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Strengthening Performance of PALF-Epoxy Composite Plate on Reinforced Concrete Beams

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Abstract. This paper presents the effective strengthening potential of pineapple leaves fiber (PALF)-epoxy composite plate on reinforced concrete (RC) beam. At first the PALF is treated with alkali (NaOH) and its morphology is observed via scanning electron microscope (SEM). The composite plates made of PALF and epoxy with fiber loading ranging from 0.1 to 0.4 v/v was tested for its flexural behaviour. The composite was then used for external RC beam strengthening. The structural properties of RC beams were evaluated and all the beams were tested under four-point bending. It was found that the flexural strength increased as the fiber volume ratio increases. The maximum flexural strength (301.94 MPa) was obtained at the fiber volume ratio of 40%. The beam strengthened with PALF-epoxy composite plate has a 7% higher beam capacity compared to the control beam. Cracks formed at the edge of the plate of PALF-strengthened beams resulted in diagonal cracking. Result from this work shows that the PALF-epoxy composite plate has the potential to be used as external strengthening material for RC beam.

1. Introduction

Reinforced concrete (RC) beam often suffers from degradation, deterioration, acid attack and seismic event. Rehabilitation of RC beams using an external strengthening method by installing the FRP plastic composite to the beam is one of the common retrofits method [1]. Besides the synthetic fiber, the natural fiber is getting a great attention in research since it is cost-effective and environment friendly. There are many natural fibers that can be used as external strengthening material such as sisal, jute, coir, kenaf, bamboo, oil palm fiber, sugar cane and others.

Abundant of pineapple leaf fibers are being produced and abandoned every year, with only very small portions are used as feedstock and for energy production [2]. Due to its high specific strength and stiffness behaviour, as well as abundantly available in Malaysia, pineapple leaf fiber (PALF) has a eat potential as an external strengthening material. PALF has large amount of α-cellulose (81.27%), low quantities of hemicelluloses (12.31%) and lignin content (3.46%) [3]. Due to its high compositions of α-cellulose and low microfibrillar angle, it can be reinforced in composite matrix [4]. PALF has been combined with thermoset, thermoplastic, biodegradable plastics such as polyester, polypropylene, epoxy, polycarbonate, and with natural rubber in the past.

Various investigations have been conducted to study the physical and mechanical properties of PALF fiber; however, limited study on the application of PALF-epoxy composite plate for external strengthening of RC beams [5]–[8]. Hence, this paper aims to elucidate the physical and mechanical properties of PALF-epoxy composite plates for use as external strengthening of RC beam.

2. Methodology

2.1. Preparation of PALF

The fibers were washed with running water at room temperature in order to remove the impurities in the fibers. After washing, the fibers were dried in oven at 70 ºC for 24 hours.

2.2. Chemical treatment

The fibers were then alkali-treated with three levels of NaOH concentration (2%, 5% and 8%), respectively at 30 ºC for an hour as shown in figure 1. The ratio of the fibers and the solution was 1:20 (w/v). After treatment, the fibers were washed and rinsed with tap water several times. The fibers were then dried in an oven at 70 ºC for 24 hours.

2.3. Fabrication of composite samples with different fiber volume ratios

The composite samples with fiber volume ratios of 0, 0.1, 0.2, 0.3 and 0.4 were fabricated (25 mm wide x 6 mm thick x 200 mm long), respectively by hand-laying technique as illustrated in figure 2. The specimens were tested under ASTM D790. The crosshead speed was set at 5 min^{-1}.

Figure 1. Fibers treated in NaOH solution.

Figure 2. Composite samples with different fiber volume ratios.

2.4. Fabrication of PALF composite plate

The fibers were treated with 4% NaOH, washed and dried in oven. The fibers were placed into a mould with a size 100 mm width, thickness of 8 mm and 600 mm in length by hand-layup method as shown in figure 3.

Figure 3. PALF-epoxy composite plate.

2.5. Beam preparation
A total of three beams were cast with the concrete grade 25 MPa in a dimension of 100 mm width x 130 mm height and 1600 mm in length. Two steel bars of diameter 10 mm were used as tension and compression reinforcement, respectively. Steel bars of diameter 6 mm with spacing 300 mm centre to centre were used as the shear links. The fibers were washed with running water at room temperature in order to remove the impurities in the fibers. After washing, the fibers were dried in oven at 70 ºC for 24 hours.

2.6. Fiber morphology analysis
The treated fibers were observed under SEM to study the changes in fiber surface morphology. The test was conducted using TM3030, HITACHI. The acceleration voltage used was 5 kV.

2.7. Flexural strength test
The composite samples at various fiber volume ratios described earlier in section 2.1.3 was tested for its flexural strength. The specimens were tested under ASTM D790. The crosshead speed was set at 5 min^{-1}.

2.8. Four-point bending test
The fabricated composite plate was bonded at the mid-span of the bottom soffit of the beam with Sikadur 30 epoxy adhesive. All the beams were tested to failure under four-point loading using Universal Testing Machine (UTM) at 100 kN as illustrated in figure 4.

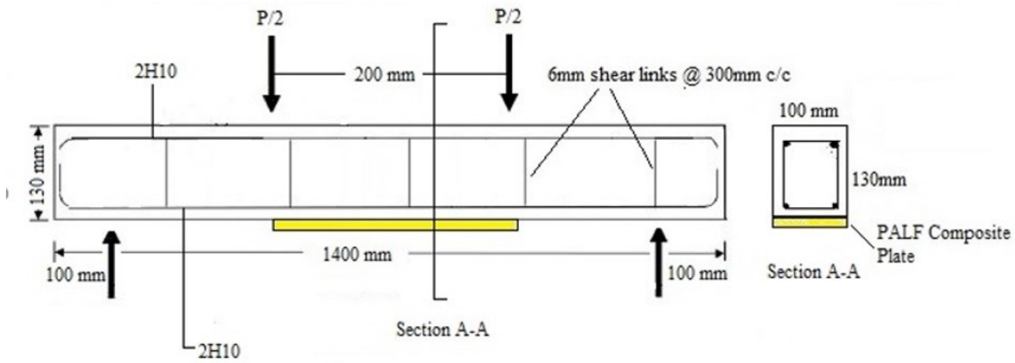

Figure 4. Schematic diagram of four-point bending test.

3. Results and discussion
3.1. Fiber morphology
The untreated fibers contained impurities such as dust as shown in the red circle in figure 5(a). NaOH treatment removed the impurities from the surface of the fibers and also partially removed the hemicellulose, lignin and other soluble materials [9]. It was observed that the presence of voids inside the fiber increases with increasing concentration of NaOH treatment.

3.2. Flexural strength of PALF-epoxy composite plate
Figure 6 shows the relationship between the flexural strength versus the fiber volume ratio. The flexural strength increases as the fiber volume ratio increased from 0.1 to 0.4. However, the fiber volume ratio of 0.1 did not exhibit significance difference compared to the neat epoxy sample.

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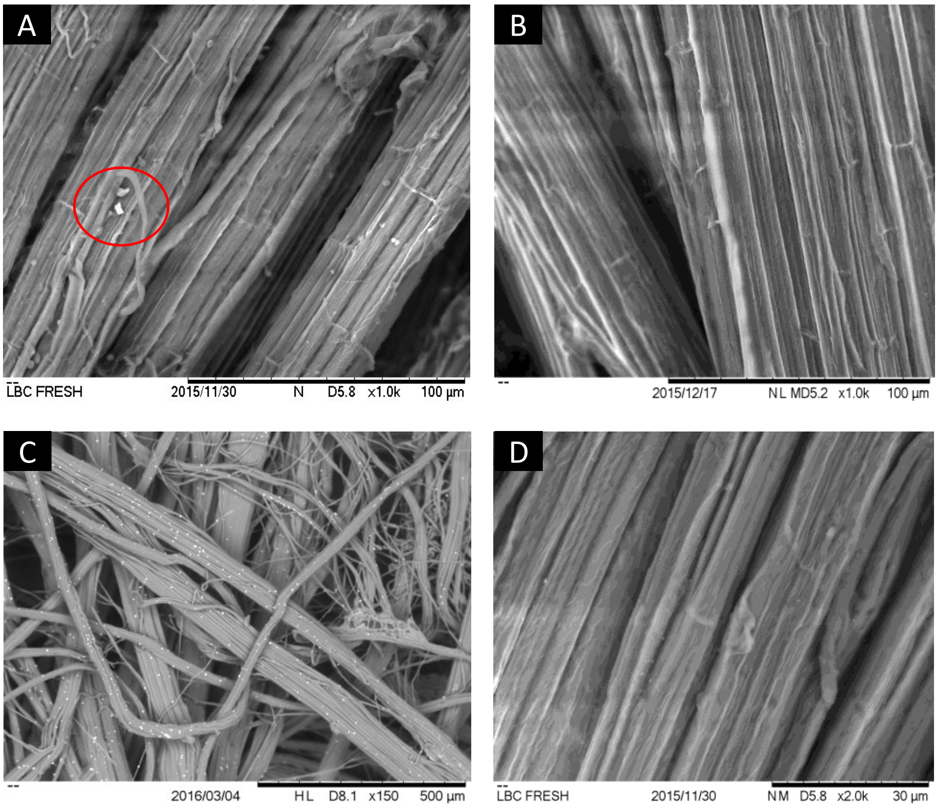

Figure 5. SEM result: (a) untreated PALF; (b) 2% NaOH treated PALF; (c) 5% NaOH treated PALF; (d) 8% NaOH treated PALF.

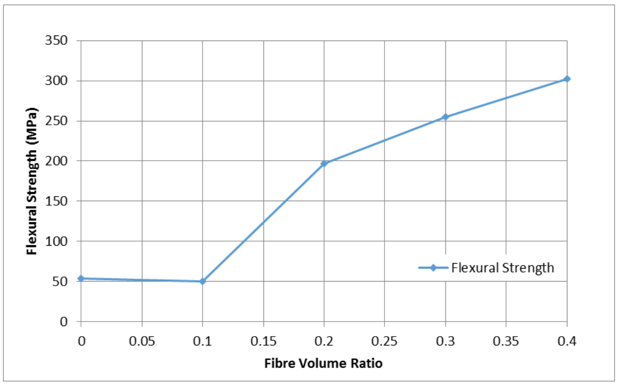

Figure 6. Load versus strain of composite plates.

The flexural strength is calculated according to equation (1).

$$\text{Flexural strength} = 3PL/2bd^2 \tag{1}$$

where L is the support span; b, the specimen width; d, the thickness; and P, the maximum load.

Table 1 summarizes the maximum peak load and flexural strength of plates reinforced with different PALF to epoxy fiber volume ratio. It was found that the flexural strength increased with the increase of PALF content. In the case of pure epoxy, the flexural strength is 54.06 MPa. The flexural strength of composite with a fiber volume ratio of 0.1 is 50.11 MPa, which decreased 7.31% as compared to the neat epoxy, due to higher elasticity of the pure epoxy plate. The flexural strength of the composite with 0.2 fiber volume ratio increased 292% as compared to the composite with 0.1 fiber volume ratio. The flexural strength of the composite with 0.3 fiber volume ratio increased 30% as compared to composite with 0.2 fiber volume ratio. Meanwhile, the flexural strength of the composite with 0.4 fiber volume ratio increased 19% as compared to the composite with 0.3 fiber volume ratio. In addition, the increase in fibre content from 20% to 40% increased the flexural strength in the range of 260% to 460% as compared to the neat epoxy. The maximum flexural strength was obtained at volume ratio 40%.

Table 1. The maximum peak load and flexural strength of plates reinforced with different PALF/Epoxy fibre volume ratio.

PALF/Epoxy Fibre Volume Ratio	Maximum Peak Load (N)	Flexural strength (MPa)
0	202.71	54.06
0.1	187.90	50.11
0.2	737.23	196.60
0.3	954.50	254.54
0.4	1132.28	301.94

3.3. Strengthening of RC beam under four-point bending

The ultimate load of the control beam and beams strengthened with PALF-epoxy composite plate is listed in table 2. The ultimate load of the control beam was attained at 15.04 kN, whereas the ultimate load of the beam specimens strengthened with PALF-epoxy composite plates, B1 and B2 were 16.14 kN and 14.68 kN, respectively, which demonstrated an increment in the beam strength by 7.3% in PALF B1 as compared to the control beam.

Table 2. Ultimate load of beam specimens.

Beam	Ultimate Load (kN)	Strengthening Percentage (%)	Strengthening Ratio
CB	15.04	-	
PALF B1	16.14	+7.3	1.07
PALF B2	14.68	-2.4	0.98

The load-deflection curve in figure 7 shows that the curve lines of the beam with PALF-epoxy composite plate exhibited a steeper slope compared to the control beam at the early stage of loading in the elastic phase. This indicates that the PALF-epoxy composite plates have a better stiffness as compared to the control beam, and hence the composite plates can resist the deformation of RC beam.

The deflection at ultimate load of the control beam was obtained at 21.30 mm, whereas the deflection at ultimate load of beam with PALF-epoxy composite plate B1 and B2 was 20.35 mm and 11.82 mm, respectively, as shown in table 3. PALF B1 strengthened beam shows about 4.5% of the mid-span deflection while PALF B2 strengthened beam shows about 45% reduction in deflection compared to the control beam. Generally, the result demonstrates that the beams strengthened with PALF-composite plates exhibited a lower deflection compared to the control beam.

Table 3. Deflection at ultimate load.

Beam	Deflection at Ultimate Load (mm)	Percentage of Deflection Reduction (%)
CB	21.30	-
PALF B1	20.35	4.5
PALF B2	11.82	45

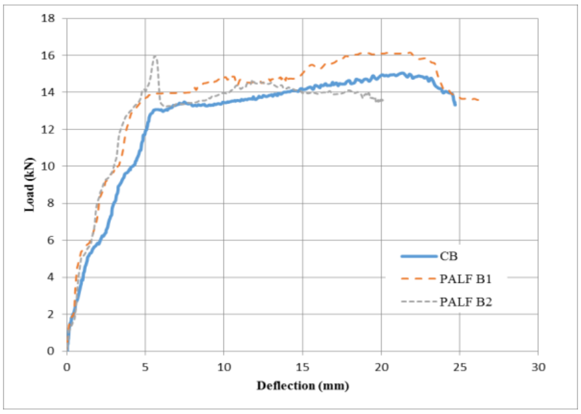

Figure 7. Load versus deflection of beam specimens.

Figure 8 shows the crack pattern of the control beam. When a load was applied to the control beam, cracks started to appear starting from the soffit of the beam and then widened when the load increased as the bottom surface of the beam was weak in tension. The first crack of the control beam appeared at the mid-span of the beam. The first crack occurred at the load of 5.72 kN. Cracks started to appear continuously as the load increased. The appearance of cracks and propagation of cracks continued to the point load with the increased of load. It was observed that a large amount of crack propagation around 13 kN of load. The propagation of cracks continued until the failure of the beam. The cracks happened at the middle of the tension zone. All the cracks were vertical flexural cracks.

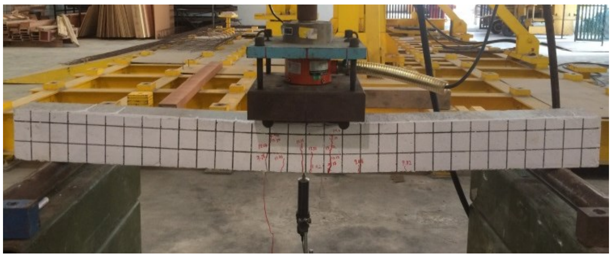

Figure 8. Crack patterns of control beam.

Meanwhile, the crack pattern of the strengthened beam with PALF-epoxy composite plate, PALF B1 is shown in figure 9. It was observed that the first cracks appeared at the load of 9 kN which can be seen at the end of the plate. The cracks at both ends continued to extend and penetrate and the crack width became wider as the load increased. As the load reaching 13.4 kN the cracks had penetrated towards the neutral axis of the beam in diagonally. However, there were very little flexural cracks formed at the mid-span of the beam at the same time. As the load continually increases, the cracks widened and two main diagonal cracks can be seen clearly at both ends of the plate. The crack width increased before beam failure. This signifies that the PALF-epoxy composite plate had resisted all the tensile stress in the mid-span and directed the cracks in the flexural zone at the end of the plate forming diagonal crack failure. Hence, the cracks in the mid-span of the beam were lesser than the control beam.

Figure 10 shows the crack pattern of beam, PALF B2. The first crack appeared at the load of 10 kN and followed by the increasing of diagonal cracks as the load increased. The cracks propagated through the neutral axis of the beam in a diagonal direction at the load of 13 kN. More cracks were developed and appeared at both ends of the plate. Very little vertical cracks were seen at the flexural zone. Wider cracks formed as load applied continuously. The beam fails with a detached of PALF-epoxy composite plate from the concrete surface as depicted in figure 10. The plate has the ability to resist and transfer the load to the region without strengthening. This caused fewer flexural cracks found at the mid-span of the beam. Large crack width identified upon beam failure at the left end of the plate was possibly due to plate end interfacial debonding.

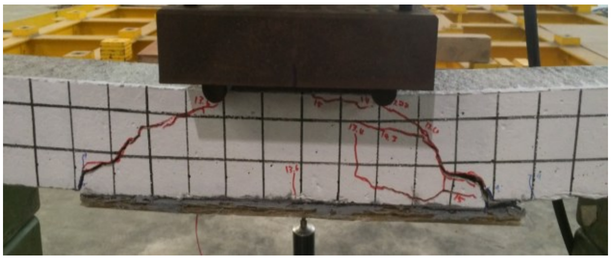

Figure 9. Crack patterns of beam PALF B1.

Figure 10. Crack patterns of beam PALF B2.

4. Conclusions

It can be concluded that the alkali treatment of fibers managed to remove impurities and binding materials, which then increased the interaction of fiber and matrix. The PALF-epoxy composites with the volume ratio 0.4 showed the best flexural properties compared to other volume ratios. Strengthening of PALF-epoxy composite plate has increased the beam strength and reduced the beam deflection up to 45% compared to the control beam. The main contribution of this research work is to study the effectiveness of using natural fiber; pineapple leaves fiber composite plate as external strengthening material in the strengthening of RC structures. From the positive aspects, it was found that this cost-effective and environmental friendly composite plate managed to increase the beam stiffness and ultimate load as well as reduce the beam deflection and cracking compared to the control beam. In terms of deficiencies, beam with PALF B2 attained an early ultimate load of 15.98 kN at a deflection of 5.59 mm as the beam experience yielding and eventually strain hardening takes places before plate end interfacial debonding. It is recommended that this work can be improved with proper surface preparation to ensure sufficient surface bonding as well as to increase the length of the PALF-epoxy composite plate.

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