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Strengthening Reinforced Concrete Beams using Kenaf Fiber Reinforced Polymer Composite Laminates

Bhutta, M.A.R.[1], Nur Hafizah, A.K.[2], Jamaludin, M.Y.[1], Warid, M.H.[3], Ismail, M [3]., Azman, M.[4]

[1]Associate Professor, [3]Professor
Construction Research Centre (UTM CRC), Universiti Teknologi Malaysia, Johor, Malaysia
[2]Postgraduate Student
Department of Structure and Materials, Faculty of Civil Engineering,
Universiti Teknologi Malaysia, Johor, Malaysia.
[4]Department of Engineering, Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, International Campus, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
marafique@utm.my, fiza_johor2003@yahoo.com.sg, jamaludin@utm.my, , warid@utm.my, az_man@ic.utm.my*

ABSTRACT

This paper presents the findings of an experimental research program that was conducted to study the structural behavior of reinforced concrete (RC) beams that had been externally strengthened with various types of kenaf fiber reinforced polymer composite laminates with 50% fiber volume content. To test the flexural strength, eight beams were used; six of the beams were strengthened with kenaf/epoxy, kenaf/polyester, and kenaf/vinyl ester composite laminates while the two of beams were not strengthened and were designated as control specimens. Comparisons were made on the load-deflection, strain behavior and failure mode. The research findings indicated that all strengthened beams had improved structural performance with the maximum flexural strength increased 40% and maximum deflection reduced 24%.

Keywords. Kenaf fiber, reinforced polymer composites, strengthening laminates, strengthened beam, composite beam

INTRODUCTION

There are many existing reinforced concrete structures that need to be strengthened due to a change in function, increase in loading and construction error. The strengthening process should preferably facilitate ease in handling during erection and is able to minimize disruption to the structure and its tenants. Some conventional materials used as strengthening materials are, for instance, timber and steel. The main disadvantage of using timber is that the material can easily decay from insects or fungi attacks and it also has a lower strength. Even though steel has satisfying tensile resistance, it corrodes easily particularly if utilized for outdoor applications. Though such corrosion does not profoundly reduce the laminates' strength, it destroys the bonding between the strengthening and adhesive materials. Moreover, steel is expensive and heavy in most rehabilitation works, in which case it further complicates the handling process during erection. Other materials that can be used are from synthetic composites materials such as glass fiber reinforced polymer (GFRP). Such materials possess better engineering properties as compared to conventional materials. However, these fiber reinforced polymer (FRP) materials impose high costs during the manufacture process, installation and end-life services (Liew, 2008). Moreover, such materials are less environmental friendly (Joshi *et al.*, 2004) and can possibly cause adverse effects on human health, particularly problems related to skin and respiratory systems (Karnani *et al.*, 1997). Additionally, current pressing environmental issues on global warming (increase of carbon dioxide) have triggered rapid and drastic development of advanced materials like the natural fiber reinforced polymer composites (NFRPC) as sustainable materials for structure strengthening purposes.

The use of NFRPC as strengthening materials has been gaining the interest of many researchers as these materials provide attractive strengthening solutions for existing structures. These materials are superior to others materials in terms of the strength to weight ratio, ease in handling, sustainability and local availability. In Malaysia, government agencies like the National Kenaf and Tobacco Board are undertaking intensive research and development (R&D) endeavors on natural fibers, profoundly the kenaf plant, due to the plant's potential in replacing local tobacco. The other objective is to promote and develop the kenaf industry to include other applications. Previous research from Liew (2008), Dweib *et al.* (2006), Cutter (2008), Mesbah *et al.* (2004), Chow *et al*. (1992) and Ngatijo *et al*. (1990) cited that natural fiber has potential in structural and non-structural applications.

Kenaf is scientifically known as *Hibiscus cannabinus L.* and is closely related to cotton and jute (Hongqin *et al.,* 2007; Bismarck *et al.*, 2005). This is because the crystalline cellulose content and microfibril angles of the two fibers are fairly similar. Kenaf is cultivated for its fiber and is well suited in India, Bangladesh, United States of America, Indonesia, Malaysia, South Africa, Vietnam, Thailand, parts of Africa, and in specific parts of southeast Europe. China also has actively developed this plant and is now one of the largest kenaf producers in the world (Hongqin *et al.,* 2007). Recently, kenaf in Malaysia has been identified as one of the potential natural raw fibers to replace tobacco in manufacturing a multitude of products for the construction, automotive, textile and advanced technology sectors.

Some researchers have previously investigated the use of natural fibers as reinforcement in polymeric strengthening materials. For instance, Liew (2008) and Chew (2009) investigated the potential of unidirectional oil palm fiber polymer composites as strengthening material. The flexural strength and stiffness of the composite improved significantly when the fiber volume ratio increased. This evidence shows that oil palm fiber polymer composite is a strengthening material suitable for reinforced concrete (RC) beams. The researchers further revealed that oil palm fiber reinforced polymer composites increased the stiffness and ultimate load of ordinary RC beam. Current researches on natural short fiber are not exhaustive, but researches on continuous fibers are considerably lesser. Therefore, this study has been executed to demonstrate that continuous natural fibers are, indeed, a potential reinforcement component in polymeric materials for structural elements as well.

MATERIALS AND METHODS

Kenaf Composite Materials. The methods used to produce and test the tensile strength of each kenaf composite material strictly followed the ASTM D3039 with different types of thermoset matrices - epoxy, polyester and vinyl ester resin. A total of 5 samples for every resin type were shaped according to the standard with dimension of 25 mm x 6 mm x 200 mm. All the procedures were designed for hand lay-up system and precautions were taken into account during the fabricating process. Moreover, only longitudinal arrangement of kenaf fibers were of interest and tested in this study, since such unidirectional arrangement would be more effective in enhancing the mechanical properties of the reinforced structure. Several fiber volume fractions (10%, 20%, 30%, 40% and 50%) were investigated with Instron 5567 Universal Testing Machine. The polymer composite strain gauge series with 1 meter of prewire was used to obtain the value of strain. Slipped and defected samples were rejected. The aforementioned machine and Low Voltage Displacement Transducer (LVDT) were connected to the data logger, TDS-303, to obtain test results from the computerized control systems. The stress-strain curves were then plotted from the results using Microsoft Excel to obtain the ultimate tensile strength and Young's modulus.

Manufacture of Beams. The RC beam and concrete design were based on BS8110. The standard concrete mix design was in accordance with the Department of Environmental, British. The characteristic strength of the concrete was designed to 30 N/mm^2 and the expected concrete slump was 30-60 mm. The proportions in concrete materials, i.e., cement, water and aggregates required to meet specific strength, workability, durability, and other requirements are as listed in BS 5328. Figure 1 shows the detailed dimensions of beams. Trial mix was carried out prior to the actual testing and involved a total of 18 concrete cubes with the size of 100 mm x 100 mm x 100 mm prepared and cured for further cube crushing test. This test was specifically conducted to obtain the compressive strength of the cured concrete after 7 days, 14 days and 28 days.

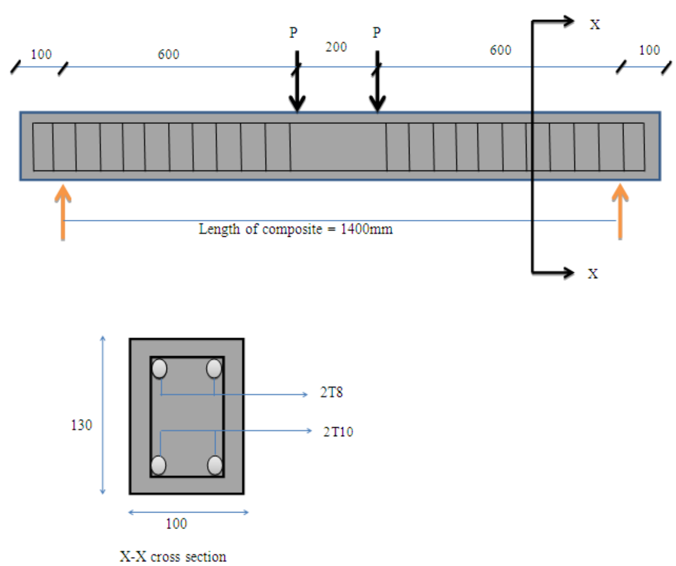

Figure 1. Beam dimension

Manufacture of Composite Strengthening Laminates. A total of six kenaf fiber composite laminates (100 mm x 6 mm x1400 mm), as shown in Figure 2, were prepared according to the method used to prepare the composite samples. However, this process is more manpower demanding. Constraint also lies in the period of composites polymerization where precautions have to be seriously taken into consideration. The strengthening laminate was glued onto the soffit of the RC beams after both contact surfaces were roughed down.

Figure 2. Kenaf fiber composite laminates

Test on composite beams. The composite beam samples were prepared and tested according to BS (EN) 1504-4:2004. A total of six beams strengthened with composite laminates were tested under a four-point load system. Two beams were not strengthened to serve as control samples. Before the test was conducted, three concrete strain gauges and two polymer composite strain gauges were glued respectively onto the top and side surfaces of every RC beam and the surface of strengthening composites laminates as shown in Figure 3. Each beam's symmetrical cross section (neutral axis) was taken as the reference line to determine the locations of strain gauges at the side of all beams using the common transformed-section method.

(a) (b)

Figure 3. Location of strain gauge- (a) Side surface of the beam. (b) Polymer strain gauge on strengthening composites laminate.

Three LVDTs were used and placed at selected positions in order to measure the deflection of beams. Two LVDTs were placed directly under the applied force and a LVDT was placed at the middle span of the beams. The LVDT, 300 kN of load cell and all strain gauges were connected to the TDS-303 data logger. Subsequently, the four-point bending test was set up by arranging the beam at the correct position. The reading of strain gauge and displacement were recorded every 1 kN increment of load. All samples were tested until the subjected load started to reduce and maximum displacement at the middle span had been reached. The structural failure mode was observed visually and the cracks were marked at every load increment.

RESULTS AND DISCUSSION

Mechanical Properties of Composite Materials. The ultimate tensile strength of composites with different type of resins, viz. Kenaf/Epoxy composites, Kenaf/Polyester composites and Kenaf/Vinyl Ester composites are presented in Figure 4. The Kenaf/Epoxy composites had higher ultimate tensile strength than Kenaf/Polyester composites and Kenaf/Vinyl Ester composites when the fiber content was up to 40%. However, all composites showed similar ultimate tensile strength at 50% fiber content; the Kenaf/Epoxy composites had an ultimate strength of 78.34 MPa, whereas those of Kenaf/Polyester composites and Kenaf/Vinyl Ester composites were recorded at 76.67 MPa and 78.92 MPa, respectively. Overall results showed that Kenaf/Epoxy had the highest ultimate tensile strength. It is believed that this is because epoxy resins have better mechanical properties as compared to others. Additionally, the results showed that the overall kenaf composites' performances improved with increasing fiber content. Similar findings had been observed by Ku *et al.* (2011) and Seki (2009).

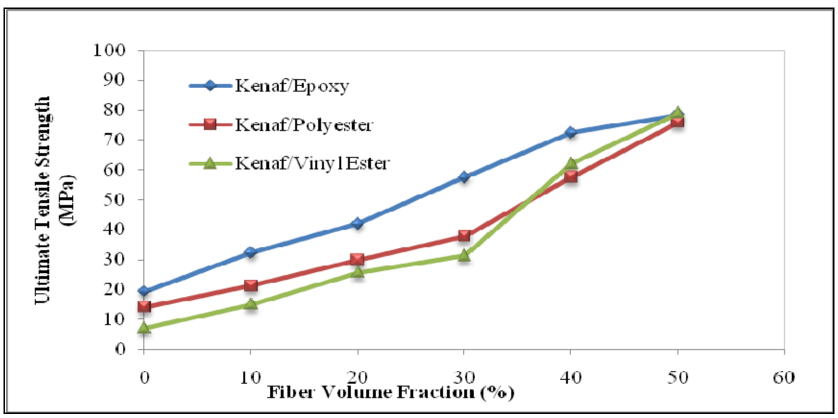

Figure 4. Ultimate tensile strength of kenaf fiber reinforced polymer

The Young's modulus of kenaf fiber reinforced polymer composites were measured at the initial slope of the stress-strain diagram and presented as shown in Figure 5. The Young's modulus, E, of Kenaf/Epoxy composites, Kenaf/Polyester composites and Kenaf/Vinyl Ester composites exhibited inconsistent trends since their ultimate tensile strength, σ, did not show consistent increments when the fiber contents increased. Kenaf/Epoxy composites at 0% to 50% fiber volume fraction showed higher Young's modulus as compared to other composites. Meanwhile, the Young's modulus of Kenaf/Polyester composites and Kenaf/Vinyl Ester composites had similar properties. These results corresponded to those of ultimate tensile strength (UTS) in Figure 4. Based on Figure 5, it can be said that the Young's modulus increases with increasing fiber content up to 30% fiber volume fraction for all the composites. Beyond that, the Young's modulus fluctuates due to the effects of fibers arrangement and viscosity of resins.

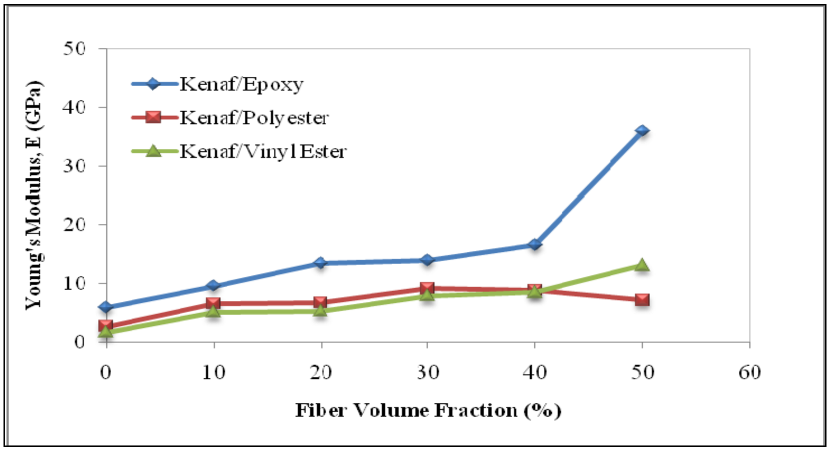

Figure 5. Young's modulus, *E*, of kenaf fiber reinforced polymer composites

Load-Deflection Behavior of Beam. Figure 6 shows the average maximum load and average maximum deflection for different types of strengthened beams and control beams. All strengthened beams had improved maximum flexural strength and maximum deflection of approximately 40% and 24%, respectively. This performance corresponded with the behavior of composites materials as shown in Figure 4. Concurrently, this has proven that with up to 50% of fiber content, the performance of all composite materials resemble each other to a certain extent. Different performance was, nevertheless, observed in control beams. These control beams exhibited ductile behavior after achieving maximum load whereas other beams demonstrated brittle behavior; the beams failed abruptly at maximum load. It could also be inferred that all strengthened beams, in general, had been over-reinforced. Nonetheless, all strengthened beams had increased structural stiffness as compared to control beams. This shows that kenaf fiber reinforced polymer composites laminates have the potential to be used as strengthening materials where it can increase the bearing capacity and stiffness of RC beams.

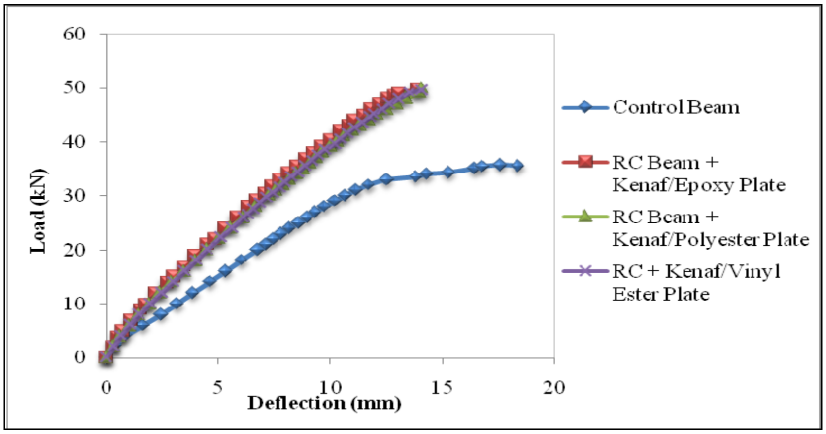

Figure 6. Load – deflection behavior of strengthened beams and control beams

Stress-Strain Behavior of Composites Strengthening Laminate. Figure 7 shows the stress-strain behavior of composites strengthening laminates during flexural action. Its failure mode further supported the fact that all composites strengthening laminates were brittle. Kenaf/Epoxy composites laminate had higher strength if compared to the others. Meanwhile, Kenaf/Polyester composites laminate and Kenaf/Vinyl Ester composites laminate had approximately the same strength. The same characteristics were discovered during material development.

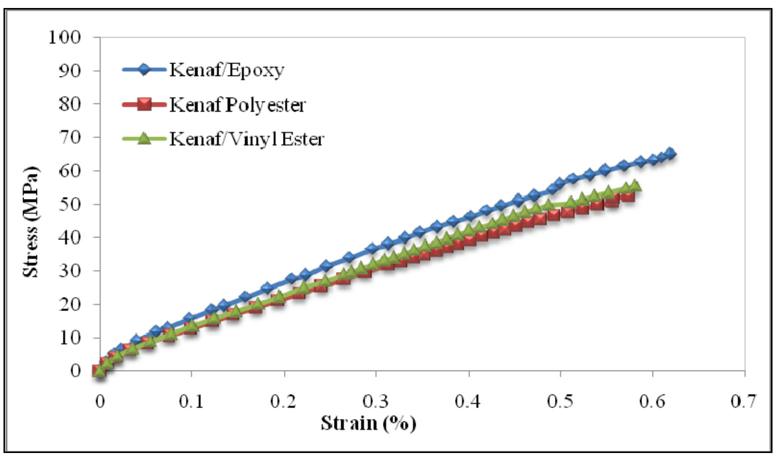

Figure 7. Stress-strain behavior of kenaf composites strengthening laminates

Strain Behaviour at Different Depth of Beam. Figure 8 shows the summary of strain blocks for all beams under scrutiny at 30 kN load. The figure shows that the locations of neutral axis for the strengthened beams were different to those of control beams, but the strain in compression zone maintained. The RC beams strengthened with Kenaf/Epoxy composites laminate (2644 $\mu\varepsilon$), Kenaf/Polyester composites laminate (1437 $\mu\varepsilon$) and Kenaf/Vinyl Ester composites laminate (1621 $\mu\varepsilon$) had lower strain values than control beams (3244 $\mu\varepsilon$) with 30%, 56% and 50% of reduction, respectively. This situation indicated that the RC beams strengthened with composites laminate had improved structural stiffness. In addition, the strain for RC beam strengthened with Kenaf/Epoxy composites laminate was higher than that strengthened with Kenaf/Polyester and Kenaf/Vinyl Ester. On top of that, it had the highest plasticity as well.

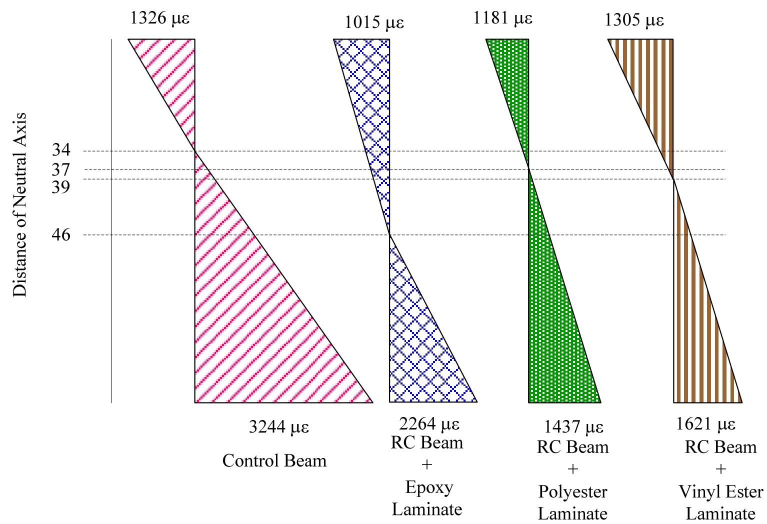

Table 8. Failure modes for control and strengthened beams.

Mode of Failure. Flexural failure occurs when the shear span/depth ratio exceeds the value of 6 ($a_v/d > 6$). Firstly, vertical cracks were initiated at the middle of the beam span before shear cracks were formed. Then, ultimate failure took place. The results as shown in Table 1 summarize that all composite beam failures occurred after the rupture of the composites laminates (Figure 9). However, ultimate failure of RC was due to bending failure of the beams and at this stage, the load was increased to achieve ultimate strength before the strengthening laminate ruptured. The functionality of beams was carefully assessed when the strengthening laminates were mobilized to resist the loading before structural failure occurred (David and Sami, 2008). It means that, failure is only established when the composites rupture and the fibers fracture before the beams crash (Xiong *et al*., 2004). In this study, such situation had been noticed at the middle span which had maximum moment during the flexural test. Peel off and debonding of the concrete surface were overlooked to concentrate on the performance of composites laminates under flexure action, similar to that done in the study of Khaled and Amir (2009).

Figure 9. Structural failure mode

Table 1. Structural failure mode

Specimen	Sequence of Failure Mode	Remarks
Control Beam	1) Vertical cracking 2) Crushing of concrete at compression zone	Normal failure mode of ordinary RC beam
RC Beam + Kenaf/Epoxy Laminate	1) Vertical cracking 2) Rupture of composites laminates 3) Crushing of concrete at compression zone	Material failure
RC Beam + Kenaf/Polyester Laminate	1) Vertical cracking 2) Rupture of composites laminates 3) Crushing of concrete at compression zone	Material failure
RC Beam + Kenaf/Vinyl Ester Laminate	1) Vertical cracking 2) Rupture of composites laminates 3) Crushing of concrete at compression zone	Material failure

CONCLUSIONS

The properties of kenaf fiber reinforced polymer composites and their potential as strengthening materials are established as follows:

1. The Kenaf/Epoxy composites had the highest ultimate tensile strength compared to Kenaf/Polyester composites and Kenaf/Vinyl Ester composites. All composites' strength gradually increased when the fiber volume fraction increased.

2. Kenaf/Epoxy composites with up to 50% fiber volume fraction exhibited the highest Young's modulus. Meanwhile, the Young's modulus of Kenaf/Polyester composites and Kenaf/Vinyl Ester composites were approximately the same.
3. All strengthened beams behaved in brittle manner while the control beam behaved in ductile manner. All strengthened beams also had increased structural stiffness compared to control beams with their flexural strength improved about 40% for average ultimate load and the average maximum deflection reduced by 24%.
4. The vertical cracks appeared during the initial failure until the end of structural failure and it increased when the load increased. Additionally, rupture of composites strengthening laminate was observed during flexural test.
5. The ultimate load capacity and stiffness of the RC beams increased when kenaf fiber reinforced polymer composites were used.
6. All evidences indicate that kenaf fiber reinforced polymer composites can be used as strengthening materials for RC beams.

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