The Effects of Weight Fraction on Mechanical Behaviour of Thermoset Palm EFB Composite

Kim Y. Tshai, Eng H. Yap, and Tang L. Wong

***Abstract*—The mechanical properties of varying percentage mass fraction, Mf, of empty fruit bunch (EFB) palm fibre/epoxy composite, ranging from 0 to 30% was investigated. A predefined weightage of loose EFB fibre was manually distributed within the effective area of the mould cavity surface. The fibre mat was subsequently wetted with epoxy and subjected to curing under compression. Enhancement was observed in the EFB loaded composite as compared to pure epoxy. Composite with 27% of EFB showed the greatest improvement in the measured tensile strength (14.8%) and Young's modulus (87%). However, there was a reduction in elongation at break with increasing fibre loading. Similar trend was observed for flexural test whereby the flexural strength and flexural modulus showed an increasing trend with the addition of EFB fibre.**

***Index Terms*—Flexural, empty fruit bunch, epoxy, tensile.**

I. Introduction

Reinforced materials possess higher mechanical performance with a much lighter weight. Carbon and glass fibres which are amongst the most widely used reinforcement in load bearing engineering applications have a high price tag and an alternative source of fibres may provide an opportunity for development and improvement. In this respect, there are increasing interest in employing natural resources as reinforcing materials in composite for low-cost applications and consumer goods [1].

Malaysia as one of the largest oil palm producers has abundance of EFB fibres that can be obtained readily from the oil palm industry's by-products [2]. Compared to inorganic fillers, oil palm fibres are light weight, low cost, renewable, biodegradable, and less abrasive, possesses high specific stiffness, and reduced dermal and respiratory irritations. Moreover, composites with the incorporation of natural fibres are ease of disposal through composting or by recovery of their calorific value in a furnace at the end of their life cycle, making it green to environment and enhanced in energy recovery [1]-[3].

Kalam *et al*. [1] research on unidirectional oil palm fruit bunch fibre (OPFBF)/epoxy composites with fibre volume fractions, V_f, of 35% and 55% observed that the ultimate tensile strength and Young's modulus were nearly unaffected by the fibre loading within this range. Prasad *et al*. [4] investigation on the mechanical properties of banana empty fruit bunch fibre (BEFB) reinforced polyester, up to a maximum V_f of 37% shown significant improvement in mean tensile strength, modulus and specific flexural modulus, recorded a 36% (43 MPa), 68% (1.06 GPa) and 142% (141.7 J/m) respectively. Yusoff *et al*. [5] studied the mechanical properties of short and random orientated oil palm fibre (OPF)/epoxy composite with V_f, of 5, 10, 15 and 20% found that tensile and flexural properties of the composites decreased with an increase in fibre loading. Further investigation revealed that the unconventional observation was due to the lack of wettability or bonding between fibre and matrix during fabrication.

While previous work on OPF/epoxy composite neither did not recorded much variation [1] nor decreased in mechanical properties [5], the current work aim to further investigate the effect of random EFB fibre/epoxy composite on mechanical properties through a well-controlled fabrication procedure. Varying fibre composition ranging up to 30 wt% was investigated in term of the ultimate tensile strength (UTS), Young's modulus, and bending stiffness.

II. Materials and Methods

The EFB fibres, Fig. 1, were sponsored by Malaysian Palm Oil Board with properties shown in Table 1. The epoxy resin DER324, epoxy hardener and defoamer (anti-foam) supplied by Suka Chemicals (M). The resin/hardener/defoamer in the fraction of 66.6/33.3/0.1 parts by weight was employed. The composite was allowed to cure for a period of 24 hours at room temperature.

A. Weight Fraction

The density of fibres in a cured epoxy resin matrix was calculated by adopting the rules of mixture, as in (1), where V_f and V_r denote fibre and resin volume fraction respectively. The fibre V_f ranging from 0 to 0.4 was chosen.

$$V_f = 1 - V_r \quad (1)$$

The density of the composite, ρ_c, can be calculated from (2), where M_r and M_c are the mass of resin and composite respectively, and ρ_r is the resin density. These parameters were obtained from physical measurement and resin suppliers. V_r and V_f are define in (2) and (3).

$$V_r = \frac{M_r}{M_c} \cdot \frac{\rho_c}{\rho_r} \quad (2)$$

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$$V_f = \frac{M_f}{M_c} \cdot \frac{\rho_c}{\rho_f} \qquad (3)$$

The fibre V_f can be converted to fibre mass fraction, M_f, through (4),

$$W_f = \frac{\frac{\rho_f}{\rho_r}}{\frac{\rho_f}{\rho_r} \cdot V_f + V_r} \cdot V_f \qquad (3)$$

Fig. 1. The loose EFB palm fibre.

TABLE I: THE ARRANGEMENT OF CHANNELS

	Values	Researcher
Density (g/cm^3)	0.895	[1]
	0.7-1.55	[7]
Tensile strength (MPa)	24.9	[1]
	71	[5]
	50-400	[7]
	52	[3]
Elongation at break (%)	4.0	[1]
	11	[5]
	8-18	[7]
	10	[3]
Flexural strength (MPa)	42.4	[1]
Young's modulus (GPa)	1.7	[5]
	1-9	[7]
	2.4	[3]

B. Specimen Preparation

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

The initial condition of the EFB palm fibres were in tangling form, full of contaminants and uneven branches. These fibres were hand-picked to remove solid branches and washed with distilled water to flush away contaminants. The cleaned fibres were left to dry in oven of 60°C for 5 hours. The dried fibres are separated in accordance to V_f calculated based on the mass fraction. Manual hand lay-up was adopted to form an evenly distributed rectangular fibre mat of 100×150mm, Fig. 2, which was then dried in oven at 60°C to remove residual moisture. 2 layers of mould release agent were applied on the mould surfaces. Measured quantity of the epoxy mixture was degassed for 5 minutes using suction chamber prior to its application in wetting the fibres mat laid in the centre cavity of the mould. The composite was allowed to cure for 24 hours less than 740 mmHg pressure imposed from vacuum bagging. The same method was used on other composites with M_f between 0 and 30%.

C. Experimental Set-up

For the tensile experiment, dumbbell specimens of ASTM D638M type IV, Fig. 3, were tested with LLYOD universal testing machine under a crosshead speed was 2.0 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.

For the flexural experiment, specimens' compliance with ASTM D790M was prepared with a 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.

Fig. 3. Tensile specimens with varying *Mf* (from left: 0%, 4.3%, 7.8%, 10.4%, 12% and 15.2%).

III. RESULTS AND DISCUSSIONS

A. Tensile Properties

It can be shown in Fig. 4 and Fig. 5 that at 4.3% M_f, a 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.

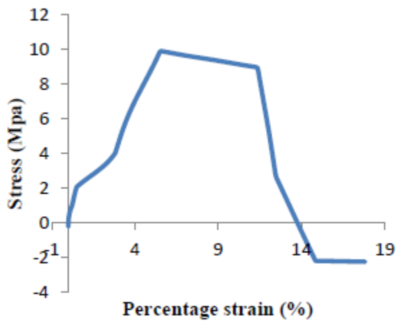

Fig. 4. The stress-strain curve of specimen with 4.3% *Mf*.

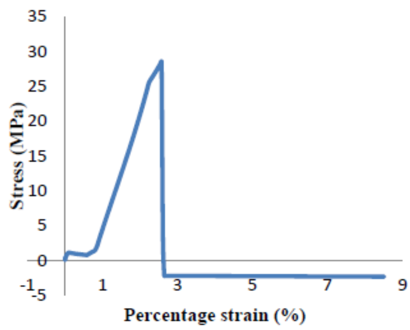

Fig. 5. Stress-strain curve of specimen with 24.5% *Mf*.

Fig. 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, these fibres tend to introduce imperfection in surface bonding and disturb effective stress transfer. Prasad et al. [4] reported that lower fibre loading performed more as impurities than reinforcement while Khalid et al found that incorporation of filler into polymer matrix induced interruption in transferring of stress in the direction of the applied force [2].

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 can be attributed to the increasing contribution from additional fibres as reinforcement and raises 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 [4].

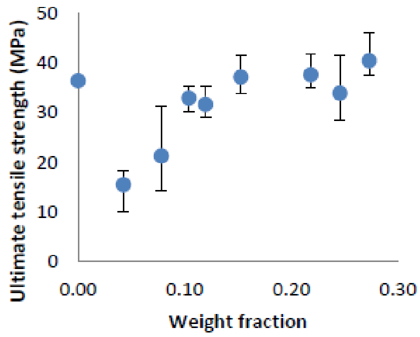

Fig. 6. UTS at different *Mf*.

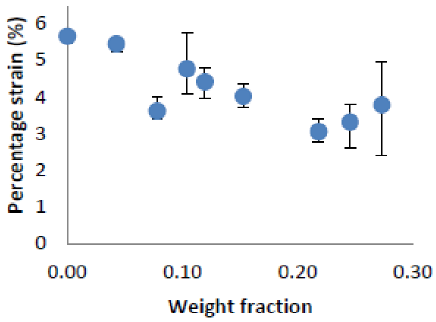

Fig. 7. Strain (%) at different M_f.

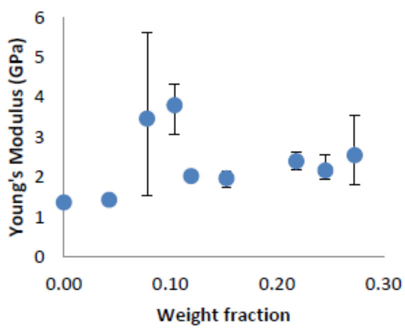

Fig. 8. Modulus at different M_f.

Fig. 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 Fig. 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 the work of Prasad et al. [4]. 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.

B. Flexural Properties

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

$$\sigma_f = \frac{3PL}{2bd^2} \tag{4}$$

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 the modulus of elasticity can be calculated using (5).

$$E_B = \frac{L^3 m}{4bd^3} \tag{5}$$

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

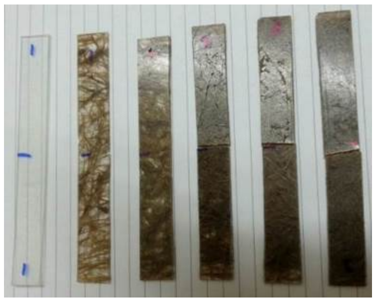

Fig. 9. Flexural specimens with varying M_f (from left: 0%, 4.3%, 7.8%, 10.4%, 12% and 15.2%).

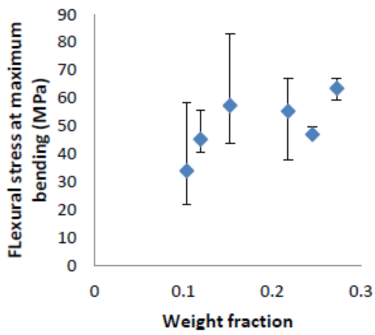

Fig. 10. Flexural stress at different M_f of EFB fibre.

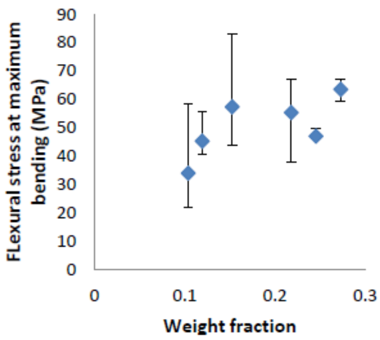

Fig. 11. Flexural modulus at different M_f of EFB fibre.

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, Fig. 9, during the 3-point bending test and hence are disregarded.

Fig. 10 and Fig. 11 demonstrated that higher fibre loading increases the flexural properties of the composites. Specimens with 27.3% *Mf* 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% *Mf* 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 [2].

C. Discussions

The results obtained in the current paper showed similarity in trend compared to those available in the open literature [1], [2], [4]. 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, Fig. 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.

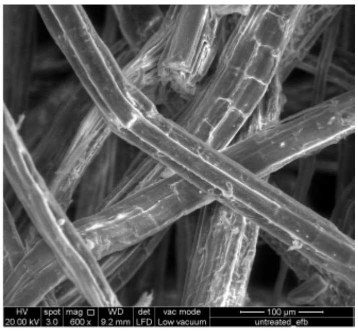

Fig. 12. SEM (600× magnification) showing the morphology of EFB fibre.

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.

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 Mf capable of improving the mechanical properties of the EFB/epoxy composite.

IV. 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% *Mf* 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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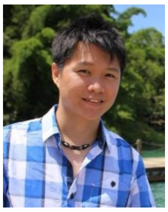

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