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SHEAR STRENGTHENING OF RC DEEP BEAMS USING GLASS CHOPPED STRAND MAT (GCSM)

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ABSTRACT

The strengthening of existing reinforced concrete structures is required due to substantial increment in service and live loads or due to the severe environmental deterioration. Fiber Reinforced Polymer (FRP) has been a popular material for strengthening technique due to its high strength, ease of use and lightweight. The current paper presents an experimental investigation of shear strengthening of RC deep beams with glass chopped strand mat (GCSM). Six rectangular deep beams were constructed and tested in the same manner. One beam was used as a control specimen and the remaining five were strengthened with different layers and wrapping schemes. The experimental results show that externally bonded GCSM is effective to increase the shear strength of RC deep beams. Its contribution depends on the thickness and bonded configurations of fiber composites. An increasing number of GCSM layers leads to increase the shear strength of RC deep beams. U-wrapped bonded GCSM strengthening is more effective compared to two-sided bonded.

1. Introduction

Strengthening or retrofitting reinforced concrete structures is needed when the strength of existing structures is unable to withstand the substantial increment in loads. Misuse of the structures and degradation due to environmental effects are the reasons which lead the original structural capacity to upgrading. In order to solve these problems, suitable methods and economical materials for the repair and retrofitting of obsolete and degraded structures are investigated through many years. Many methods have been studied and used to increase ductility and the loading capacity of the reinforced concrete beams. External bonded steel plates, concrete jacketing, ferrocement and external post-tensioning are some techniques available for enhancing the strength of structural members [1]{ACI, 2002 #59}{ACI, 2002 #59}. Using external prestressing tendons to strengthen flexural reinforced concrete and steel members has been investigated and studied [2-4]. The results showed that this technique is effective to improve fatigue deflections and to increase the ultimate strength with sufficient ductility. However, it will lead to damage the existing beams if there is a lack of special attention of the blocks and deviators construction [3]. Many works have been conducted to study the performance of ferrocement as a strengthening technique [5-7]. This technique is the viable alternative strengthening component for the rehabilitation of reinforced concrete structures [8]. This common strengthening technique effectively enhances strength, stiffness and ductility of reinforced concrete members, but it increases the cross-sectional dimensions, dead load of the structures and labor-intensive [9; 10]. Strengthening or repairing precracked reinforced concrete beams by bonding steel reinforcing plates to the structures have been studied [11; 12]. This technique significantly improves ultimate load, crack control and stiffness. However, this technique has the disadvantages such as difficulty in manipulating the heavy steel plates at the construction site, the need of scaffolding, limited delivery length of steel plates and steel corrosion [10]. Deterioration caused by the steel corrosion may cause strength reduction which is not favorable in the strengthening systems [13].

Externally bonded fiber reinforced polymer composites have become a strengthening and retrofitting technique of concrete structures since the mid-1980s. This technique has been investigated and used to strengthen reinforced concrete members such as beams, columns, walls and beam-column joints. Because of their high strength, high stiffness, lightweight, non-corrosive and ease of use, FRP composites are widely distributed and developed as construction materials for strengthening and retrofitting RC structural members [1; 10]. Externally FRP reinforcements have been used for strengthening structural capacities of RC members through many ways. Flexural strength and stiffness of reinforced concrete beams are improved by bonding FRP system to the tension face of the members [14; 15]. Shear capacity of beams has been improved by wrapping FRP systems to the three sides of beams (U-wrapping) or bonding to both opposite sides of beams while fully wrapping on four sides is not applicable at construction sites [1]. Khalifa and Nanni [16] studied the contribution of carbon fiber reinforced polymer composites on shear strength of RC beams. Many parameters have been investigated in this study such as CFRP types, web reinforcement, shear span-to-effective depth ratio and distribution of CFRP. The experimental results showed that externally bonded CFRP effectively enhanced shear capacity of beam which depend on the variables investigated. Few studies have investigated the shear behavior of deep beams with external fiber reinforced plastics [17-19]. Sudden and brittle shear failure is most likely to occur in deep beams rather than in slender beams. Thus, strengthening or retrofitting of deep beams with insufficient shear strength is of great momentousness. Zhang, et al. [19] carried out a series of experimental tests to investigate the shear behavior of deep beams with externally bonded CFRP shear reinforcement. The results demonstrated the viability of using externally CFRP technique to restore or increase the shear strength of deep beams. An experimental investigation conducted by Islam, et al. [17] showed that the externally bonded FRP system led to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to fulfil most of the practical upgrading requirements. The shear contribution of the FRP system to shear strength of a member is based on the fiber orientation and an assumed cracked pattern [19; 20]. Lee, et al. [18] investigated the behavior and performance of RC T deep beams strengthened with externally CFRP sheets by considering the strengthening length, fiber direction combination and an anchorage using U-wrapped CFRP sheets. The test results indicated that the fiber direction combination of CFRP sheets has a significant influence on the ultimate load and ductility of the tested deep beams. The two horizontal plies of CFRP sheets may provide a greater contribution to the shear strength compared to other fiber direction combinations. Concerning the fiber orientations, it was found that the diagonal fiber orientation of the FRP restricted growth and widening of the shear crack which lead to increase the gain in the loading capacity [21]. The shear strength of beams is also increased by wrapping fiber perpendicular to the longitudinal axis of the specimens. Bonding the fiber on the two sides of beam horizontally provided the horizontal restraint which also improves the shear capacity of beams [16]. Shear contribution of deep beams bonded with the double-layered CFRP laminates, which consist of one layer of vertical CFRP laminates and one layer of longitudinal CFRP laminate, are increased more than that of deep beams bonded with two layers of vertical CFRP laminates [19].

In the present paper, shear strengthening of reinforced concrete deep beams with E-glass chopped strand mat fiber has been studied. RC deep beams mostly support the load from one or more columns and transfer it laterally to other columns. They have been used in high-rise buildings, offshore structures and foundations [22]. E-glass chopped strand mat (GCSM) is made from continuous fiber glass strand, which is chopped into a certain length, distributed in a random and non-directional position. Due to the orientation of the fibers, the mat can be assumed to have equal properties in all directions [23]. The roving of E-glass chopped strand mat was shown in Figure 1. Key variables evaluated in this study are the effectiveness of the thickness (number of plies) and the strengthening schemes of FRP. A total of six rectangular deep beams were constructed and tested in the same manner with a shear span-to-overall depth ratio of 1.25. One beam was used as a control specimen whereas the remaining five were strengthened with different layers and wrapping schemes.

Figure 1 E-glass chopped Strand Mat fiber

2. Experimental Program

2.1 Details of Reinforced Concrete Deep Beams

The six reinforced concrete deep beams constructed were identical in every respect. Each of the beams was 900 mm long with a rectangular cross-section, 100 mm in width and 300 mm in overall depth (h). The flexural reinforcement consisted of 2DB12 deformed bars of yield strength 370 MPa. Longitudinal skin reinforcement was uniformly distributed along both side faces of the member with 3 layers of 6 mm round bar. Vertical shear reinforcement consisted of 6 mm round bar with the spacing of 120 mm. Additional vertical shear reinforcements were provided at each supporting regions to prevent premature local failure. Details and dimensions of the rectangular cross-section deep beams are shown in Figure 2. The compressive strength of the beams were measured by testing the standard cylindrical specimens at the age of testing beams. The average measured compressive strength concrete is 30 MPa. The material properties of the stirrups and longitudinal rebars are given in Table 1.

2.2 Strengthening materials and Methods

Six RC deep beams were tested in this study. One beam was used as a control specimen which was tested without strengthening. The remaining five beams were strengthened with different layers and wrapping schemes. They were divided into two groups. Group 1 consists of three specimens which were wrapped on both opposite sides of beams with different number of layers. Whereas, two beam specimens in group 2 were strengthened by wrapping the FRP laminate around three sides of the member (U-wrapped). A detailed summary of all beam specimens is shown in Table 3.

Before strengthened, the concrete surfaces were first prepared by cleaning to remove all debris. Then the mixed solution of matrix was applied to the beam surfaces. A first layer of E-glass chopped strand mat fiber (GCSM) was attached to the concrete surface. In order to impregnate the fiber in the adhesion layer and remove the air voids, ribbed rollers were used to roll on the GCSM fiber. A second layer of mix resin was coated on the first layer of GCSM fiber and then the second layer of the fiber was added. Additional fiberglass and resin were applied as the amount considered (Table 3). The corners of deep beams in Group 2 were first rounded before apply resin and chopped strand mat fiber (Figure 3). The strengthened specimens were left to dry for 7 days before testing. Chopped Strand mat fiber glass No. 300 and Smart CF-Resin provided by SMARTCOAT Company were used in this study. E-glass CSM has a weight of 300 ± 20 g/m^2. The mechanical properties of the epoxy resins are detailed in Table 2.

Table 1 Materials properties of stirrups and rebars

Type	Yield strength (MPa)	Ultimate tensile strength (MPa)
RB6	470	600
DB12	370	590

Table 2 Properties of resin

Tensile Strength (MPa)	Density	Adhesive tensile strength (MPa)	Tensile strength (MPa)	Mixing Ratio
30	1.30±5%	>2.5	>30	2:1

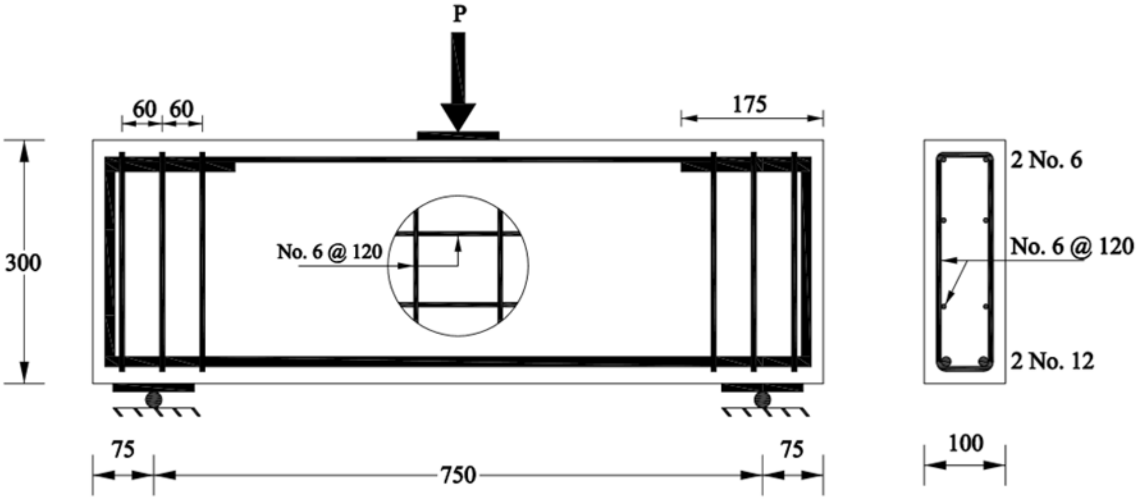


Figure 2 Dimensions and reinforcement details of beam [mm]

2.3 Instrumentation and Loading Process

All beams to be tested were simply supported by two steel rollers located 75 mm from each end of the beam and loaded under three points bending with the shear span to depth ratio (a/h) of 1.25. Steel plates were used and inserted between concrete and roller to prevent the local failure at the support. The load was measured by a load cell mounted on a hydraulic jack while deflection was measured at the middle of the beams by using LVDT transducers. All beams were instrumented by electrical resistance strain gauges for measuring strains in the reinforcement of beams. The test set-up for the deep beams is illustrated in Figure 4.

3. Results and Discussions

3.1 Control Beam

All beams were tested until failure by static loading. Experimental load and deflection data were automatically recorded. Load deflection-curves of all tested beams are shown in Figure 7 and Figure 8. The failure modes of the tested specimens are observed from one point loading test. The control beam CB0 failed due to "Shear Compression Failure" as shown in Figure 5. First, the flexural crack initiated at about the mid span of the beam soffit at a load of 53.72 kN. By increasing the load, the cracks propagated vertically upward and new flexural cracks appeared near the supports. Diagonal cracks occurred afterward in the beam web parallel to compression strut, then propagated upward to the loading point and downward to a location near support.

With increasing loads, width of diagonal shear cracks became wider and wider along with concrete crushing at the loading point. Applied load and deflection of tested beams were measured accordingly during the test. According to the experimental observation, the control beam failed at a load of 224.40 kN.

Figure 3 Rounded corners of U-wrapped specimens

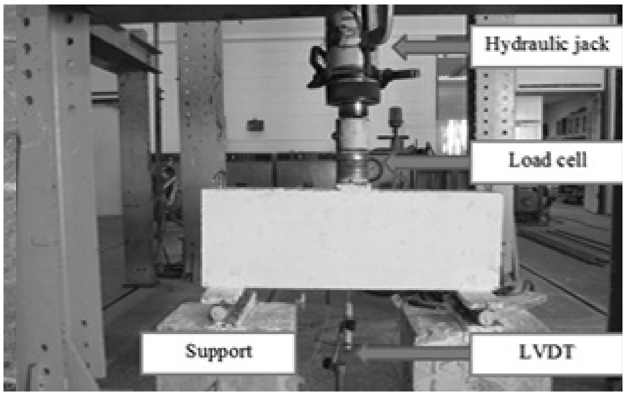
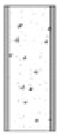
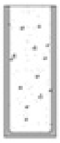


Figure 4 Loading set-up

Table 3 Details of RC deep beam specimens

Group	Designation	Strengthening configuration	Illustration
Control	CB0	-	-
I	2S3L	Both sides with 3 layers	
	2S6L	Both sides with 6 layers	
	2S9L	Both sides with 9 layers	
II	3S6L	U-wrap with 6 layers	
	3S9L	U-wrap with 9 layers	

3.2 Beam Group 1

Wrapped E-glass chopped strand mat fiber on both-side of the beam leads to increase both stiffness and load capacity compared to the control beam. Beam 2S3L and 2S6L, strengthened by 3 layers and 6 layers of E-glass CSM fiber on both-side, failed at an ultimate load of 280.34 kN and 296.39 kN, respectively. The beam 2S9L exhibit the highest load-carry capacity with an ultimate load of 321.82 kN. Load-deflection curves of group 1 specimens are shown in Figure 7.

According to test observation, the failure mode of strengthened beam 2S3L was shear-compression failure due to crushing of the concrete at the loading point along with fiber composite delamination. Fiber delamination of specimen 2S3L initiated at the compression zone and further propagated to the region near the supports. None of the diagonal shear cracks were observed in all the strengthened specimens since all the beam webs were totally wrapped with the fiber composites. However, deformation of E-glass CSM wrapped of specimen 2S3L can be seen as white formation when ultimate load almost reached. Beam 2S6L failed due to brittle shear compression failure along with debonding of fiber composites and crushing of concrete at loading point. Delamination occurred from the loading point and propagated to edges of the beam through the diagonal shear crack.

Beam 2S9L failed at the same pattern as that of beam 2S6L, except that the shear compression failure and delamination are more severe than beam 2S6L, as shown in Figure 6.

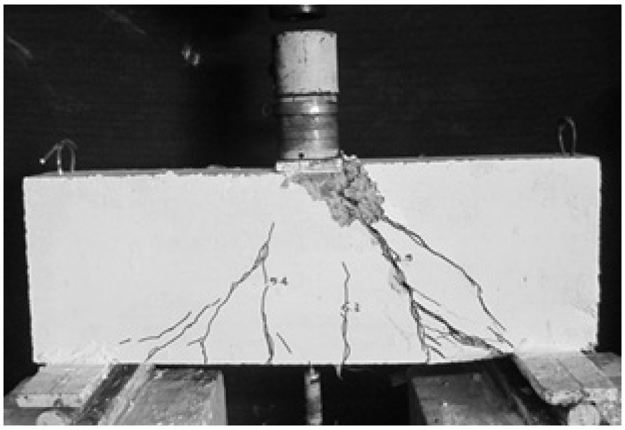


Figure 5 Failure patterns of control specimen

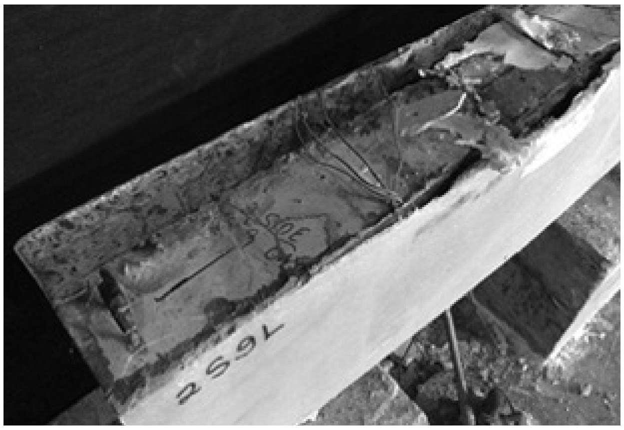


Figure 6 Failure mode of Beam 2S9L

3.3 Beam Group 2

The load-deflection curves of group 2 are plotted in Figure 8. The loading capacity at failure of specimen 3S6L and 3S9L are 334.38 kN and 366.32 kN, respectively. The loading capacity of specimen 3S6L and 3S9L are increased up to 49% and 63% compared to the control specimen respectively. Beam 3S6L which was strengthened with U-wrapped scheme exhibited severe and brittle shear-compression failure conjunction with delamination of glass fiber composites. It was observed that the delamination of fiber composites were occurred from the loading point and completely deboned in the triangle shape above the inclined shear cracks. The failure mode of beam 3S9L was almost the same that of beam 3S6L. However, it was shown a more brittle failure due to crushing of the concrete and delamination of polymers.

It can be seen from the Table 4, Figure 7 and Figure 8 that, strengthened RC beep beam with E-glass CSM fiber lead to increase loading capacity and stiffness of the beams. Increasing the thickness of E-glass CSM fiber lead to increase the strength of the beam.

The strengthened beams in the U-wrapped scheme is more effective than the beams strengthened in 2-side wrapped. Loading capacity of beam 3S6L and 3S9L, which strengthened in U-wrapped scheme, provide an increase of 38 kN and 44.5 kN compared to beam 2S6L and 2S9L, respectively. These lead to increase 12.82% and 13.83%.

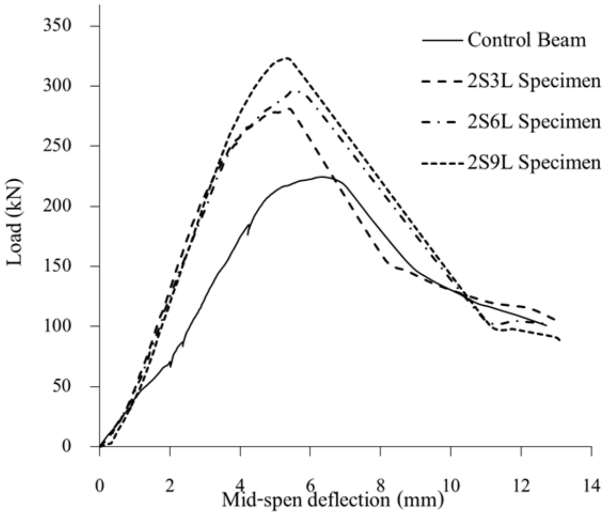


Figure 7 Load-Deflection curves of beams in Group 1

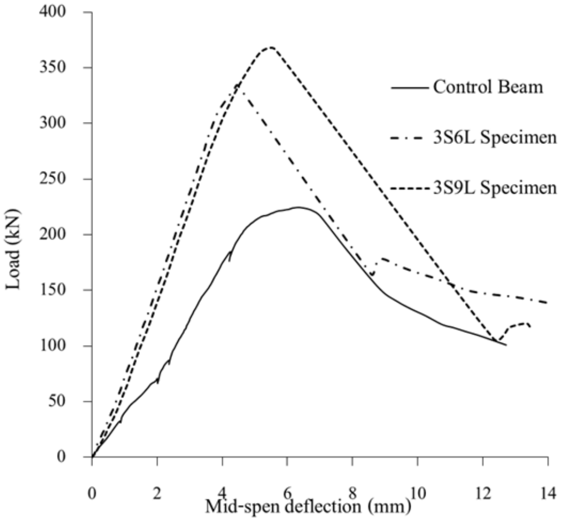


Figure 8 Load-Deflection curve of beams in Group 2

Table 4 Summary of experimental results

Specimen	Loading capacity (kN)	Deflection (mm)	Failure mode	Increase rate (%)
CB0	224.40	6.40	Diagonal shear crack	0
2S3L	280.34	5.46	Fabric delamination	25
2S6L	296.39	5.54	Fabric delamination	32
2S9L	321.82	5.45	Fabric delamination	43
3S6L	334.38	4.49	Fabric delamination	49
3S9L	66.32	5.63	Fabric delamination	63

4. Conclusions

Shear strengthening of reinforced concrete deep beams by using E-glass chopped strand mat is an effective method, suitable low cost and ease of use, which is an essential goal for the development of repairing and strengthening techniques. Applying E-glass chopped strand mat composites to the webs of the beams leads to increase the shear strength and stiffness of RC deep beams compared to the control specimen. Increasing the number of layers would lead to increase the loading capacity of the beams. U wrapped scheme is more effective for shear strengthening compared to two-side bonding technique. Applied 6 layers of U-wrapped scheme to the surface of beams, ultimate loading capacity was increased more than applying 9 layers with both sides.

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