Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 3 (2023) 128-136

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

An Investigation on Flexural Strengthening in Concrete Beam Using Woven Fabric Kenaf Composite Plates

Ahmad Farhan Mohd Kamal[1]**, Hilton Ahmad**[2]***,**

[1,2]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Associate Professor, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia

DOI: https://doi.org/10.30880/rtcebe.2023.04.03.014
Received 06 January 2022; Accepted 15 May 2023; Available online 31 December 2023

Abstract: Concrete beams are common structural elements in housing and bridge projects, primarily to carry flexural loads, necessitating a strengthening technique involving Fiber Reinforced Polymer (FRP) and the presence of kenaf composites manufacturing, which can replace synthetic composites in strengthening the flexural of beams, thereby expanding the applicability of green materials. The main aim for this research is to produce Kenaf Fiber Reinforced Polymer (KFRP) layer of plain-weave architectures as KFRP plates for flexural strengthening, conduct four-points bending test of normal concrete beam with variation of KFRP plate length and compare flexural strength of strengthened beam using KFRP plates with available synthetic composites materials. Twisted kenaf yarns were woven to exacting specifications, and epoxy glue was utilized to adhere the woven fabric kenaf plate to the concrete beam surface. A four-point bending test based on ASTM C78 standard was used to test the plain concrete beam strengthened with KFRP plate for this investigation. When compared to un-strengthened concrete beams (4.74 MPa), KFRP plate can improve flexural strengthening by up to 18% (5.28 MPa). However, this study found that when the length of the KFRP plate increases, concrete beams do not show increasing trends in flexural strengthening. The solution proposes that the woven fabric kenaf composites fabrication technology be improved by adopting automated manufacturing production for consistency, and that concrete beam mixing be done in a single batch to eliminate concrete strength variances.

Keywords: Flexural Strengthening, Woven Fabric Kenaf Composite

**Corresponding author: hilton@uthm.edu.my*

1. Introduction

Beams in concrete structures are one of the most important structural elements in buildings and bridges. As well as cracks occurred in the concrete, reinforcement is required. Steel plates were once utilized as reinforcing materials, however steel was prone to corrosion and had a significant weight penalty. FRP composites were then expanded to include manufacturing and producing bridge beam components. Reinforcing fibers come in a variety of shapes and sizes, including randomly oriented, continuous, and woven fabric mats [1].

Many researchers around the world have reported on a study of Natural Fiber Reinforced Polymer (NFRP) to investigate the practicality of applying natural fiber reinforced polymer as structural design, with surprisingly positive results for the usage as reinforcing fibers in composite manufacturing. Previously, the appearance of natural fiber derived from the plant's stem was hybridized with a combination of glass fiber and its shapes were either woven cloth or mat, which were then converted into reinforced polymeric composites [2]. Increasing awareness of environmental issues such as material sustainability and pollutions causing development of green technology as a remarkable achievement in material production [3]. Kenaf fiber is one of the natural composites that can be used in fiber reinforced polymer products. Woven Fabric Kenaf Composites (KFRP) are a type of woven fabric with high elongation at break and specific strength that can be used to replace synthetic composite materials. Kenaf is described as a fast-growing dicotyledonous from the family of Malvaceae and originated from Africa and India while Department of Agriculture from US has approved that kenaf has lofty potential crop in which it has been selected as fiber sources in pulp and paper industries [4].

One of the areas of inquiry is the use of kenaf composite plates to strengthen concrete beams and increase flexural strength. Mechanical testing was carry out utilizing a Universal Testing Machine (UTM) to perform a four-point bending test that was standardized according to ASTM C78. When compared to a beam without any reinforcing material, the concrete beam may exhibit remarkable ductility. The use of KFRP on the beam concrete must be weighed against the use of synthetic composite materials in the reinforced concrete beam.

Comparable reinforcements has been proven by implementing natural fiber such as jute, sisal, oil palm and coir fibers in terms of thermoplastic matrices and later embedded within matrices such as thermoset polymers [5]. The selection of kenaf fibers are due to great mechanical properties, low cost, low density and recyclable materials, just like other natural composite [6]. Normally the epoxy resin was strengthened by the use of graphene nanosheets and been used in ordinary Portland cement (OPC) to enhance its durability and mechanical properties of chloride resistance, water absorptivity and freeze-thaw actions [7]. The characteristics of $\pm 45^{o}$ weave in orthotropic from woven fabric composites allow to great withstanding to shear deformation of fabric materials in square units, while (0/90) degree radial direction allowed square units of fabric materials to be stretched and consider with contraction at normal direction [8]. The selection of Carbon Fiber-Reinforced Polymer (CFRP), Glass Fiber-Reinforced Polymer (GFRP) and hybrid fiber-reinforced polymer sheet applied onto the specimen in terms of simply supported beam and laboratory testing on four-point bending test were adapted [9]. The addition of CFRP length able to increase the failure load of specimens with the highest failure load of 22.23 kN for the plain concrete beam strengthened with 250 mm CFRP plate [10].

2. Methodology

This study's techniques included data collection, data processing and comparison with available synthetic composites materials of existing research.

3.1 Weaving of Kenaf Yarn

The twisted kenaf yarn was tied at the backrest and aligned with the weaver beam, then placed into the hole in the steel comb and turned over the front rest. The same methods were repeated until all warp directions were covered. The kenaf yarn was tied at the left beam, just as the previous steps in weaving in the warp direction. The steel comb was moved upward before entering the kenaf yarn in the weft direction, after which the right beam was turned over and the weave continued with the steel comb moved lower. Repeat the processes until the 0/90 plain weave architectural layer is completed, as shown in Figure 1.

Figure 1: The weaving of kenaf yarn using handloom machine

3.2 Concrete Mixing

The Department of Environmental (DOE) Method is used to create the design combination, which has a target strength of 40 N/mm^2. To avoid mixing water absorbed by aggregates and resulting in a dry mixture, water adsorption was measured and a proportion of water absorption was applied. The concrete was then poured into a 100 x 100 x 400 mm^3 plastic prism mould. After 24 hours, the concrete prisms were scraped and placed in water to cure.

3.3 Testing Specimen Installations

The KFRP sheet sizes indicated in the testing series were used to cut the weave kenaf fiber layers. As illustrated in Figure 2, the flat surface of the concrete was chosen and sanded with a grinder before adhesively bonding kenaf sheets using epoxy resin. After that, a little amount of epoxy resin is put onto the woven cloth kenaf layer and smeared with a scapper across the kenaf layer.

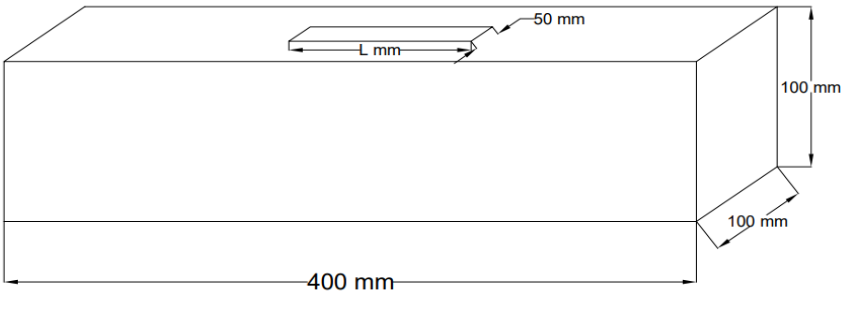

Figure 2: Adhesively bonded KFRP sheet upon concrete beam at tension zone prior to testing

3.4 Four Point Bending Test

The mechanical testing was carried out utilizing the ASTM C78 four-point bending test. The mechanical testing is carried out at UTHM's Light Structures Laboratory, which is part of the Faculty of Civil Engineering and Built Environment. To achieve quasi-static loading conditions, a loading rate of 0.1 kN per minute is used. As illustrated schematically in Figure 3, the concrete dimensions were constant, i.e. 100 x 100 x 400 mm^3 with 300 mm between end supports.

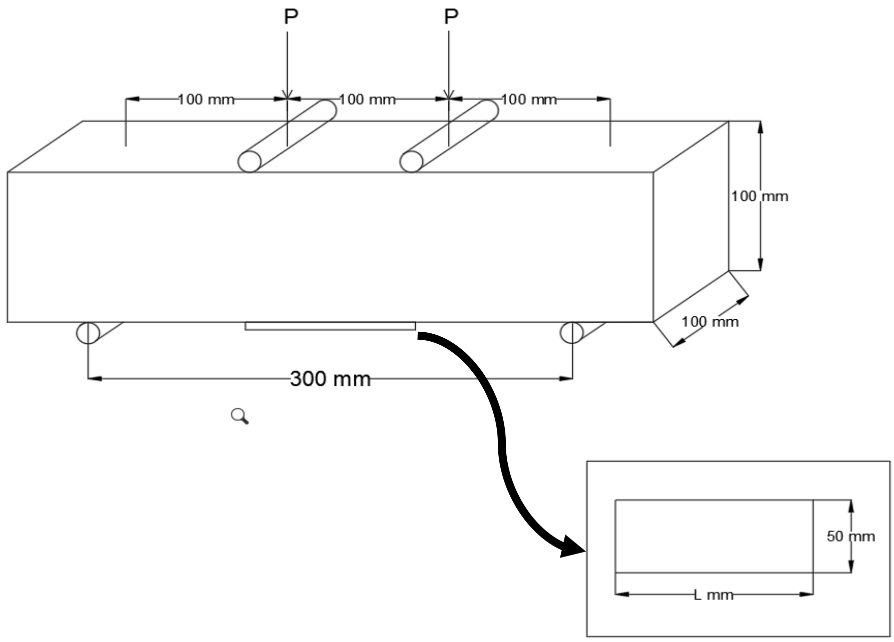

Figure 3: Concrete specimen dimensions with KFRP sheet length variation

3.5 Determination of Flexural Stress at Failure

Expression Eq. 1 is used to compute flexural strength in a four-point bending test.

$$\sigma = \frac{FL}{wd^2} \; Eq. 1$$

The maximum force applied, specimen length, specimen width, and specimen depth are represented by F, L, w, and d, respectively. In terms of stress development and flexural improvement, all of the testing series evaluated were compared to current synthetic composite materials in reinforced concrete beams.

3. Results and Discussion

The failure mode of the plain concrete beam and associated load-displacement profile were described first, followed by the discussion on flexural stress at failure as a function of KFRP plate length. All experimental datasets of plain concrete beam strengthened with KFRP plates were illustrated and compared with plain concrete beam strengthened with available synthetic FRPs counterparts as reported in the available literatures.

4.1 Compressive Strength of Normal Concrete Grade C40

Concrete mixture was produced from DOE Method with a target strength of 40 N/mm^2. Then, three cubes of size 100 x 100 x 100 mm^3 were tested for compressive strength for 7 days and 28 days using the compressive testing machine. Table 1 shows the tested compressive cubes for the two batching conducted. The laboratory result for these researches able to achieved 89% of targeted concrete strength, recorded as 35.8 MPa. Subsequently, the average compressive strength was tracked as 47.8 MPa at 28 days where the result was in the range of targeted mean strength (40 MPa – 53 MPa).

Table 1: Result of compressive strength of concrete for Batch 1 and Batch 2

Batching No.	Compressive strength (MPa)	
	7 days	28 days
Batch 1 (9 prisms)	35.5	45.9
		47.6
		48.8
Batch 2 (9 prisms)	36	47.0
		49.9
Average	35.8	47.8

4.2 Observation of Failure Mode for Each Testing Series

The beam failure mode occurred at the beam mid-span in the directions of maximum tensile stress and known as beam fracture shown in Figure 4(a). The crack is initiated at the beam mid-span and propagated vertically to the compression concrete surface. On the other hand, as shown in Figure 4(b) the plain beam with externally strengthened KFRP plate leads to KFRP fracture. However, beam bending failure was the final cause of concrete failure, and the load was increased at this point to attain maximal strength before the strengthening laminate burst [11]. Shear failure began at the border of the adhesively attached KFRP plate and spread diagonally across the applied force. As the load increased, the plate adhered to the concrete beam's tensile surface began to hinder macrocrack (smeared crack) propagation, as seen in Figure 4(c) [12].

Shear failure is more common in concrete beams reinforced with relatively short KFRP plates. The crack was occurred at the edge of the KFRP plate in all testing series of concrete beams strengthened with 50 mm and majority of the 100 mm beam specimens. Plain concrete beams strengthened with 100 mm (just one beam specimen, two other tested beams indicated shear failures), 150 mm, 200 mm, and 250 mm KFRP plate are among the remaining testing series explored.

(a) Beam fracture (b) KFRP fracture

(c) Shear fracture

Figure 4: Experimentally final failure mode; (a) beam fracture; (b) KFRP fracture; (c) shear fracture

4.3 Load-Displacement Curve Profile

The flexural load at failure for series NB-100 was 17.65 kN, while the failure load for NB-NC (control) was 15.79 kN, according to Table 2. It demonstrates that the implementation of a KFRP plate to the plain concrete beam's outer tensile surface can improve the concrete beam's flexural strength.

The smallest standard deviation (16.94 ± 0.31 kN) comes from the NB-250 testing series, while the largest standard deviation (15.79 ± 1.69 kN) comes from the NB-NC testing series. The lower the standard deviation, the more accurate each testing series' failure load will be.

Table 2: Average failure load and standard deviation for each testing series

	Testing series	Load (kN)	Average Failure Load (kN)	Standard Deviation on Failure Load (kN)
NB - NC	NB-NC-A	14.27	15.79	15.79 ± 1.69
	NB-NC-B	17.61		
	NB-NC-C	15.50		
NB - 050	NB-050-A	14.89	16.34	16.34 ± 1.57
	NB-050-B	16.12		
	NB-050-C	18.01		
NB - 100	NB-100-A	16.93	17.65	17.65 ± 0.68
	NB-100-B	18.29		
	NB-100-C	17.72		
NB - 150	NB-150-A	17.48	17.45	17.45 ± 0.48
	NB-150-B	16.95		
	NB-150-C	17.91		
NB - 200	NB-200-A	18.89	17.61	17.61 ± 1.30
	NB-200-B	16.29		
	NB-200-C	17.64		
NB - 250	NB-250-A	16.92	16.94	16.94 ± 0.31
	NB-250-B	16.63		
	NB-250-C	17.26		

4.4 Flexural Stress Development and Flexural Improvement

The applied force at failure was used to compute the flexural stress and flexural improvement of the plain concrete beam strengthened with KFRP plate, as indicated in Table 3. The plain beam strengthened with KFRP plate has the maximum flexural stress of 5.29 MPa, whereas the plain beam strengthened with KFRP plate has the lowest flexural stress of 4.93 MPa. The testing series of NB-050 has the lowest strength gain (10.39 %) while the NB-100 has the highest strength gain (18.45 %).

Table 3: Stress developed and strength gain for each testing series

Testing Series	Load (kN)	Stress (MPa)	Flexural Improvement %
NB-NC	15.79	4.74	-
NB-050	16.34	4.93	10.39
NB-100	17.65	5.28	18.23
NB-150	17.45	5.23	17.11
NB-200	17.61	5.27	18.45
NB-250	16.94	5.08	13.75

4.5 Comparison with Commercial Synthetic Composites

The load-displacement curve for plain concrete beam strengthened with KFRP plate were compared with extracted CFRP plate strengthening curve of similar plate length reported. The flexural stress of a plain concrete beam enhanced with Carbon Fiber Reinforced Polymer (CFRP) plate is tabulated in Table 4, which was collected from the literature [10].

Table 4: Stress developed and flexural improvement for CFRP plate [10]

Flexural strengthening plain beam using CFRP plate			
Testing series	Load (kN)	Stress (MPa)	Flexural Improvement %
F0B0L0N	18.47	6.46	-
F0B0L100N	19.73	6.91	15.97
F0B0L150N	20.43	7.15	20.08
F0B0L200N	21.42	7.50	25.90
F0B0L250N	22.23	7.78	30.66

Figure 5 shows the flexural improvement (%) of KFRP plate strengthening plain concrete beams against CFRP plate strengthening plain concrete beams. In comparison to commercial synthetic composite fibers such as carbon fiber, kenaf composite fiber has a lower tensile strength. As a result, the plain concrete beam enhanced with the KFRP plate has a lesser strength gain than the concrete beam reinforced with the CFRP plate. It can be concluded that concrete beams is not showing increasing trends to flexural strengthening as KFRP plate increased as larger KFRP length are demonstrating KFRP flexural failure, opposed to delamination failures in CFRP plate strengthening series.

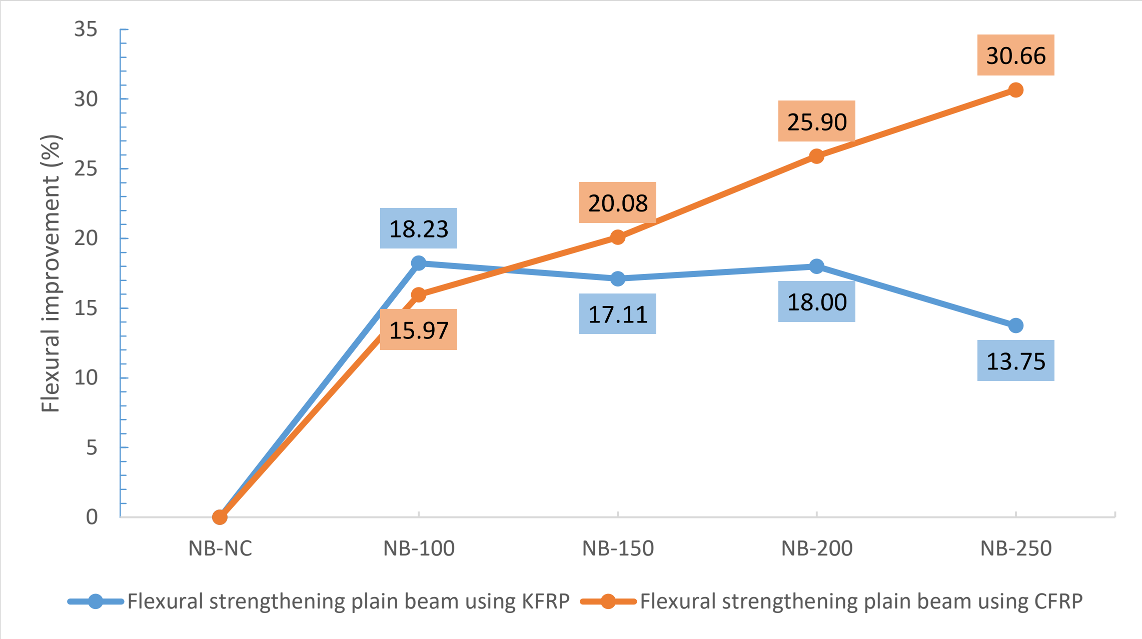

Figure 5: Comparison in the flexural strengthening of the plain concrete beam using KFRP plate and CFRP plate

4. Conclusion

When compared to other testing series, the plain concrete beam strengthened with a 100 mm length of KFRP plate had the highest flexural strength, but no significant trends were visible. As the KFRP length increased more than 100 mm, low peak load at failure may resulting from larger bending from KFRP plate to increase tensile stress and hence lower load carrying capacity. When compared to an un-strengthened concrete beam, it was discovered that KFRP plate can improve flexural strengthening by up to 18%. When compared to CFRP plates used to reinforce plain concrete beams, KFRP plates have lower flexural strength as plate length increases. This is to be expected, given FRP plate ductility is only observable when the failure mode is delamination failures, as witnessed in all CFRP series recorded. Several recommendations for future research to improve the flexural performance of plain concrete beams reinforced with woven fabric kenaf composites including the improvement of woven fabric kenaf composites fabrication technique by using automated manufacturing production for consistency and dense KFRP productions. To eliminate concrete strength differences, concrete beam mixing should be done in a single batch with enough mixer capacity.

References

[1] A. Alavudeen, N. Rajini, S. Karthikeyan, M. Thiruchitrambalam, and N. Venkateshwaren, "Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation," *Mater. Des.*, vol. 66, no. PA, pp. 246–257, 2015, doi: 10.1016/j.matdes.2014.10.067.

[2] T. A. Negawo, Y. Polat, Y. Akgul, A. Kilic, and M. Jawaid, "Mechanical and dynamic mechanical thermal properties of ensete fiber/woven glass fiber fabric hybrid composites," *Compos. Struct.*, vol. 259, no. July 2020, p. 113221, 2021, doi: 10.1016/j.compstruct.2020.113221.

[3] A. F. M. Nor, M. T. H. Sultan, A. Hamdan, A. M. R. Azmi, and K. Jayakrisna, "Hybrid Composites Based on Kenaf, Jute, Fiberglass Woven Fabrics: Tensile and Impact Properties," *Mater. Today Proc.*, vol. 5, no. 5, pp. 11198–11207, 2018, doi: 10.1016/j.matpr.2018.01.144.

[4] C. C. Chu, S. C. Chew, and K. L. Nyam, "Recent advances in encapsulation technologies of kenaf (Hibiscus cannabinus) leaves and seeds for cosmeceutical application," *Food Bioprod.*

Process., vol. 127, pp. 99–113, 2021, doi: 10.1016/j.fbp.2021.02.009.

[5] S. S. Kumar, R. Muthalagu, and C. H. Nithin, "Materials Today : Proceedings Effects of fiber loading on mechanical characterization of pineapple leaf and sisal fibers reinforced polyester composites for various applications," *Mater. Today Proc.*, vol. 44, pp. 546–553, 2021, doi: 10.1016/j.matpr.2020.10.214.

[6] N. Kumar, J. S. Grewal, T. Singh, and N. Kumar, "Mechanical and thermal properties of chemically treated Kenaf natural fiber reinforced polymer composites," *Mater. Today Proc.*, no. xxxx, 2021, doi: 10.1016/j.matpr.2021.03.368.

[7] G. Ying, C. Song, J. Ren, S. Guo, R. Nie, and L. Zhang, "Mechanical and durability-related performance of graphene / epoxy resin and epoxy resin enhanced OPC mortar," *Constr. Build. Mater.*, vol. 282, p. 122644, 2021, doi: 10.1016/j.conbuildmat.2021.122644.

[8] B. Taye Wondmagegnehu, V. Paramasivam, and S. K. Selvaraj, "Micro hardness and optical microscopy analysis of textile waste/glass fiber hybrid composite material," *Mater. Today Proc.*, no. xxxx, 2021, doi: 10.1016/j.matpr.2020.12.993.

[9] N. Attari, S. Amziane, and M. Chemrouk, "Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets," *Constr. Build. Mater.*, vol. 37, pp. 746–757, 2012, doi: 10.1016/j.conbuildmat.2012.07.052.

[10] R. Z. Al-Rousan, M. A. Alhassan, and E. A. AlShuqari, "Behavior of plain concrete beams with DSSF strengthened in flexure with anchored CFRP sheets—Effects of DSSF content on the bonding length of CFRP sheets," *Case Stud. Constr. Mater.*, vol. 9, no. November, p. e00195, 2018, doi: 10.1016/j.cscm.2018.e00195.

[11] S. Said, "Advantages of Using Knowledge Management System in Public Organization," p. 145, 2013.

[12] X. Huang, J. Wang, F. Zhang, S. S. Niu, and J. Ding, "An Experimental Investigation on the Failure Behavior of a Notched Concrete Beam Strengthened with Carbon Fiber-Reinforced Polymer," *Int. J. Polym. Sci.*, vol. 2015, 2015, doi: 10.1155/2015/729320.