

Behavior of RC Deep Beams Strengthened in Shear using Glass Fiber Reinforced Polymer with Mechanical Anchors

Lalin Lam, Qudeer Hussain, Panuwat Joyklad, and Amorn Pimanmas

Abstract— This paper examines the effect of glass chopped strand mat fiber composites (GCSM) with the mechanical anchor on the shear strength of reinforced concrete deep beams. Two types of matrix system were used to provide stresses between the fibers and also between the fiber composites-to-concrete interface. Epoxy and polyester resin were investigated and compared to find the suitable resin matrix. Mechanical expansion anchor system which was recently proposed by the author was used in this study. The experimental results indicated that using GCSM composites with mechanical anchors led to enhancement of load-carrying capacity and stiffness of the beams. Epoxy resin system was found to be more effective compared to Polyester resin. The ultimate shear capacity of the RC deep beams strengthened with epoxy system was increased up to 68% compared to the control specimen. Continuously wrapped the GCSM fiber composites over the bottom and both sides of the beam in the form of a U-wrapped provided additional anchorage at the bottom end of fiber composites. This leads to the prevention of debonding and the increase of loading capacity. Providing additional bond strength of the bond interface by using mechanical anchor found to be more effective since it leads to more usage of the composites. Strengthening technique using FRP wrapped with mechanical anchors supposedly confined the compressive strut which is able to increase the loading capacity.

Index Terms— Deep beams, Glass Chopped strand mat (GCSM), Mechanical anchor, Strengthening.

I. INTRODUCTION

Reinforced concrete deep beams have been used as a transfer girders, wall footings or shear walls in high-rise buildings and offshore structures. The loads were transferred from one or more columns to other supporting columns by using RC deep beams. It has been widely used because of their convenience and economic efficiency. When the accidental mistakes at the site or in the office such as construction faults, poor construction practices, miscalculation and improper detailing of reinforcements, the existing reinforced concrete members are unable to withstand the action of applied load. Changing the usage of the structures will lead to augmentation of external loads which

is unsafe in terms of safety usage. Since demolition and reconstruction would cost much time and moneys, strengthening and retrofitting techniques have increasingly investigated and used to enhance the capacity of existing reinforced concrete structures. Many methods have been explored and proposed for the purpose of increasing the load-carrying capacity, ductility and stiffness of the RC structures. Externally bonded fiber reinforced composites to the faces of the beams has been successfully used as a strengthening method to strengthen and retrofit the strength of the RC beams [1]-[2]. This strengthening technique is becoming more attractive to structural engineers and construction industries as a modern material to strengthen and retrofit the existing structures due to its high strength, lightweight and ease of application. It showed that externally bonded CFRP or GFRP composites to the lateral and bottom faces of the beam can increase the first crack load and ultimate strength greatly [2].

Shear strength and stiffness of RC beam can be increased by using externally bonded FRP technique [3]. Three types of strengthening schemes can be used such as fully wrapped, U-wrapped and both-sided bonded configuration [4]-[5]. The studies of previous researchers mentioned that almost all beams strengthened with externally bonded FRP technique failed mainly due to the debonding of fiber composite from the concrete surfaces except that the beams with fully wrapped of FRP failed due to rupture of the fibers [6]-[7]-[8]. The debonding failure mode of fiber composite from the FRP to concrete interface showed a brittle manner which occurred immediately after the ultimate strength was reached. With such a mode of failure, the full potential of the fiber sheet is not fully used [9].

Most experimental tests have been focused on shear strengthening of RC slender beams using externally bonded FRP composites without anchors [9]-[10]-[11] and with anchors [12]-[13]-[14]. However, the shear contribution of external bonded FRP with and without anchors to the strength of reinforced concrete deep beams is not fully understood. Few studies are focused on the strengthening of deep beams using external bonded of carbon fiber wrap, strip or grid at various orientations with respect to the axis of the beam [15]-[16]-[17]. The final failure of the strengthened beams using externally bonded FRP was mostly due to the delamination of the composites from the concrete surface associated with concrete peel-off [18]. It is momentous to exploit the anchorage technique which leads to rupture of fiber rather than the anchorage failure [19]. Soleimani and Banthia [13] studied the shear strengthening of reinforced concrete beams using external bonded sprayed glass fiber

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with mechanical fasteners of through bolt and nuts. It was concluded that using through bolts as mechanical fasteners can prevent debonding failure. Micelli, et al. [20] studied the shear strengthening using FRP composites. Glass FRP rods were inserted into groove to prevent the delamination of the CFRP sheets in the near end corner. It was found that the failure of specimen strengthened with end anchors was due to end-anchor pullout rather than the debonding of the CFRP sheets.

The purpose of this study is to seek a suitable and effective strengthening technique which is ease of use and reasonable price. The external strengthening technique using glass chopped strand mat fiber with different resin matrices (i.e. epoxy and polyester resin) has not hitherto been closely investigated and compared. In this paper, two resin systems such as epoxy resin and polyester resin which are available in the market were investigated. Mechanical anchors which consisted of nut, washer, mechanical expansion anchor and bolt were used in this study. This mechanical expansion bolt anchoring system is effective to prevent the debonding failure of the sprayed glass fiber reinforced polymer from concrete surface [21]. Since it is difficult to maintain the uniformity of sprayed fiber thickness, the strengthening method using E-glass chopped strand mat with hand lay-up technique is investigated. This technique is quite suitable for in situ application. The randomly distributed direction of GCSM fiber provided similar fiber pattern compared to sprayed fiber. Effective method, suitable low cost and ease of use made this strengthening technique more interesting. The experimental program is described. The results are presented and discussed.

A. Abbreviations and Acronyms

CFRP	Carbon fiber reinforced polymer
FRP	Fiber reinforced polymer
GCSM	Glass chopped strand mat
GFRP	Glass fiber reinforced polymer
LVDT	Linear variable displacement transducer
RC	Reinforced concrete

II. EXPERIMENTAL PROGRAM

A. Specimen Details

The typical details of the specimens showing the reinforcement layout are shown in Fig. 1. A total of five beams were constructed to investigate the shear strengthening using glass chopped strand mat fiber with two different kinds of the matrix system. Epoxy resin and polyester resin were used in this study. The beams were 100 mm thick and 350 mm deep along with the total length of 1000 mm. All specimens were tested under single-point loading with a shear span of 420 mm giving a shear span-to-depth ratio (a/h) of 1.2. The longitudinal reinforcement consisted of two 12 mm diameter deformed bars. The compressive steel reinforcement consisted of three 6 mm round bars. The web reinforcement consisted of 6 mm smooth bars spaced at 150 mm and 100 mm in vertical and horizontal direction, respectively. The vertical web reinforcement was in the form of stirrups whereas the horizontal web reinforcement was longitudinal bars on both sides of the beams. Closely spaced vertical stirrups were used

at both ends of the beams to avoid premature failure at these locations.

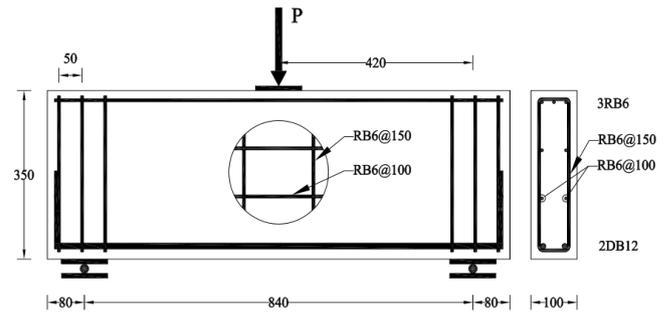


Fig. 1 Typical details of test specimen (unit in mm)

B. Test Matrix

The test matrix is given in Table I. Four beams strengthened using fiber composites with mechanical anchors were divided into two groups, group 1 and group 2, based on the different types of resin. Each group comprised two beams which were strengthened by side bonding (both-side) and by U jacketing (U-wrapped). The strengthening schemes are shown in Fig. 2. Fully wrapping the FRP system around the section on all four sides was not investigated in this study due to the impractical usage. The cured fiber composite thickness of 2 mm along with the anchor spacing of 150 mm and 100 mm in vertical and horizontal direction was kept the same for all strengthened beams. The anchor spacing was selected the same as internal stirrup spacing (Fig. 3).

The number in the specimen designation refers to the number of layers of GCSM fiber. The letters "P" and "E" refers to the polyester resin and epoxy resin, respectively. The letter "A" refers to "Strengthening in Both-Side Bonded" while the letter "B" refers to "Strengthening in U-Wrapped Scheme".

TABLE I
TEST MATRIX

Group	Specimen	a/h	Resin type	Configuration
	Control		N/A	N/A
1	2PA	1.2	Polyester	Both-side bonded
	2PB			U-wrapped
2	2EA		Epoxy	Both-side bonded
	2EB			U-wrapped

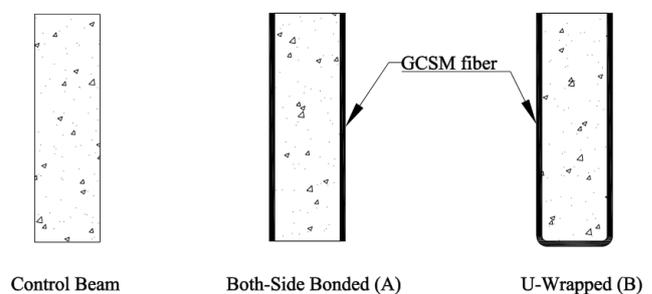


Fig. 2 Strengthening configuration.

C. Material Properties

The concrete compressive strength on testing day was 18MPa. The longitudinal steel reinforcement was deformed bar with characteristic yield stress of 520 MPa. To insure a sufficient anchorage capacity, the bars were bent up and

enclosed by two additional vertical stirrups at each end with the spacing of 50 mm. The beam webs were reinforced with smooth bars of 380 MPa yield strength. Glass chopped strand mat of 600 g/m^2 was used in this study. This fiber is made from a chopped glass fiber with a unique fiber length and randomly distributed. It is selected as an external reinforcement due to its distributed fiber direction which can allow the composite to have high bearing strength. Different types of resin such as epoxy resin and polyester resin were compared in order to find the suitable matrix with this type of fiber and strengthening technique. The mechanical anchors which consisted of nut, washer, mechanical expansion anchor and bolt were inserted into the pre-drilled holes and were installed perpendicularly through the GCSM fiber composites at the desired spacing on the beams' side faces (Fig. 4).

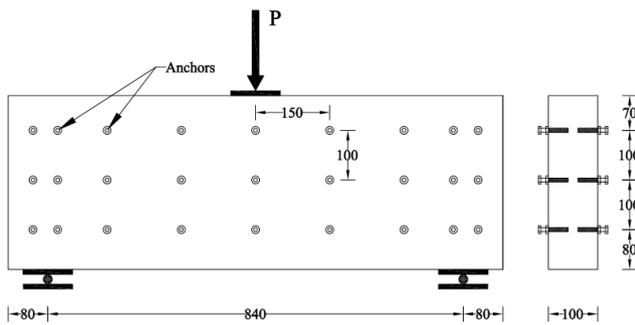


Fig. 3 Typical location of mechanical anchors (unit in mm).

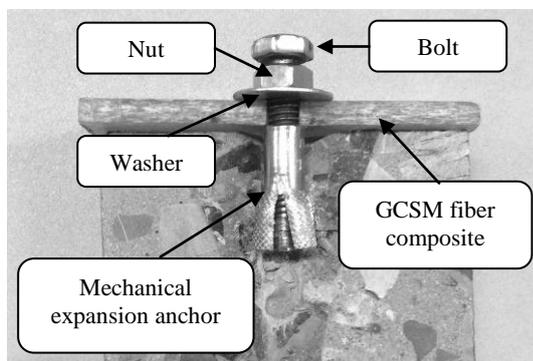


Fig. 4 Mechanical anchor system

D. Test Set-Up and Instrumentation

The test set-up for the deep beams is illustrated in Fig. 5. All tested beams were simply supported by two steel rollers

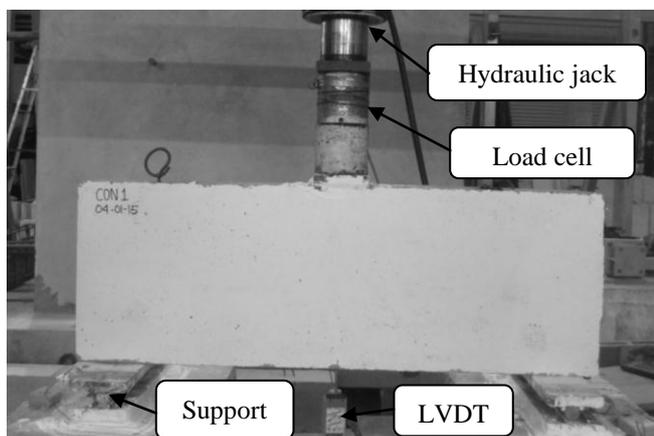


Fig. 5 Test set-up.

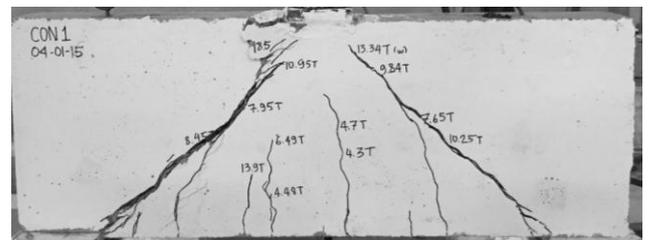
located 80 mm from each end of the beams and loaded under three-point bending, giving the shear span to depth ratio (a/h) of 1.2. Steel bearing plates of 10 mm thick and 100 mm width were used and inserted between concrete and roller to prevent the bearing failure at the supports. The steel plate was also placed under the piston of the hydraulic jack at the loading location. The loading was executed by the hydraulic jack and measured using a load cell. The corresponding deflection was monitored by the LVDTs at the mid-span of the beam.

III. TEST RESULTS AND DISCUSSIONS

All beams were tested under static loading until failure. Experimental load and deflection data were automatically recorded. The crack pattern of control beam is shown in Fig. 6. The failure mode of strengthened beams are illustrated in Fig. 7 and Fig. 9. Test results of all experimental specimens are discussed in detail in the next sections and summarized in Table II.

A. Control Specimen

The first visible flexural crack developed at beam soffit at a load of 43 kN. New bending cracks also occurred and propagated upward corresponding to the increment of the load. Shear cracks initiated afterward in the beam web parallel to compression struts which connect from the inner of the support to the loading point. These diagonal cracks propagated upward to the loading point and downward to a location near support. With incremental loads, the width of diagonal shear cracks became wider and wider and extended into the loading point along with concrete crushing. According to the experimental observation, the control beam failed at the load of 186.85 kN. Crack patterns and failure mode of the control RC deep beam were shown in Fig. 6.



and polyester resin failed at the ultimate load of 204.06 kN with a corresponding deflection of 3.863 mm. An increase of 9% compared to the control beam was measured for beam 2PA. The beam 2PB was also strengthened with two layers of fiber, but it was continuously wrapped in the U-wrapped scheme. This beam failed at the ultimate load of 226.73 kN which is 21% higher than that of the reference beam. Load-deflection curves of specimens in group 1 is shown in Fig. 8. None of the diagonal shear cracks of the reinforced concrete deep beams were able to observe in all the strengthened specimens since all the beam webs were totally wrapped with the fiber composites. The final failure mode of strengthened beams, 2PA and 2PB, were due to the rupture of fiber composite along the compression load path (Fig. 7).

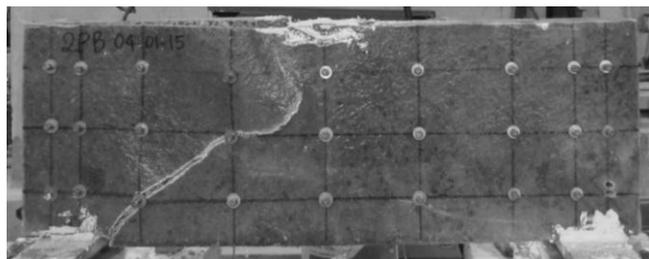


Fig. 7 Failure mode of Beam 2PB.

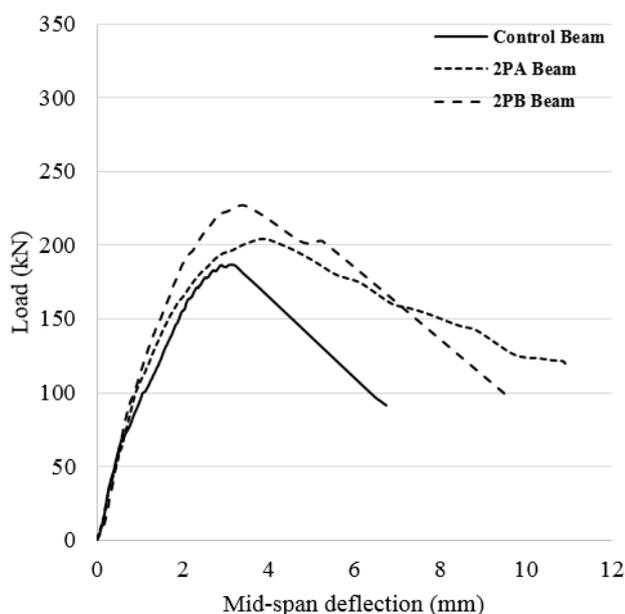


Fig. 8 Load-mid span deflection curves: group 1.

C. Strengthened Beams Group 2

The beams in group 2 consisted of two specimens which were strengthened on both-sided and three-side bonded (U-wrapped). Epoxy resin was used as a matrix in this group. Two layers of glass chopped strand mat (GCSM) of 600 g/m² with epoxy resin which provide the cured thickness of around 2 mm were wrapped over the lateral faces of the beam. The reinforced concrete beams were drilled and then the mechanical anchors were installed.

It was observed from the experimental results shown in Fig. 10 and Table II that strengthened RC deep beams with E-glass chopped strand mat impregnated with epoxy resin along with mechanical anchor considerably improved load-carrying capacity and stiffness of the beam. The beam 2EA failed at the ultimate load of 265.64 kN with a corresponding deflection of 4.641 mm. The beam 2PB which

was strengthened with U-wrapped scheme of GCSM fiber composites and mechanical anchors exhibited an ultimate load of 313.86 kN with the corresponding deflection of 4.077 mm. The loading capacity of specimen 2EA and 2EB increased up to 42% and 68% compared to the control specimen, respectively.

The final failure mode of strengthened beams in this group were due to the rupture of fiber composite at the flexural zone along with the crushing of concrete at the loading region. The failure mode of the specimen 2EA was shown in Fig. 9. It was seen that the fiber composites were partially debonded with concrete peel-off around the loading point along with concrete crushing. It is also noted that the compression steel reinforcements were bent in the beam 2EB. The bearing failure at the anchor locations or pull-out of the anchors was not observed in all strengthened specimens. Only anchors located in the diagonal shear cracks were unattached from the concrete due to crushing of concrete.



Fig. 9 Failure mode of Beam 2EA.

TABLE II
SUMMARY OF EXPERIMENTAL RESULTS

Specimen	Peak load (kN)	Deflection (mm)	Load increase (%)	Failure mode
Control	186.85	3.165	0	Shear failure
2PA	204.06	3.863	9	FRP rupture
2PB	226.73	3.452	21	FRP rupture
2EA	265.64	4.641	42	FRP rupture
2EB	313.86	4.077	68	FRP rupture

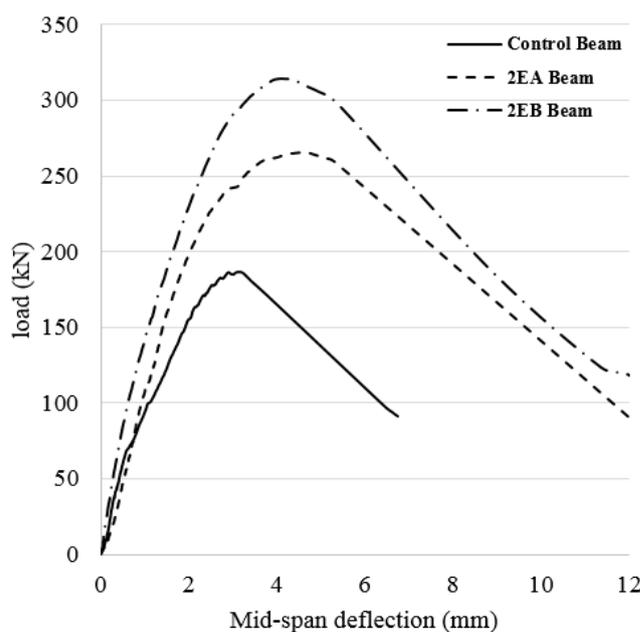


Fig. 10 Load-mid span deflection curves: group 2.

D. Effect of Strengthening Schemes and Resin Systems

The beams strengthened in the U-wrapped scheme is more effective than the beams strengthened in two-side bonded. This wrapping scheme will provide additional anchorage at the bottom end of the fibers. By providing this additional anchorage, the loading capacity of beam 2PB which was strengthened in U-wrapped scheme provided an increase of 11.11% compared to that of beam 2PA. Loading capacity of beam 2EB provided an increase of 48.22 kN compared to that of beam 2EA. This leads to the increase of ultimate loading capacity of 18.15% compared to that of beam 2EA.

Epoxy resin is more effective and suitable for this externally strengthening technique compared to polyester resin. The beam 2EB failed at the peak load of 313.86 kN which is 87.13 kN compared to the beam 2PB. This leads to the increase of load-carrying capacity of 38.43% compared to beam 2PB. The comparison of ultimate loads are shown in Fig. 11.

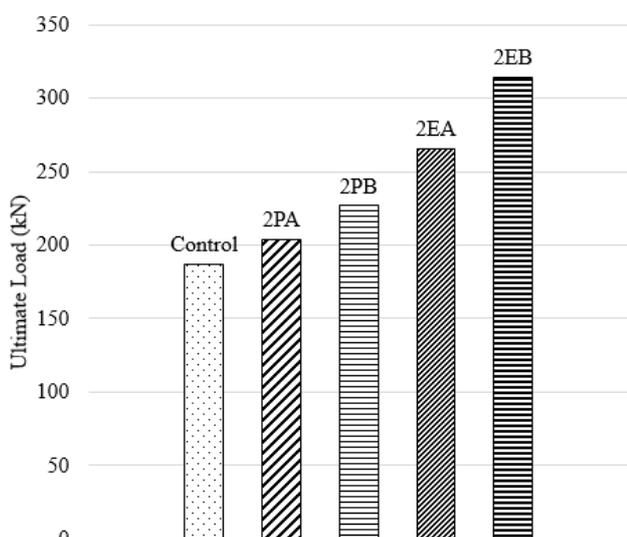


Fig. 11 Comparison of ultimate loads of all tested beams

IV. CONCLUSION

This paper discussed the effects of externally bonded Glass Chopped Strand mat Fiber Reinforced Polymer composite (GCSM) on the ultimate loading capacity of reinforced concrete deep beam. The experimental results indicated that mechanically anchor the external bonded fiber composites leads to enhancement of shear strength and stiffness of reinforced concrete deep beams. Debonding failure of GCSM fiber is prevented and rupture failure of GCSM occurred by using mechanical anchor. This allowed us to fully use the potential of fiber composites. Due to the randomly distributed direction of E-glass chopped strand mat fiber, the bearing failure at the anchor locations could be eliminated. Epoxy resin was found to be more effective and suitable for this externally strengthening technique compared to polyester resin. Externally bonded the RC deep beams with fiber composites in U-wrapped scheme is more effective compared to both-side bonded since it provided additional anchorage at the bottom end of FRP sheets. This will provide a suitable technique to the upgrading of existing structures.

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