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EPOXY EFB PALM FIBRE MAT COMPOSITES - THE EFFECTS OF FIBRE WEIGHT FRACTION ON MECHANICAL BEHAVIOUR

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ABSTRACT

The mechanical behaviour of empty fruit bunch (EFB) palm fibre/epoxy composite with varying percentage fibre mass fraction, M_f, was investigated. The mat was prepared by random distribution of a predefined weightage of loose fibres within the effective volume of the mould cavity, followed by wetting with epoxy resin and left to cure under compression. The EFB loaded specimens showed measurable improvement in mechanical properties as compared to pure epoxy. Composite loaded with 27% EFB fibres achieved the highest increment in the measured tensile strength (14.8%) and Young's modulus (87%). However, increasing fibre content led to a reduction in elongation at break. Similar trend was observed for flexural behaviour whereby the flexural strength and flexural modulus showed an increasing trend with the addition of EFB fibre.

Keywords: empty fruit bunch (EFB), epoxy, tensile, flexural.

INTRODUCTION

Polymer composites offer the advantages of enhanced mechanical and thermal properties at a much lighter weight. Conventional fibres such as carbon and glass are amongst the most widely used reinforcement in load bearing engineering applications. However, their high price tag has led active investigating being carried out to source for alternative materials as reinforcement. Over the past decades, there has been noticable increasing interest in employing natural resources as reinforcing materials in composite targeted for low-cost applications and consumer goods requiring secondary load carrying capacity (Kalam *et al*., 2005).

As one of the largest oil palm producers, Malaysia has abundance of EFB fibres readily available from by-product of the oil palm industry (Khalid *et al*., 2008). Compared to inorganic fillers, oil palm fibres possess great potential as one of the candidate reinforcement material due to their renewable and biodegradable origin, light weight, low cost, less abrasive, possesses high specific stiffness, and reduced dermal and respiratory irritations. In addition, composites incorporated with natural fibres could ease disposal at the end of their life-cycle through composting or by recovery of their calorific value in a furnace, making them greener to the environment and aid in enhancement of energy recovery (Kalam *et al*., 2005), (Khalid *et al*., 2008), (Alawar *et al*. 2009).

Research on unidirectional oil palm fruit bunch fibre (OPFBF)/epoxy composites with fibre volume fractions, V_f, of 35% and 55% revealed that the ultimate tensile strength and Young's modulus were nearly unaffected by the fibre loading within this range (Kalam *et al*., 2005). Studies on the mechanical properties of short and random orientated oil palm fibre (OPF)/epoxy composite with lower V_f of 5, 10, 15 and 20% showed that tensile and flexural properties of the composites decreased with an increase in fibre loading (Mohd Yusoff *et al*., 2010). Further investigation by the authors revealed that the unconventional observation was due to the lack of wettability during fabrication, leading to the reduction of bonding between fibre and matrix interfaces. On the other hand, Prasad et al. investigation on the mechanical properties of banana empty fruit bunch (BEFB) fibre reinforced polyester, with up to a maximum V_f of 37% observed significant improvement in the mean tensile strength, modulus and specific flexural modulus, recorded 36% (43 MPa), 68% (1.06 GPa) and 142% (141.7 J/m) respectively, highlighting an improved fibre-marix adhesion that facilitate better stress transfer from the matrix to fibre (Ratna Prasad *et al*., 2009).

While previous work on OPF/epoxy composite neither did not recorded much variation (Kalam *et al*., 2005) nor decreased its mechanical properties (Mohamed Yusoff *et al*., 2010), the current work aim to further investigate the effect of random EFB fibre/epoxy composite on mechanical properties through a well-controlled fabrication procedure. Fibre mass fraction, M_f, anging up to 30% was investigated in term of the ultimate tensile strength (UTS), Young's modulus, and bending stiffness.

MATERIALS AND METHODS

Oil-Palm EFB and epoxy resin

The EFB fibres, shown in Figure-1, were sponsored by Malaysian Palm Oil Board with properties shown in Table-1. The epoxy resin graded DER324, epoxy hardener and defoamer were supplied by Suka Chemicals (M). The percentage resin, hardener and defoamer of

66.6/33.3/0.1 parts by weight was employed in the current work.

Figure-1. The loose EFB palm fibre.

Table-1. The mechanical properties of EFB palm fibre.

	Values	References
Density (g/cm^3)	0.895	(Kalam et al., 2005)
	0.7-1.55	(Jawaid et al., 2010)
Tensile strength (MPa)	24.9	(Kalam et al., 2005)
	71	(Mohd Yusoff et al., 2010)
	50-400	(Jawaid et al., 2010)
	52	(Alawar et al. 2009)
Elongation at break (%)	4.0	(Kalam et al., 2005)
	11	(Kalam et al., 2005)
	8-18	(Jawaid et al., 2010)
	10	(Alawar et al. 2009)
Flexural strength (MPa)	42.4	(Kalam et al., 2005)
Young's modulus (GPa)	1.7	(Mohd Yusoff et al., 2010)
	1-9	(Jawaid et al., 2010)
	2.4	(Alawar et al. 2009)

Weight fraction

The density of composite, ρ_c, can be computed from Equation (1).

$$V_r = \frac{M_r}{M_c} \cdot \frac{\rho_c}{\rho_r} \tag{1}$$

where M_r and M_c are the mass of resin and composite respectively, V_r denote the chosen resin volume fraction and ρ_r is the resin density. These parameters were obtained from physical measurement and data provided by resin suppliers.

The fibre V_f can subsequently be converted to fibre mass fraction, M_f, through Equation (2).

$$W_f = \frac{\rho_f / \rho_r}{\rho_f / \rho_r \cdot V_f + V_r} \cdot V_f \tag{2}$$

Specimen preparation

The loose EFB palm fibres were extensively entangled with uneven branches and contain contaminants. Fine fibres were hand-picked and washed with distilled water to flush away contaminants. The cleaned fibres were left to dry in oven of heated to 60°C for 5 hours. The dried fibres were separated in accordance to V_f calculated based on the predefined mass fraction. Manual hand lay-up was adopted to form an evenly distributed rectangular fibre mat of 100 mm × 150 mm, Figure-2, which was then dried at 60°C to remove residual moisture.

Figure-2. EFB palm fibre mat prepared through hand lay-up.

Two layers of mould release agent were applied on the mould cavity. Measured quantity of the epoxy mixture was degassed for 5 minutes under suction chamber before introduced to the fibres mat laid in the mould cavity for wetting. The composite was allowed to cure for 24 hours under 740 mmHg pressure imposed from vacuum bagging. The same method was used on other composites with M_f between 0 and 30%.

EXPERIMENTAL SET-UP

Tensile test

Dumbbell specimens compliance with ASTM D638M type IV, Figure-3, were tested with LLYOD universal testing machine under a crosshead speed was 2 mm/s, at room temperature of 20°C. No preload was used and the breakage was determined when a 50% drop in load is detected.

Figure-3. Dumbbell specimens with varying M_f (from left: 0%, 4.3%, 7.8%, 10.4%, 12% and 15.2%)

Flexural test

Specimens complied with ASTM D790M were prepared with Perspex Cutter. Three-point bending test with a preload of 50N and a 64mm outer roller support span on the specimen was conducted with the aid of LLYOD universal testing machine.

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RESULTS

Tensile properties

The results demonstrated in Figure-4 and Figure-5 highlight that at 4.3% M_f, low UTS of 10MPa, 5.5% strain was recorded while the UTS experienced some 186% increment 28.6 MPa with a drop in fracture strain, to merely 2.6% for specimen with 24.5% M_f. The area under the curve reduces and the gradient becomes steeper, indicating an increase in brittleness of the composite with increase in fibre M_f.

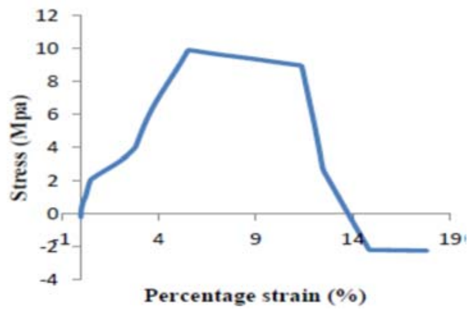

Figure-4. The stress-strain curve of specimen with 4.3% M_f.

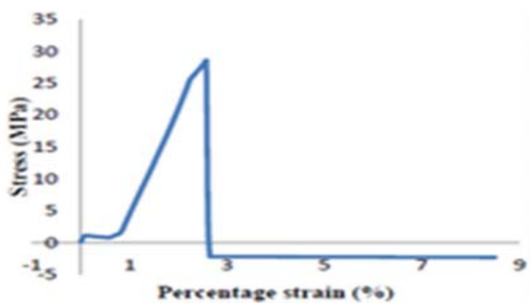

Figure-5. Stress-strain curve of specimen with 24.5% M_f.

Figure-6 shows the fracture stress against strain for composite with varying fibre M_f. It can be observed that the mechanical property of EFB composite at low M_f is inferior to pure epoxy, with a 54.7% lower in UTS on composite of 4.3% M_f. The reduction in UTS arise due to low quantity of fibre introduced and could not establish any reinforcement to the composite. Instead, this fibre tends to introduce imperfection in surface bonding and disturb effective stress transfer. In the work of Prasad *et al.*, the author reported that lower fibre loading performed more as impurities rather than reinforcement (Ratna Prasad *et al*., 2009) while Khalid and co-workers found that incorporation of filler into polymer matrix induced interruption in stress transfer in the direction of the applied force (Khalid *et al*., 2008).

Enhancement in UTS was observed with increases in M_f, where a peak could be seen in composite loaded with 27.3% M_f. This increase in UTS can be attributed to the increasing contribution from additional fibres as reinforcement and rises the effective stress transfer. Overall, the composite only showed a very small improvement in UTS due to the low mechanical properties of palm fibre as reinforcement material (Ratna Prasad *et al*., 2009).

Figure-7 shows that composite tends to be increasingly brittle with EFB fibre loading, where pure epoxy experienced the highest strain. The decrease of toughness of the composite could be related to the increases in effective stress transfer from matrix to the stiffer EFB fibre, which effectively increases the modulus of the composite with higher EFB loading, as demonstrated in Figure-8. The Young's modulus of pure epoxy is the lowest at 1.36GPa while the highest was 2.54GPa measured on composite loaded with 27.3% EFB fibre. Similar trend was observed in previous research work (Ratna Prasad *et al*., 2009). The anomaly at 7.8% and 10.4% M_f were largely attributed to random experimental error and the natural inconsistency in fibre aspect ratio, as indicated in the excessive error bars, indicating low reliability of the particular measurement.

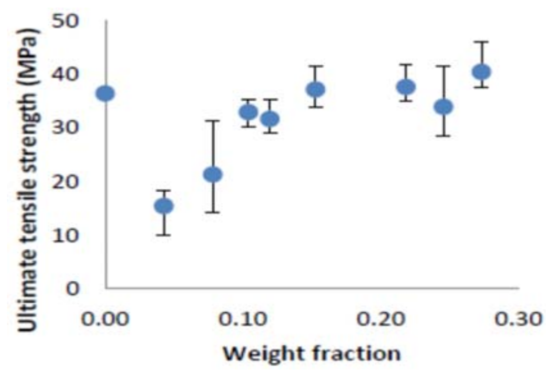

Figure-6. UTS at different M_f.

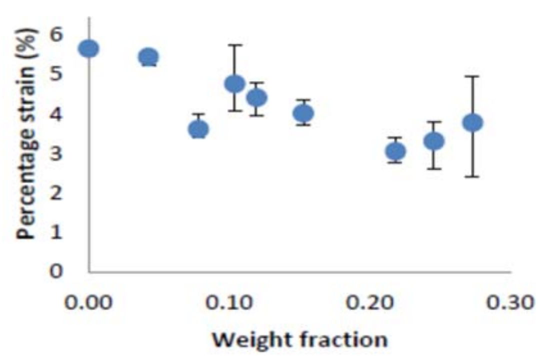

Figure-7. Strain (%) at different M_f.

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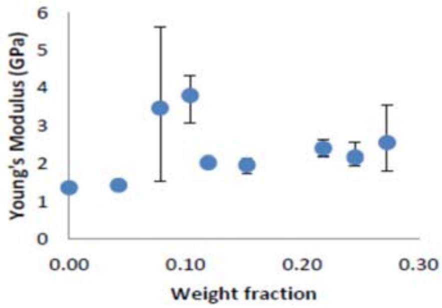

Figure-8. Modulus at different M_f.

Flexural properties

The flexural properties were calculated through classical formulation, Equation (4), where σ_f is the maximum stress at the outer surface experienced by the samples at the midpoint of a 3-point bending experiment.

$$\sigma_f = \frac{3PL}{2bd^2} \qquad (4)$$

where P is the load, L is the distance between the two support spans, b and d are the width and depth of the sample.

The tangent modulus or modulus of elasticity can be computed through Equation (5).

$$E_B = \frac{L^3 m}{4bd^3} \qquad (5)$$

where m is the tangential gradient of the initial straight-line portion obtained from the load-deflection graph.

According to ASTM D790M standard, flexural experiment is not applicable in the case where test specimen failed to demonstrate any sign of fracture. The samples with M_f of 0, 4.3%, and 7.8% did not fracture, Figure-9, during the 3-point bending test and hence are disregarded.

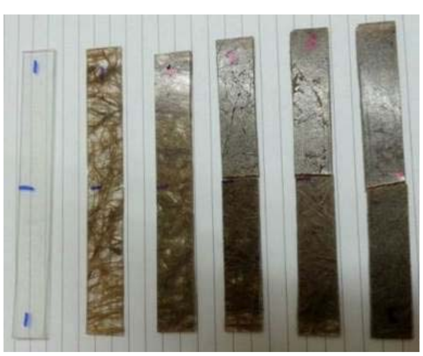

Figure-9. Flexural specimens with varying M_f.
(from left: 0%, 4.3%, 7.8%, 10.4%, 12% and 15.2%).

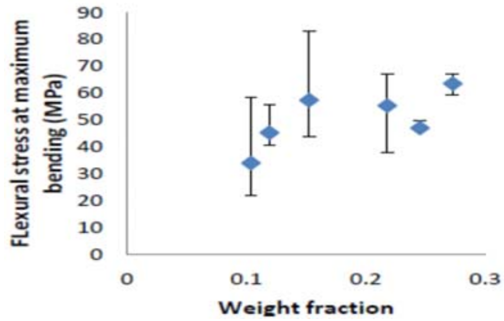

Figure-10. Flexural stress at different M_f of EFB fibre.

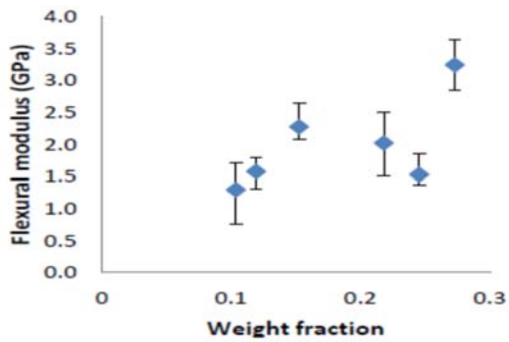

Figure-11. Flexural modulus at different M_f of EFB fibre.

Figure-10 and Figure-11 demonstrated that higher fibre loading increases the flexural properties of the composites. Specimens with 27.3% M_f showed an enhancement of 150% (3.2GPa) and 86.9% (63.5MPa) in flexural modulus and flexural stress respectively compared to composite with 10.4% M_f fibre. The overall increasing trend could be attributed to the higher stiffness of the composite due to improved fibre reinforcement with higher interfacial bonding between matrix and fibres. Similar results were obtained by Khalid *et al*. on EFB palm fibre/polypropylene (PP) composite, where the authors observed an increase of filler content caused a steady increase in flexural modulus (Khalid *et al.*, 2008).

DISCUSSIONS

The results obtained in the current paper showed similarity in trend compared to those available in the open literature (Kalam *et al*., 2005), (Khalid *et al*., 2008), (Ratna Prasad *et al*., 2009). Experimental measurement on the composites depict a rather wide range of error bars compared to pure epoxy, these deviations arise due to the nature of the palm fibres where the milling process could not effectively separate the EFB fibres into individual strand and a large proportion are still attached together in a bunch. In addition, diameter of the fibre varies from one strand to another, even along the strand itself and resulted in variation in aspect ratio, Figure-12. Therefore, the stress transfer limit of each fibre strand varies and fibre with smaller cross-sectional area tends to fail first. These factors give rise to the expected variation in the measured results. This also explained the range of fibre properties obtained from various researchers, as depicted in Table-1.

The random nature of the fibre length theoretically magnifies the significance of end effects (increased when the length to diameter ratio decreases) which causes reduced efficiency of the fibre as reinforcement, e.g. short fibre has lower length to diameter ratio and is prone to failure by fibre pull-out due to the reduced efficiency of fibre-matrix bonding. The EFB used in the current study possess a random distribution of fibre length ranging from 9 to 82mm, therefore it is expected that there exists a variation in the efficiency of fibre as reinforcement. Observation from Sumaila *et al*. [6] revealed that increases in UTS could achieved with the increase in fibre length up to an optimum value, after which the property decrease on further increase in the fibre length.

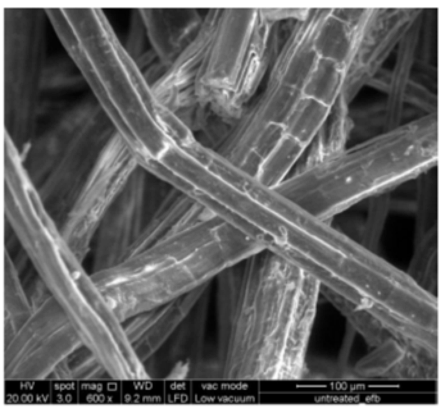

Figure-12. SEM image (600× magnification) showing the morphology EFB fibre.

Fibre orientation affects the maximum stress limit in fibre reinforced composite. Fibre aligned along the direction of applied force are more effective compared to fibre which oriented perpendicular to applied force, i.e. solely rely on the interfacial bonding between the fibre and matrix interfaces. The EFB palm fibre composites produced in the current work have a random orientation and the probability of anisotropic failure may be neglected in the current study.

The existence of the factors discussed affects the mechanical properties of EFB palm fibre mat/epoxy composite. However, within the fibre loading considered in the current study, the results obtained clearly demonstrated that increases in the fibre M_f capable of improving the mechanical properties of the EFB/epoxy composite.

CONCLUSIONS

The inclusion of EFB palm fibre into epoxy improved the overall mechanical properties of the composite in term of UTS, Young's modulus, flexural stress and flexural modulus compared to pure epoxy. Within the investigated amount of fibre loading, the 27.3% M_f produced the optimum improvement. One must note the inherent variation in the properties of natural fibres in the study of natural fibre reinforced polymer composite.

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