APPLICATION OF BAMBOO FIBRE COMPOSITE IN STRUCTURAL STRENGTHENING

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Abstract
Fibre reinforced polymer (FRP) is the most commonly used for structural strengthening, however, it requires high energy consumption to manufacture and non-environmental friendly. Alternatively, natural fibres such as bamboo, which has a high tensile strength characteristics may be used. However, limited study on the use of bamboo fibre as external structural strengthening is available. This paper presents the application of bamboo fibre vinyl-ester composite plate (BFVCP) for the strengthening of reinforced concrete (RC) beams. In this study, fibre volume fraction ranging from 0% to 40% were considered. The effect of volume fraction on the flexural and tensile strength of the composite plate was evaluated through mechanical test. The structural behaviour of RC beams was tested to failure using a four-point bending. BFVCP were applied externally in the beam's mid-span of the bottom soffit to study the structural strengthening in flexure. Results showed that the highest tensile strength of the specimen was obtained using the fibre volume fraction of 40%. Strengthening of RC beam using BFVCP successfully re-gained about 2% of the original beam structural capacity, when applied to the weakened beam in flexure along the tension zone. Strengthening by BFVCP has diverted the vertical cracks at the mid-span to the edge of the plate. Result from this study shows that BFVCP may be used for weakened beam external strengthening.

Keywords: *Bamboo fibre; Composite; RC beams; Strengthening; Vinyl-ester*

INTRODUCTION

Natural fibre composites made from agricultural plants such as kenaf, jute, sisal, mengkuang and bamboo are gaining attention in structural application recently (Tong et al. 2017). They are used as an alternative to the commonly used external strengthening material such as the fibre reinforced polymer (FRP) (Ali et al., 2016). Although FRP offers many advantages such as high tensile strength and lightweight, however, the drawbacks such as high cost and impact to the environment during production opened an avenue to the use of natural fibre composites (Chin et al., 2012; Chin et al., 2016). Natural fibre derived from kenaf (Abdul Rahman, 2011), jute (Alam et al., 2015), pineapple leaves (Chin et al., 2018), mengkuang leaves (Chin et al., 2018) were used as composite plate for strengthening of reinforced concrete (RC) beams, but none on bamboo fibre composite. Most of the studies employed bamboo as reinforcement in structural elements (Tan et al., 2017) but limited study on the use of bamboo fibre (Tong et al., 2018) especially as composite material for external structural strengthening (Lim 2017).

Strengthening of RC beams are usually conducted either in the weak location, such as in flexure and shear zone of the beam. Sen and Jagannatha Reddy (2013) investigated the use of natural jute fibre textile reinforced composite system for flexural strengthening of RC beams. Hafizah et al. (2014) studied kenaf fibre reinforced polymer composites for strengthening RC beams in flexure with 50% fibre volume fraction. The length of composite used in this study was 1400 mm along the tension zone (within the support). The size of the composites was

100 mm × 6 mm × 1400 mm. Findings showed that the strength of kenaf fibre composites gradually increased with increasing fibre volume fraction, while kenaf-epoxy composite exhibited the highest Young's modulus at 50% fibre volume fraction. Apart from that, sisal fibre composites and sisal fibre rods were also utilized for flexural strengthening of RC beams by Khan et al. (2016). Two different strengthening configurations were adopted which include sisal fibre composites and sisal fibre rods. They reported that sisal fibre rod is more effective than the composites. The ultimate load of the RC beams increased 65% with sisal FRP rods compared to the un-strengthened beams (Khan et al., 2016). Kenaf fibre hybrid composite plates were tested for potential application in shear strengthening of RC beams by Alam et al. (2016). The composite plates were fabricated using kenaf and carbon fibre with 5 different mixes. They found that carbon addition enhanced the tensile strength of the plates. The hybrid composite plate with 10% carbon content gives 130% higher tensile strength compared to those without carbon content. From the aforementioned past studies, it was noticed that kenaf, jute and sisal fibres were given much attention for structural strengthening. However, there was a limited study on bamboo fibre for structural strengthening. Hence, in this work, bamboo fibre was mixed with vinyl-ester to form a polymer composite RC beams strengthening in flexure. The mechanical properties such as flexural strength and tensile strength is evaluated. The structural behaviour of beam strengthened by bamboo fibre vinyl-ester composite plate (BFVCP) are also studied.

METHODOLOGY

Preparation of Bamboo Fibre

Bamboo Semantan (*Gigantochloa scortechinii*) obtained from Raub, Pahang is used in this study. The freshly harvested bamboo was dried and soaked with 10% of sodium hydroxide for about 48 hours in order to obtain a suitable bamboo fibre (Tong et al., 2017). The bamboo strip is roll milled to obtain monofilaments. The fibre has a density of 0.890 g/cm^3. The bamboo node may reduce the mechanical properties of the composite plate, thus the fibre was cut into a length of 450 mm to avoid the node. The extracted fibres were then washed with distilled water to remove the impurities on the surface of the fibre until the pH value was neutralized into the optimum range of pH 5 to 6. Subsequently, the fibres were dried in an oven with a temperature of 60 °C for 24 hours, before placing in a desiccator before further use.

Polymer Matrix

Vinyl-ester resin was used as a binder in this study with a density of 1.05 g/cm^3. Cobalt accelerator and methyl ethyl ketone peroxides (MEKP) hardener were mixed gently with vinyl-ester during the fabrication of the composite plate. The mix ratio of vinyl-ester to MEKP and cobalt used was 100: 2: 0.1. The mixing procedure must be carried out in sequence, firstly by blending vinyl ester and cobalt under intense stirring for 5 minutes, followed by the MEKP addition and stirring for another 5 minutes.

Fabrication of BFVCP

In the present study, hand lay-up method was adopted for composite fabrication at room temperature. Stainless steel moulds were used to cast the BFRCP plates. Five different fibre volume ratios of BFRCP including 0%, 10%, 20%, 30% and 40% were fabricated. Various sizes of BFRCP were fabricated and tested. For the flexural test, the BFRCP with a dimension of 12.7 × 127 mm, and 4 mm thick plate was used, whereas for tensile test, a dimension of 25 × 250 mm, and a thickness of 3 mm was prepared. The plate strengthening at soffit of flexural zone of RC beam has a dimension of 120 × 450 mm, with thickness of 10 mm.

The mould releasing agent (honey wax) was applied to the mould and Teflon paper was put underneath the bottom part of the mould to avoid adhesion between the composite plate and the mould. The vinyl ester resin and the bamboo fibres were arranged across the mould uniformly and layer sequentially. At first, a thin layer of vinyl ester was poured into the steel mould, followed by a layer of unidirectional bamboo fibres. After that, the second layer of resin was poured on the previous surface of bamboo fibres for interfacial bonding. Subsequently, another layer of bamboo fibres was then placed over on the previous layer. These steps were repeated until the thickness of the plate considered in this study was obtained. The final step of the fabrication was compression of the composite plate after the required thickness of the plate had been achieved. The fabricated BFRCP were cured at room temperature for 24 hours before post-cured in oven with the temperature of 110 °C for about 4 hours and kept in a desiccator for 24 hours.

Reinforced Concrete Beam

The test comprises of three RC beams which includes a solid beam as control beam (CB), RC beam for strengthening with bamboo fibre vinyl-ester composite plate (VSSB) and beam without strengthening with bamboo fibre vinyl-ester composite plate (VUSB), respectively. In this study, all the beams were in the dimension of 120 × 300 mm with a length of 1500 mm. All the beams were reinforced with two steel rods of 10 mm diameter at both the tension and compression zones. Shear link using 6 mm diameter steel rod with spacing of 100 mm center to center were placed on the full length of the solid beam. The shear link was omitted in the flexure zone to evaluate the effectiveness of the BFVCP. Ready-mixed concrete of grade 30 MPa was used in this study. Figure 1 shows a schematic diagram of the reinforcement arrangement without a shear link in the mid-span of the beam. All the beams were tested to failure using a four-point bending.

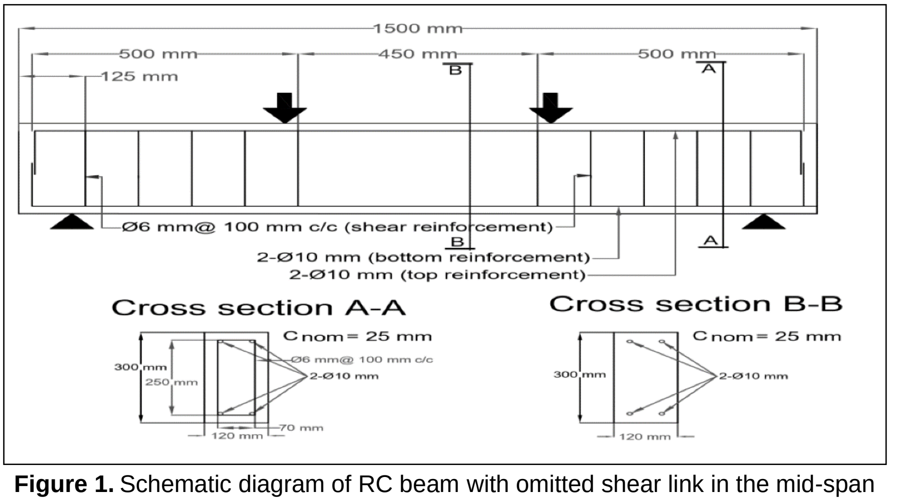

Figure 1. Schematic diagram of RC beam with omitted shear link in the mid-span

Mechanical Properties Tests

The flexural strength test was conducted using a Universal Testing Machine (UTM) with the capacity of 5 kN. The composite samples were prepared in accordance to standard ASTMD790-03 with fibre ratio ranging from 0% to 40% in order to determine the most effective fibre loading of bamboo fibre reinforced composite plate (BFRCP). The size of composite plates for flexural test were in the dimension of 127 × 12.7 mm, and 4 mm thick. The flexural test was performed via three-point loading where the load imposed to the mid-span of the samples until failure. Similarly, tensile strength test of the composite plate samples was conducted using a 5 kN UTM. The composite samples were prepared in accordance to ASTM D3039 with fibre ratio ranging from 0% to 40%. The fibre to volume ratio that gave the strongest sample was chosen to prepare the strengthening plate for RC beam. The composites were in a dimension of 250 × 25 mm, and thickness of 3 mm. A uniaxial load was applied at the ends of the composite with a test speed of 5 mm/min.

RESULTS AND DISCUSSION

Flexural Strength of BFVCP

The flexural strength provides an information about the bending strength of the bamboo composite material. The flexural test is needed to evaluate the strengthening potential that may be gained from the BFVCP application. Table 1 summarizes the result of ultimate flexural strength and peak load for different volume fractions of BFVCP under three-point loading test. It was found that, a neat vinyl ester plate (0% fibre) has the lowest ultimate flexural strength. The sample with fibre volume fractions ranging from 10% to 40% showed significant improvement of flexural strength of 104.7%, 140.2%, 240.4% and 271.6%, respectively, compared to the neat vinyl-ester plate. The result proves that bamboo fibre increases the flexural strength of the vinyl-ester plate. The strength of pure vinyl-ester plate is quite low (37.9 N/mm^2), because the polymer atom on its own has a limited flexural strength. Addition of bamboo fibre provides a strengthening reinforcement to the vinyl-ester polymer due to the bonding between the polymer and bamboo fibre microstructure. The flexural strength was observed to increase proportionally with the fibre volume fraction added in a manner similar to those reported by Hafizah et al. (2014) for the case of polymer-kenaf fibre composite. The extent of strengthening by the bamboo fibre is unknown, because in this work the flexural strength keeps increasing with increasing fibre load. However, most of the practical natural fibre composite application often uses the ratio of about 10% to 40%, therefore in this work the test is limited to 40% fibre loading. Moreover, at a higher fibre loading, the outer layer of the fibre will be exposed to moisture absorption, hence may cause a deterioration of the fibre for a long-term use.

Table 1. Flexural strength of BFVCP

Fibre volume fraction	Peak Load (N)	Ultimate Flexural strength (N/mm^2)
0	120.6	37.9
0.1	246.6	77.6
0.2	289.7	91.1
0.3	411.3	129.1
0.4	475.7	141.0

Tensile Strength of BFVCP

Figure 2 shows the comparison of tensile strength in terms of stress vs. strain for various fibre volume fractions. It was found that the sample with fibre addition has a significantly higher tensile strength than the neat polymer. The BFVCP containing 40% fibre gave the highest tensile strength (990 MPa). The result from the test performed in this work shows the tensile strength increases with the fibre loading, but the extent of the strengthening effect is unknown. As mentioned earlier, the most practical fibre loading for polymer composite application ranging from 20% to 40%. Moreover, composite with more than 60% fibre content tend to be brittle (Ngo et al., 2014), hence not suitable as strengthening material. Therefore, in this work the test is limited to 40% fibre loading and further test was made using the mix with strongest flexural and tensile strength, i.e. 40% fibre.

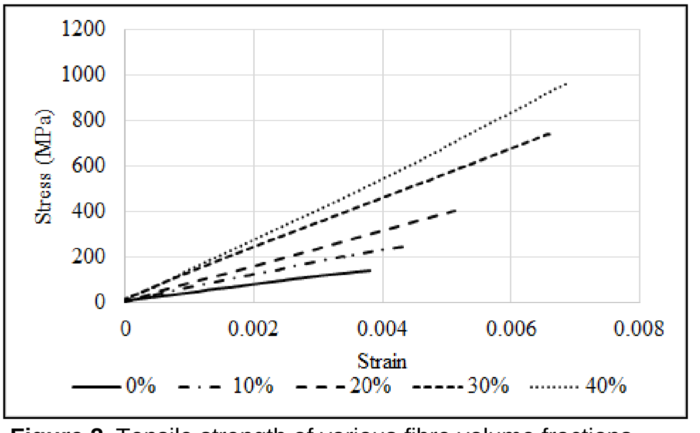

Figure 2. Tensile strength of various fibre volume fractions

Strengthening of RC Beams with BFVCP in Flexure

The effect of BFVCP on structural strengthening was studied by comparing the strength of a control beam (CB) to that of weakened beam, i.e. with shear link omitted in the flexural zone, denoted as unstrengthened solid beam (VUSB) as well as RC beam strengthened with BFVCP (VSSB). The BFVCP was placed in the flexural zone at the bottom soffit of the beam. All the beams were tested to failure under four-point loading. Table 2 summarizes the results of ultimate load from the four-point loading test. Figure 3 shows the comparison of load-deflection curves between the control beam, beams strengthened with BFVCP and without strengthening, respectively. It was found that the omission of a shear link in the midspan of the beam VUSB showed a reduction in the load-carrying capacity, about 13.0% compared to the control beam, CB. Meanwhile, beam VSSB has shown slight re-gained in the beam capacity to approximately 2.0%, compared to the un-strengthened beam in flexure (VUSB). However, strengthening with BFVCP was unable to restore the original beam capacity of the control beam. Earlier, Hafizah et al. (2014) requires about 90% of the length of the beam bonded at the tension zone in their study on kenaf fibre polymer composite, in order to re-gain most of the beam capacity. In the case of bamboo fibre, it is not possible to fabricate a plate that covers almost the entire length of the beam because each bamboo culm is limited to about 450 mm. Hence, it was not possible to achieve a full anchorage length along the tension zone of the beam with BFVCP due to the length limitation of the fibre.

Table 2. Ultimate load of various beam specimens

Beam	Ultimate Load (kN)	Strengthening Percentage (%)	Strengthening Ratio
CB	151.9	-	
VUSB	132.1	-13 (compared to CB)	0.87
VSSB	134.9	+2 (compared to VUSB) -11.2 (compared to CB)	1.02

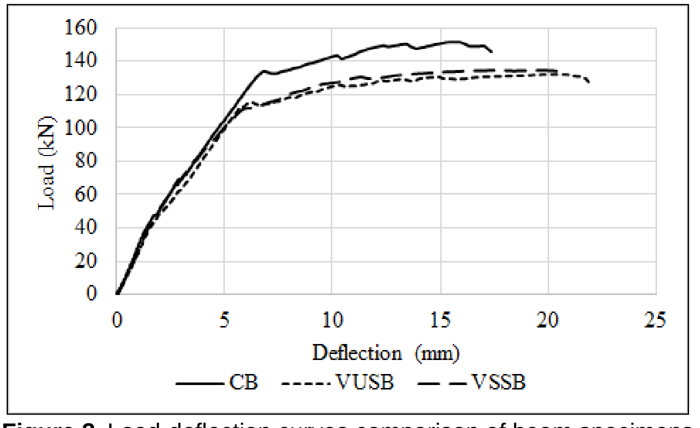

Figure 3. Load-deflection curves comparison of beam specimens

In terms of crack pattern, vertical cracks were formed along the tension zone in the mid-span of the control beam (CB) as shown in Figure 4. On the other hand, Figure 5 shows the crack pattern of VUSB. More visible vertical cracks were seen in the mid-span of the beam due to the absence of shear link. Figure 6 shows the crack pattern of VSSB. A large visible vertical crack was formed at the edge of the BFVC plate. This signifies that strengthening using BFVCP managed to divert the vertical cracks by resisting the tensile stresses in the mid-span to the end of the plate. All the beams failed in bending.

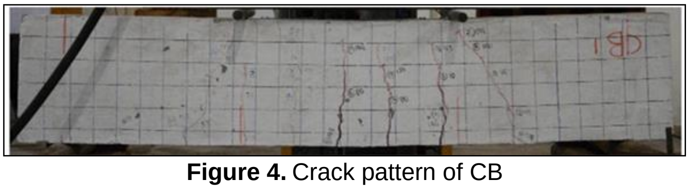

Figure 4. Crack pattern of CB

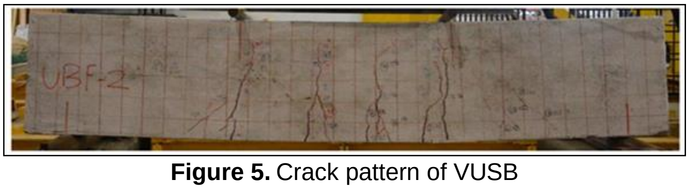

Figure 5. Crack pattern of VUSB

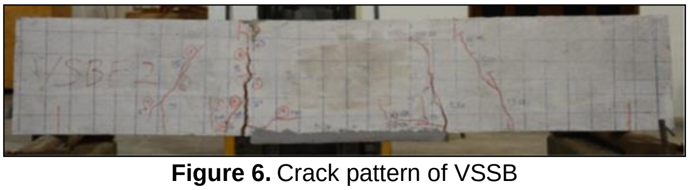

Figure 6. Crack pattern of VSSB

CONCLUSIONS

Based on the results obtained, 40% fibre volume fraction gives the highest tensile and flexural strength compared to other fibre loading. Strengthening of RC beam in flexure using BFVCP increases the load-carrying capacity of the beam without the shear link in the midspan (VUSB) by 2%. The drawback of this study is due to the short bamboo fibre length (450 mm due to bamboo culm), which causes insufficient of anchorage length bonded along the tension zone of the beam. Consequently, a limited improvement in the beam structural capacity was achieved.

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