. BBC2L1W vs. SBC2L1W



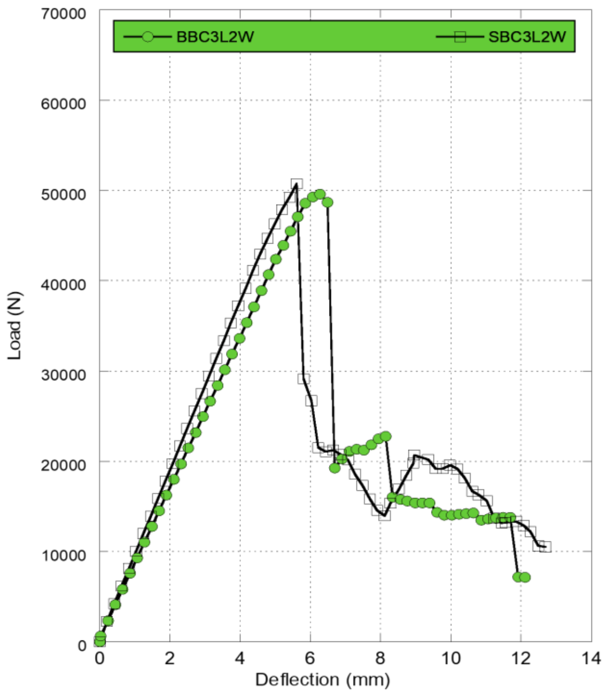


Fig. 9. BBC3L2W vs. SBC3L2W

Likewise, figure 8 and figure 9 explicates the dissimilarities in load carrying capacities as well as distinct deflections with same FRP confinements (layout and wrapping) for beams with different aggregates. For two layers and one U-wrapping and three layers two wrappings of FRPs on stone beam governed the brick beam by 53% and 4% respectively. Brick beam of this same configuration (2 layers 1 wrapping) undergoes more deflection than stone beams before failure and it is 0.2 mm.

Fig. 10. BBJ1L1W vs. SBJ1L1W

Interestingly, stone and brick beams with 3 layers and 2 wrapping of CFRP carry almost the same load before failure and it is near 50000 N. But the deflection for brick beams in this case is more than the stone bricks and it is

0.4 mm in total (See figure 9).

In case of 1 layer and 1 U-wrapping of Jute Fiber Polymers (figure 10), the ultimate load capacity of both the stone and brick beams is similar, but the brick beams undergo significant deflection (approximately 4.5 mm) before failure compared to stone beams.

3.3 Failure patterns

Failure patterns of concrete specimens are observed during experiments. The main objective was to study effects on failure modes due to confinement of principal compression arcs of RC beams without using web reinforcements along them. CFRPs and JFRPs were used as stirrups externally. Failure patterns of the entire specimens are noticed to understand the failure modes of concrete beam and shear members. Failure modes are found different for the control and FRP used specimens. In the RC beams made of plain concrete, flexural cracks as well as shear cracks are observed. Due to flexural reinforcement the beams are strong in flexural but weak in shear capacity. So, the beams mainly failed in shear.

4. CONCLUSION

Based on the experimental investigations, RC beams were casted without any shear reinforcement to make them weak in shear capacity, so that the enhancement of shear capacity by the FRP could be observed.

Two types of FRPs, such as CFRP and JFRP were used. Variation in reinforced concrete beam was brought by using stone and brick as coarse aggregate in five specimens each. Significantly, while performing load tests, each of the samples were noticed to fail at shear. The load-deflection behavior shows that the bending capacity for brick beam control had maximum load carrying capacity of 19500 N, deflection is 3.2 mm and. For BBC3L2W we found maximum load 49000 N, deflection 6.2 mm.

The maximum load carrying capacity of BBCON is 19000 N and deflection is 3.2 mm. We found that the load carrying capacity of BBC2L, BBC2L1W, BBC3L2W and BBJ1L1W were increased by 13%, 64%, 154% and 151% respectively with respect to BBCON. On the other hand, the maximum load carrying capacity of SBCON is 35000 N and deflection is 6 mm. We found that the load carrying capacity of SBC2L1W, SBC3L2W and SBJ1L1W were increased by 40%, 45% and 38% respectively with respect to SBCON. But the load carrying capacity of SBC2L was decreased by 5% with respect to SBCON.

Here, the stone beams are showing more strength than brick beams. The effects of aggregate for load carrying capacity SBCON, SBC2L, SBC2L1W, SBC3L2W, SBJ1L1W are higher than BBCON, BBC2L, BBC2L1W, BBC3L2W, BBJ1L1W by 80%, 53%, 53%, 4%, 3% respectively. The effects of FRP confinement for brick beams, the load carrying capacity is maximum for BBC3L2W and minimum for BBC2L. Again, for stone beams, the load carrying capacity is maximum for SBC3L2W and minimum for SBC2L. The dissimilar types of FRP wrappings on these two types of beams have also been noticed to affect the deflections. Brick beams with u wrappings of FRPs showed more deflections than stone beams. Only the beams provided with two layers of FRPs went through less deflections than the stone beams with the same configurations.

5. ACKNOWLEDGEMENT

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