International Journal of GEOMATE, July, 2018 Vol.15, Issue 47, pp.89-94
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.47.STR167
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

BEHAVIOURS OF RC DEEP BEAMS STRENGTHENED IN SHEAR USING HEMP FIBER REINFORCED POLYMER COMPOSITES

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ABSTRACT: This paper presents an experimental study on externally bonded hemp fiber reinforced polymer composites reinforced concrete deep beams to investigate the efficiency of hemp fibers in shear strengthening. Reinforced Concrete (RC) deep beam is a beam with the depth comparable to the span length. There are several applications of RC deep beams, such as transfer girders in tall buildings, a wall of water tanks, and footings. Despite a number of research works on strengthening RC deep beams, a current literature review demonstrated no studies on the use Hemp fiber to increase the shear strength of RC deep beams. Hemp fibers are natural fibers which can be obtained from plants. Hemp fibers are externally applied to the beam's surface using epoxy resin. A series of three-point loading tests were conducted on natural hemp fiber strengthened reinforced concrete deep beams. The research parameters included hemp fiber thickness and strengthening configuration, i.e. hemp fiber applied onto two or three sides (U shape). Test results indicated that hemp fiber reinforced polymer composite was capable of enhancing the ultimate load and deflection of RC deep beams. In general, the experimental results demonstrated a higher increase in the shear strength when the thickness of the hemp fiber was increased. Strengthening configuration also has a great impact on the strength and ductility. The U-shaped strengthening with hemp fiber applied onto the side and bottom faces of the beam was superior to strengthening on side faces only.

Keywords: Hemp fiber, Deep beams, Shear strengthening, Composites

1. INTRODUCTION

The Reinforced Concrete (RC) deep beam is a beam with the depth comparable to the span length. Based on ACI 318-05, an RC beam is defined as a deep beam if the span length-to-depth ratio is less than or equal to four [ACI-318, 2005]. There are several applications of RC deep beams, such as transfer girders in bridges and buildings. During the last few years, the demand for restoration, strengthening, and rehabilitation of existing RC structures has been extensively increased. The strengthening of building and bridge structures may be required due to the increase in load demand and/or the degradation of strength owing to material deterioration [Qudeer and Amorn 2015]. There existed a large number of previous researchers on the use of concrete and steel by means of external jacketing for retrofitting and strengthening the deficient RC members (Chai, Priestley, & Seible, 1994; Rodriguez & Park, 1994). However, the use of such materials has posed some disadvantages such as intensive labor demands and increase in weight and volume. These drawbacks can be overcome by applying fiber-reinforced polymer (FRP) composites. The FRP composites can be externally applied by using uni-directional or bi-direction fabric sheets along with suitable epoxy resin [Al-Rousan et al. 2016] and or can be directly sprayed over the concrete surface using spray gun [Qudeer and Amorn 2016]. Extensive studies have documented attempts to strengthen RC deep beams without web openings and with web openings using FRP fabrics and sprayed FRP. Zhang et al. 2004 investigated the shear behavior of RC deep beams with externally bonded carbon fiber reinforced polymer (CFRP). It was found that externally bonded CFRP are very effective to restore the shear capacity of RC deep beams. Islam et al. 2005 explored the prospect of strengthening structurally deficient deep beams by using an externally bonded fiber reinforced polymer (FRP) systems. RC deep beams were strengthened using a carbon fiber wrap, strip or grids. Test results have shown that the use of externally bonded FRP system leads to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to a level quite sufficient to meet most of the practical upgrading requirements. Maaddawy & Sherif 2009 examined the potential use of externally bonded carbon fiber reinforced polymer (CFRP) composite sheets as a strengthening solution to upgrade reinforced concrete (RC) deep beams with openings. Two square openings, one in each shear span, were placed symmetrically about the midpoint of the beam. Test parameters included the opening size, location, and the presence of the CFRP sheets. Externally bonded CFRP shear strengthening around the openings was found very effective in upgrading the shear strength of RC deep beams. The strength gain caused by the CFRP sheets was in the range of 35–73%. Qudeer and Amorn 2015 performed an experimental study to investigate the efficiency of sprayed glass FRP in the shear strengthening of RC deep beams. Test results indicated that the sprayed FRP system was capable of enhancing the ultimate load and deflection of RC deep beams. Although different types of FRP are very effective to enhance strength and ductility of RC members, however, these FRPs are very expansive and are not easily available in many developing countries. Recently a new method of repair or strengthening using natural fiber such as sisal, jute, and hemp is investigated by different researchers. The present study is mainly conducted to investigate the efficiency of natural hemp fibers to enhance strength and ductility of reinforced concrete deep beams. Towards this goal a large scale experimental program is conducted. A series of three-point loading tests were conducted on natural hemp fiber strengthened reinforced concrete deep beams. The research parameters included hemp fiber thickness and strengthening configuration, i.e. hemp fiber applied onto two or three sides (U shape).

2. MATERIALS AND METHODS

2.1 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 natural hemp fiber reinforced polymer composite. The beams were 100 mm thick and 350 mm deep along with the total length of 900 mm. All specimens were tested under single-point loading with a shear span of 375 mm giving a shear span-to-depth ratio (a/h) of 1.25. 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. A concrete cover of 15 mm was provided on all sides.

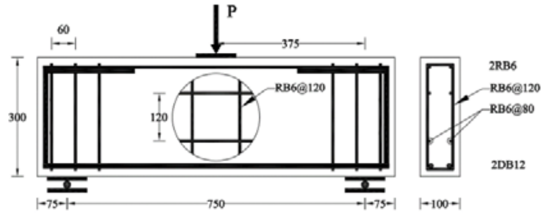

Fig.1 Typical detail of test specimen (unit in mm)

2.2 Test Matrix

Five reinforced concrete deep beams were constructed to investigate the behavior and failure mechanisms of hemp fiber reinforced polymer composites strengthened RC deep beams. Four RC deep beams were strengthened with hemp fiber using epoxy resin. The experimental test matrix is shown in table 1. Group 1 is containing one control beam. Group 2 and 3 containing two beams which were strengthened using hemp fiber applied onto two or three sides (U shape). The strengthening schemes are shown in Fig.2. The specimen names are given to represent a number of hemp fiber layers, i.e., one or two layers and strengthening configuration such as configuration A or configuration B.

Table 1 Experimental test matrix

Group	Specimen	Fibre thickness (layer)	Configuration
1	Control	-	-
2	1-A	1	A
	1-B	1	B
3	2-A	2	A
	2-B	2	B

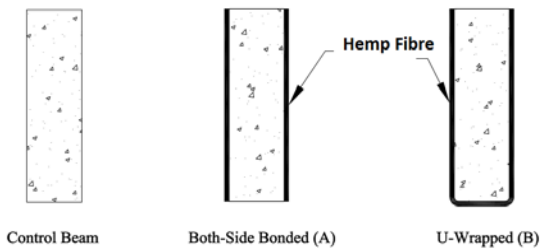

Fig.2 Details of strengthening configuration

2.3 Material Properties

The concrete compressive strength on the testing day was 27MPa. The longitudinal steel reinforcement was deformed bar with a characteristic yield stress of 520 MPa. To ensure 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. The epoxy which was used as a matrix resin in this experimental program was provided by Smart and Bright Co., Ltd, Thailand under the product name "SMART CF-RESIN". It consisted of two parts; i.e., resin (Part A) and hardener (Part B). SMART CF-RESIN uses 2 parts of resin to 1 part of hardener by weight. The mechanical properties of epoxy resin provided by the manufacturer are listed in table 2. In this study, the tensile strength of hemp FRP composites was determined by testing the strip specimens of hemp FRP in accordance with ASTM Standard D638. The mechanical properties of hemp FRP composite are given in Table3.

Table 2 Mechanical properties of epoxy resin

Properties	Configuration
Curing Time	7-10 hours
Compression	650 kgf/ cm^2
Tensile strength	50 MPa
Elongation at break	2.5%
Flexural strength	75 Mpa
Bond strength	2.11 N/mm^2
Thermal conductivity	0.083 W/m°K

Table 3 Mechanical properties of hemp FRP composite

Properties	Value	Unit
Tensile strength	156	Mpa
Fracturing strain	0.505	%
Modulus of elasticity	6.414	Gpa

2.4 Hemp Fiber Strengthening of RC Beams

In the experimental program, hemp fiber was used for the strengthening of RC deep beams. Hemp fibers were obtained from local farms in the form of fabric sheets. The strengthening of reinforced concrete beams was performed using hand lay-up technique as shown in the figures 3 and 4

Fig.3 Epoxy application

Fig.4 Hemp fiber strengthening

2.5 Test Set-Up and Instrumentation

The test set-up for all specimens is illustrated in Fig.5. All beams were simply supported by two steel rollers and loaded under one-point loading. The load was applied in the middle of the beam using a hydraulic jack and measured using a load cell. All beams were tested under static loading to failure. Two linear variable displacement transducers (LVDTs) were installed at the mid-span of the beam to record the corresponding deflection values. A steel plate of 10 mm thick and 100 mm width was placed under the load cell at the loading point. The steel bearing plates were also used and inserted between concrete and roller to prevent the bearing failure at the supports.

Table 4 Experimental test results

Group	Specimen	Ultimate load (kN)	Increase in ultimate load (%)	Mid span deflection (mm)	Increase in mid span deflection (%)
1	Control	191.90	-	3.52	-
2	1-A	247.79	29.00	4.46	27.00
	1-B	253.14	32.00	4.93	40.00
3	2-A	284.04	48.00	5.28	50.00
	2-B	279.88	46.00	3.70	5.11

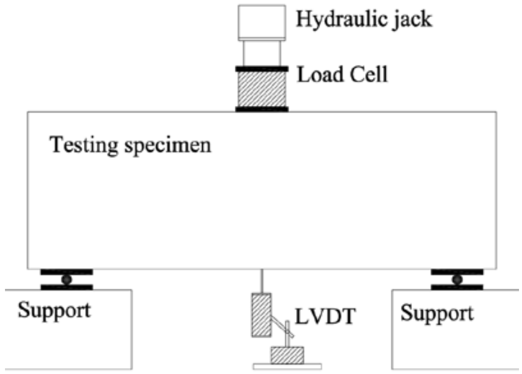

Fig.5 Loading setup

3. RESULT

Experimental load and deflection data were automatically recorded. The load versus midspan deflection responses of testing beams are shown in fig.6 and fig.7. Test results of all experimental specimens are discussed in detail in the next sections and summarized in Table 3.

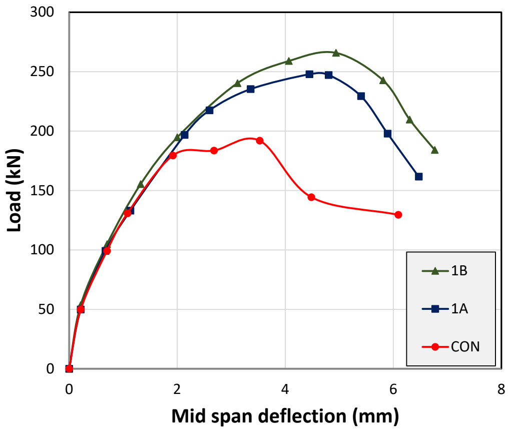

Fig.6 The load-deflection response of beams in group 1 and 2

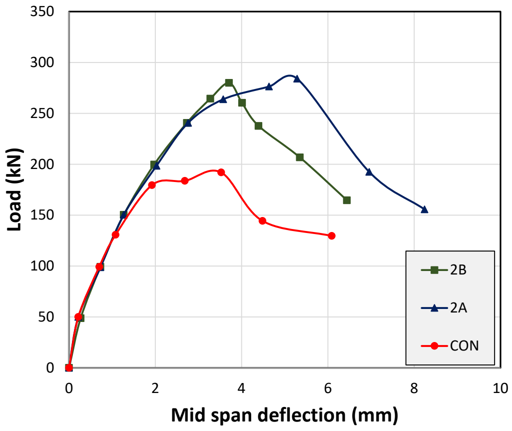

Fig.7 The load-deflection response of beams in group 1 and 2

3.1 Control Beam

The first visible flexural crack developed at beam soffit at a load of 81 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 191.90. Crack patterns and failure mode of the control RC deep beam are shown in figure 8.

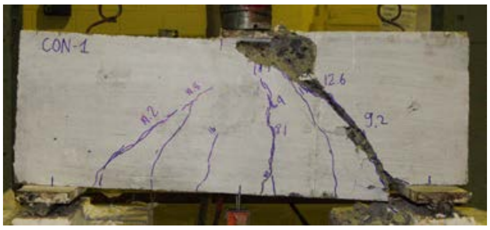

Fig.8 Failure mode of control beam

3.2 Beam Group 2

Group 2 is comprised of two beams i.e., beam 1-A and beam 1-B. Beam 1-A was strengthened using strengthening configuration A and beam specimen 1-B was strengthened using strengthening configuration B. Both beams were strengthened using one layer of hemp fiber. Experimental test results indicate that hemp fiber is ever effective to enhance load carrying capacity and ductility of RC deep beams (Fig.6). Beam 1-A was failed at 29.0% and 27.0% increased ultimate load carrying capacity and mid-span deflection, respectively, compared with control beam. For strengthening configuration B, an increase of 32.0% and 40.0% in ultimate load carrying capacity and mid-span deflection, respectively, compared with control beam was observed for beam specimen 1-B. The final failure mode of both beams was observed due to inclined shear rupture in beams and hemp fiber as shown in fig.9 and Fig.10.

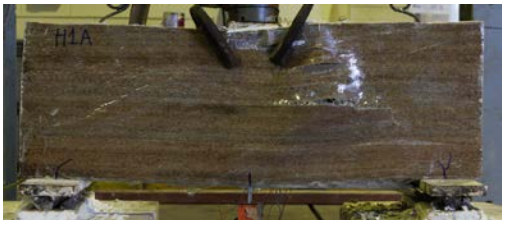

Fig.9 Failure mode of beam 1-A

Fig.10 Failure mode of beam 1-B

3.3 Beam Group 3

Group 2 is comprised of two beams i.e., beam 2-A and beam 2-B. Beam 2-A was strengthened using strengthening configuration A and beam specimen 2-B was strengthened using strengthening configuration B. Both beams were strengthened using two layers of hemp fiber. Experimental test results indicate that hemp fiber is ever effective to enhance load carrying capacity and ductility of RC deep beams (Fig.7). Beam 2-A was failed at 48.0% and 50.0% increased ultimate load carrying capacity and mid-span deflection, respectively, compared with control beam. For strengthening configuration B, an increase of 46.0% and 5.0% in ultimate load carrying capacity and mid-span deflection, respectively, compared with control beam was observed for beam specimen 2-B. The increase in ultimate load carrying capacity and ductility is observed lower for strengthening configuration B. This is supposedly due to the rupture in hemp fiber and concrete at the left support region as shown in figure 12. The final failure mode of beam 2-A was an inclined crack in the fiber and de-bonding of hemp fiber from the concrete surface (Fig.11). In case of beam 2-B, an inclined rupture in the concrete and hemp fiber was observed on the left bottom side as shown in the Fig.12.

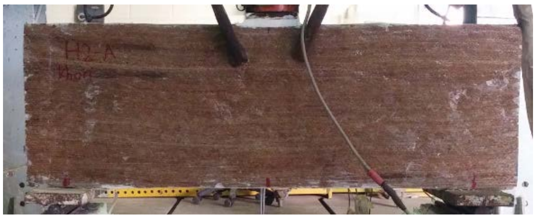

Fig.11 Failure mode of beam 2-A

Fig.12 Failure mode of beam 2-B

3.4 Effect of strengthening configuration

In this study, two types of strengthening configurations, i.e., strengthening configuration A and B were used for strengthened RC deep beams. In general, the beams strengthened in the U-wrapped scheme is more effective than the beams strengthened in two-side bonded. In case of one layer of hemp fiber, the RC deep beam strengthened using strengthening configuration B was failed at higher load as compared with RC deep beam strengthened using strengthening configuration A as shown in Table 3. This is supposedly due to the reason that in strengthening configuration B, the fiber at the bottom side of beam provides additional anchorage. However, in case of two layers of hemp fiber, the RC deep beam using strengthening configuration B was failed at lower load as compared with RC deep beam strengthened using strengthening configuration A as shown in Table 3. This exception is associated with the premature failure of the fiber at the bottom of the beam (2-B) as shown in the fig.12.

4. CONCLUSION

This paper discussed the effects of externally bonded hemp fiber reinforced polymer composites on the ultimate loading capacity and mid-span deflection of the reinforced concrete deep beam. The experimental results indicated that externally bonded hemp fiber composites lead to enhancement of shear strength and ductility of reinforced concrete deep beams. Externally bonded hemp fiber composites with the strengthening configuration U scheme are more effective compared to both-side bonded since it provided additional anchorage at the bottom end of the fiber. This will provide a suitable technique to the upgrading of existing structures.

5. ACKNOWLEDGEMENTS

The authors are very grateful to the Thailand Research Fund (TRF) for providing the grant No. MSD58I0071 and RDG5830008 to carry out the research. A financial support provided by Thammasat University Research Fund under the TU Research Scholar, Contract No.TN66/2558 and SIKA (Thailand) Co., Ltd. was also acknowledged. Thanks, are also extended to Asian Institute of Technology (AIT) for partially supporting test facilities.

6. REFERENCE

[1] Hussain Q., Pimanmas A., Shear strengthening of RC deep beams with sprayed fiber-reinforced polymer composites (SFRP) and anchoring systems: part 1. Experimental study. European Journal of Environmental and Civil Engineering Vol. 20,2016, pp.79-107.

[2] Chai YH., Priestley M., Seible F., Analytical model for steel‐jacketed RC circular bridge columns. Journal of Structural Engineering Vol.120, 1994, pp.2358‐2376.

[3] Rodriguez M., Park R., Seismic load tests on reinforced concrete columns strengthened by jacketing. ACI Structural Journal Vol. 91, 1994, pp.150–159.

[4] Al-Rousan, Rajai Z., Mohsen A. Issa., The effect of beam depth on the shear behavior of reinforced concrete beams externally strengthened with carbon fiber–reinforced polymer composites. Advances in Structural Engineering Vol. 19, Issue 11, 2016, pp.1769-1779.

[5] Hussain Q., Pimanmas A., Shear strengthening of RC deep beams with openings using Sprayed Glass Fiber Reinforced Polymer Composites (SGFRP): Part 1. An experimental study." KSCE Journal of Civil Engineering Vol. 19, Issue 7, 2015, pp.2121-2133.

[6] Zhang Z., Hsu CTT., Moren J., Shear strengthening of reinforced concrete deep beams using carbon fiber reinforced polymer laminates. Journal of Composites for Construction Vol. 8, 2004, pp.403–414.

[7] Islam MR., Mansur MA., Maalej M., Shear strengthening of RC deep beams using externally bonded FRP systems. Cement & Concrete Composites Vol. 27, 2005, pp.413–420.

[8] Maaddawy TE., Sherif S., FRP composites for shear strengthening of reinforced concrete deep beams with openings. Composite Structures Vol. 89, 2009, pp.60–69.