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Mechanical Properties of Natural Fibre (Kenaf, Oil Palm Empty Fruit Bunch) Reinforced Polymer Composites

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ABSTRACT

This paper is focused on the tensile and flexural properties of natural fibre reinforced polymer composites. Kenaf (KE) and palm empty fruit bunch fibre (EFB) with volume fraction, V_f of 20, 40 and 60% were used in this study to prepare composites comprise of polylactic acid (PLA), polystyrene (PS) and epoxy (EP) as the matrices. Both natural fiber reinforced PLA and PS were prepared via chemical dissolution with subsequent compression moulding. The thermoset EP composites were vacuum press moulded at room temperature. Synthetic E-glass (GLS) fibre reinforced PLA was also prepared for comparison purposes. The tensile strength and flexural strength increase with an increase in natural fibre V_f, up to an optimum value, these properties were found to fall back at higher fibre V_f. Scanning electronic microscope (SEM) micrographs revealed that the fibre particles were dispersed uniformly within the matrix and the tensile failure occurred through extensive fibre pull out and debonding.

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INTRODUCTION

The utilisation of natural fibre as reinforcement in polymer composites, both thermoplastic and thermoset matrices such as polyesters, epoxies and elastomers are attracting much attention in replacing the synthetic fibre for engineering application. Natural fibers have been used due to their advantages such as low density, low cost, acceptable specific strength, biodegradability and renewability [9,3,13]. Various types of natural fibers have been investigated for use in composites including jute, bamboo, flax, sisal, coconut and coil. In this work, kenaf (KE) and oil palm fruit bunch fiber (EPB) are selected because they found in abundance in Malaysia. Moreover, the utilization of EPB which is a by-product of palm oil refinery can ease the agricultural waste disposal issue and KE has been well known for its long history as reinforcement in polymer composites [1]. One of the drawbacks that restrict the use of natural fiber as reinforcement in composites is their susceptibility to moisture absorption. Due to the hydrophilic nature of natural fibres, they tend to absorb moisture from the environment and swell, forming voids and microcracks at the fibre-matric interface region which subsequently lead to a reduction of mechanical properties [2].

Polylactic acid (PLA) is a renewable polymer derived from biomass such as sugarcanes and corn. PLA can be processed via conventional machinery and it has been widely used in several applications such as packaging and medical industry to replace petroleum-based plastics, e.g., polystyrene (PS). However, the low thermal stability and inherent brittleness of PLA has restricted its use in certain application [10,8]. In order to overcome these drawbacks, approaches such as plasticization and incorporation of reinforcing filler have been proposed to improve these properties [8]. Previous study by Nakagaito et al., [10] showed that the reinforcement attained by the incorporation of microfibrillated cellulose resulted in better mechanical properties over neat PLA. Epoxy is a thermoset which is widely used as matrices in advanced composites due to their good impregnation and adhesion to fibre reinforcement, resulting in excellent mechanical properties [12].

The incorporation of natural fibre into PLA can produce a bio-based composite material which is biodegradable and environmental friendly. The objective of the study was to investigate the effects of the addition of natural fibres (KE and EFB) on the properties of PLA, and compare against the petroleum based

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matrices- PS and EP. Synthetic E-glass (GLS) fiber reinforced PLA was also prepared for comparison purposes. The mechanical properties and morphology of the fibre reinforced composites are presented in this paper.

Objectives:

This main objective of this paper is to investigate the mechanical properties of a series of natural fibre reinforced polymer composites, where the parameters under study are type of natural fibres (KE, EFB) and synthetic E-glass fibre, type of matrix materials (renewable thermoplastic PLA, synthetic thermoplastic PS and thermoset EP resins) and the fibre-matrix volume fraction.

Methodology:

Materials:

The thermoplastics, thermosetting materials and their properties are listed in Table 1. For the fibre, two different natural fibres and a synthetic fibre were used. EFB was obtained from Malaysian Palm Oil Board, bundle diameter of 60 – 100 µm, length at 6 – 10mm with an aspect ratio of 100 and density of the EFB is 0.8 g/cm^3. KE was obtained from Kenaf Natural Fiber Industries Sdn Bhd, Malaysia, bundle diameter and length of KE are in the range of 40 – 60 µm and 15 – 30mm respectively, giving an aspect ratio of 450 and density of 0.6 g/cm^3. The GLS obtained from JiaXing Sure Composite Co. China has bundle diameter of 50 – 80 µm and a uniform length of 6mm, aspect ratio of 8 and density 2.5 g/cm^3.

Table 1: Thermoplastics, thermosetting materials and their properties.

Polymer	Manufacturer	Tg (°C)	Tm (°C)
Polylactic Acid 3051D (PLA)	NatureWorks LLC	55.0 - 65.0	150 - 165
General Purpose Polystyrene (PS)	Total Petrochemicals Pte Ltd	95 - 100	200 - 240
Epoxy D.E.R. 324	Dow Chemicals	-	-
Hardener JOINTMINE 903-3s	SUKAChemicals (M) Sdn.Bhd	-	-
BYK 066N (Defoamer)	SUKAChemicals (M) Sdn.Bhd	-	-

Method:

Dissolution Method (Thermoplastics):

The dissolution method used acetone as a solvent to dissolve PLA and PS. PLA pellets and EFB were dried at 60 °C for at least 16 hours to remove moisture absorbed by the polymer and fibre. The pre-dried PLA pellets were subsequently dissolved in acetone at 75°C at ratio of 1:9 on a hotplate and well stirred by a magnetic stirrer. Varying volume fraction, V_f of pre-dried EFB, as shown in Table 2, was added into the PLA solution to form slurry. The V_f can be calculated through equation 1, where W_f is the weight of fibre, ρ_r is the density of matrix, and ρ_f is the density of fibre.

$$V_f = \frac{(W_f \times \rho_r)}{(W_f \times \rho_r) + (1 - W_f)\rho_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq.1)$$

The slurry was dried at 100°C for three hours to remove the residual acetone and reprocessed into homogenous solid mixture of fibre-polymer composite pellets. The composite pellets were transferred into the cavity of a purpose built mould which was subsequently heated to 200°C for 2 hours prior to the compression to yield fibre reinforced composite (FRC) plate. The FRC plate was then stamped using a ASTM type IV dumbbell cutter to produce specimen for tensile test. Vertical bend saw was used to produce specimen for the three point bending. The EFB was replaced by the KE to produce PLA-KE composite. The procedure was repeated by replacing PLA with PS.

Vacuum Press Moulding:

As for EP grade D.E.R. 324, a conventional vacuum press moulding was used to fabricate the FRC. A stoichiometry ratio of 2:1 (EP to hardener) was used in the fabrication of the FRC. A small quantity of deformer BYK 066N was added to aid extraction of residual gas bubbles from the mixture which was placed within a vacuum desiccators. 40% V_f natural fibre was then introduced into the EP mixture to form slurry. The slurry was transferred into the cavity of a mould pre-laminated with peal ply and subsequently pressed with the aid of a vacuum press table. Curing was allowed to take place for 12 hours before removal of the FRC plate. Specimens for tensile and flexural tests were prepared according. Table 2 depicts the computed mass fraction of the various fibre and resin which corresponds to the fibre volume fraction of 20, 40 and 60% respectively.

Table 2: Weight of composites by its volume fraction

	PLA-EFB	PLA-KE	PS-EFB	PS-KE	EP-EFB	EP-KE						
Volume Fraction	Weight of Fibre,g	Weight of Matrix,g	Weight of Fibre,g	Weight of Matrix,g	Weight of Fibre,g	Weight of Matrix,g	Weight of Fibre,g	Weight of Matrix,g	Weight of Fibre,g	Weight of Matrix,g	Weight of Fibre,g	Weight of Matrix,g
0.2	9.66	60.34	7.5	62.5	12.07	57.93	9.46	60.54	NA	NA	NA	NA
0.4	20.93	49.07	16.97	53.03	25	45	20.59	49.41	22.86	47.14	18.67	51.33
0.6	34.29	35.71	29.3	40.7	38.89	31.11	33.87	36.13	NA	NA	NA	NA

Tensile Test:

Tensile test was carried out using Universal Testing Machine according to the standard ASTM D3039 / D3039M with a 1 kN load cell. The crosshead speed for the tensile test was set at 0.01 mm/s. The measured force-displacement data as obtained from the Universal Testing Machine was extracted for computation of the nominal stress-strain response of the composite.

Flexural Testing:

Flexural test was carried out in three points bending using Universal Testing Machine according to the standard ASTM 790. The total specimen length and width were 120mm and 10 mm respectively.

Scanning Electron Microscopy:

Field emission SEM (model FEI Quanta 400F FESEM) was used to observe the surface and fracture morphology of the specimens. Specimens were sputtered-coated with a thin layer of gold to avoid electrical charging during examination.

RESULTS AND DISCUSSION

Mechanical properties:

In theoretical model, as the fibre content increases, the strength of the composite increases accordingly. However, in this study, the mechanical strength of composite deteriorates when V_f of fibre increase over a specific value. The tensile strength of neat PLA increases when it is reinforced by EFB and KE. The result is shown in **Fig. 1**. It can be observed that the maximum tensile strength for both PLA-EFB and PLA-KE were recorded at fibre loading of 40%, which exhibited the value of 58.9 and 76.1 MPa, respectively. The strength of the composites started to deteriorate with further increase of fibre V_f at 60%. This is supported by previous studies that at V_f greater than 50%, the fibres tend to aggregate in the composite which weakens the interfacial area and debonding tends to take place between the fibres and matrix. [7,4]. PS-EFB and PS-KE revealed similar trend as those observed in PLA composites, in which the maximum tensile strength was recorded at 40% fibre V_f, at 17.6 and 18.9 MPa, respectively.

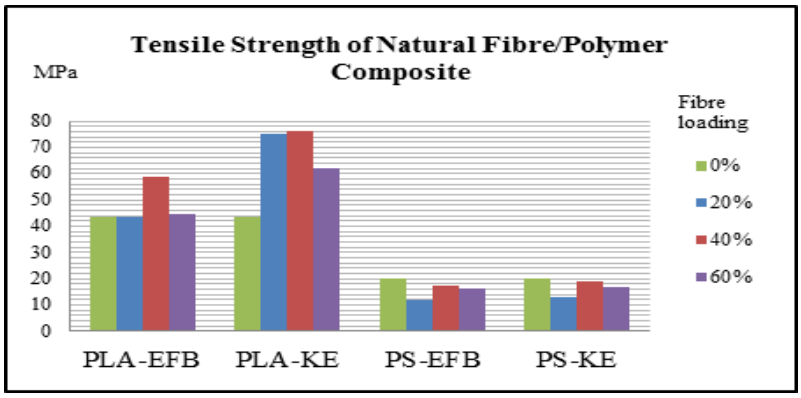

Fig. 1: Tensile strength of natural fibre/polymer composite.

Fig. 2 represents the result of flexural study. The flexural strength of neat PLA is 121 MPa and increases with reinforcement of EFB and KE. The optimum flexural strength of PLA-EFB and PLA-KE composites were reported at 40% fibre loading, which has the value of 169.8 and 209.2 MPa, respectively. The natural fibre dispersion into the matrix facilitates better bonding at the interface and provides improved properties of the composites [5]. In this study, the flexural strengths of the natural fibre reinforced polymer composites increases with the increase in fibre content, reaching a maximum at 40% fibre loading but the measured value drop when fibre content was further increased to 60%. The reduction in flexural strength at 60% fibre content could be

attributed to the poor dispersion in the matrix as excessive loading of fibres tend to aggregate in the composite. On the other hand, PS composites exhibited the highest flexural strength at 40% fibre loading (50.5 MPa) as compared to 20% (47.6 MPa) and 60% (27.8 MPa) for EFB reinforcement. Similar trend was observed for PS-KE composites where the highest flexural strength was obtained at 40% fibre loading. In general, natural fibres reinforced polymer composites exhibit better mechanical properties than the pure matrix. However, in this study, the neat PS flexural strength was higher than PS-EFB and PS-KE composites and this may be attributed to the composites preparation process as well as incompatibility between the fibre and chosen matrix whereby plant fibre is hydrophilic but polystyrene is hydrophobic in nature. Ku et al. [6] also stated that decrease of composite strength with increasing fibre content can be attributed to many factors such as incompatibility between matrix and fibre, improper manufacturing processes, fibre degradation and others.

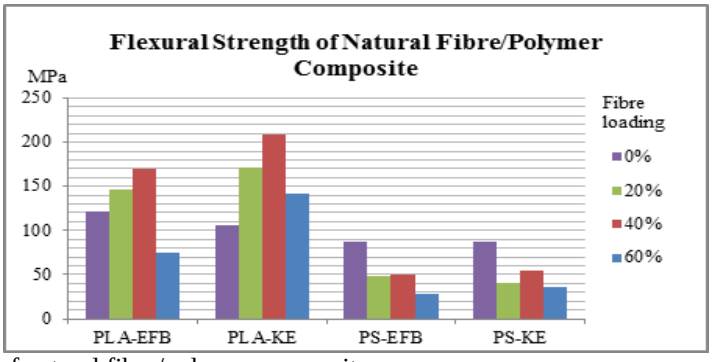

Fig. 2: Flexural strength of natural fibre/polymer composite.

Fig. 3 shows the optimum tensile and flexural strength of thermoplastics (PLA and PS composites), thermosetting (EP composites) and benchmark (PLA-GLS) composite. The addition of EFB and KE increases the tensile strength by 35% and 75% for PLA-EFB and PLA– KE as compared to neat PLA. The flexural strength of PLA-EFB and PLA-KE also show an improvement of 40% and 73%, respectively. This indicates that PLA has strong fibre-matrix adhesion with natural fibres and hence results in greater surface area of particle reinforcement. The KE reinforced composite demonstrated greater strength potentially due to the higher aspect ratio of 450 compared to EFB with the aspect ratio of merely 100. The longer fibre has greater surface area of particle reinforcement hence the better mechanical properties. Overall, glass fibre has better strength as compared to natural fibres, for example, E-glass tensile strength was 2 times higher than kenaf fibre [6]. Thus, it can be observed that the mechanical performance of GLS as reinforcement in PLA was better than EFB and KE. However, natural fibres offered the advantages of low material cost and a reduction in density compared to glass fibres. It can be observed that the tensile strength of PS composite was lower than the neat PS by 12% and 5% for PS-EFB and PS-KE, respectively. The drop in flexural strength of PS-EFB and PS-KE is more significant, stood at 42% and 37% respectively as compared to neat PS. The poor performance of natural fibre reinforced PS could be due to fibre-matrix incompatibility and partial dissolution of PS by acetone which results in poor fibre-matrix interface. Similar to PLA composites, the mechanical properties of EP composites increase with reinforcement of EFB and KE. The improvement in tensile strength of EP composites was recorded at 42% and 66% for EP-EFB and EP-KE, respectively. The flexural strength increases slightly, at 17% and 2.8% for EP-EFB and EP-KE, respectively.

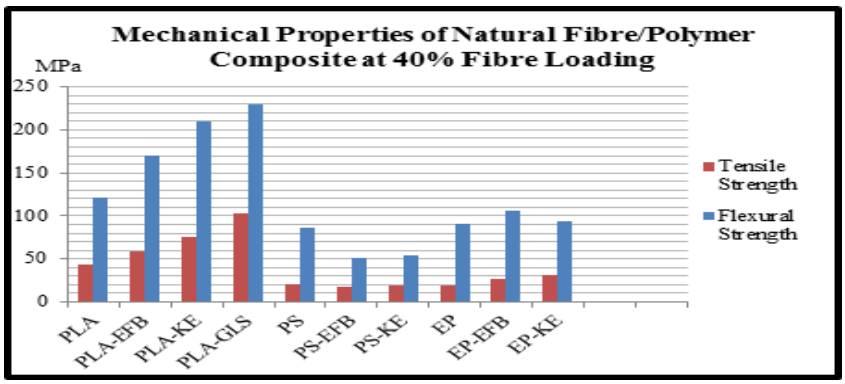

Fig. 3: Mechanical properties of fibre/polymer composite at 40% fibre loading.

Morphology:

The tensile fracture surface of 40% EFB reinforced composites was analysed by the scanning electron microscope (SEM). It can be seen from Fig. 4, PLA-EFB 40% showed good adhesion between natural fibre and matrix. There were more EFB wetting in PLA matrix and fewer voids caused by fibre pull-out. This allows effective stress transfer between the matrix and fibres which results in higher stress value (Sathishkumar et al., 2012). The SEM image of EP-EFB composite shown in Fig. 5 indicates a poor adhesion between the EFB and EP. It can be seen that there were fibre pull-out and formation of voids due to air bubbles trapped within the EP composites. This may act as a crack initiator and reduce the overall strength of the EP-EFB composite. Fig. 6, the micrograph of the tensile fracture surface of PS-EFB, illustrates the highest amount of fibre pull-out and voids. This indicates the weak adhesion between EFB and PS. Hence, this could explain the reason why PS-EFB showed the lowest mechanical properties as compared to PLA-EFB and EP-EFB.

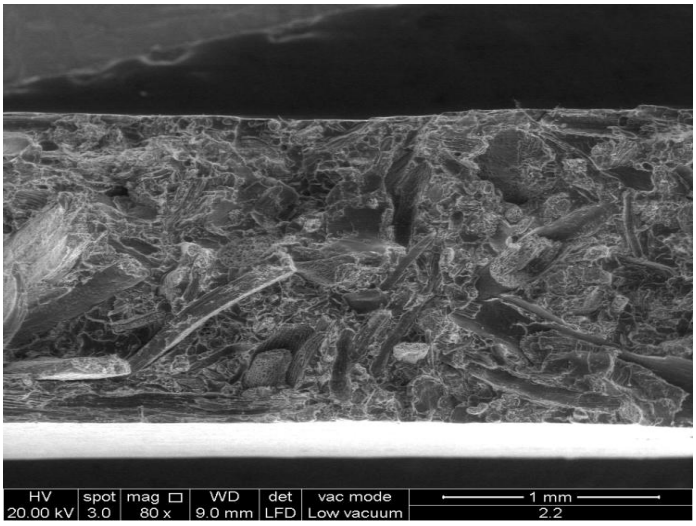

Fig. 4: SEM micrograph of tensile fracture of PLA-EFB at 40% fiber loading.

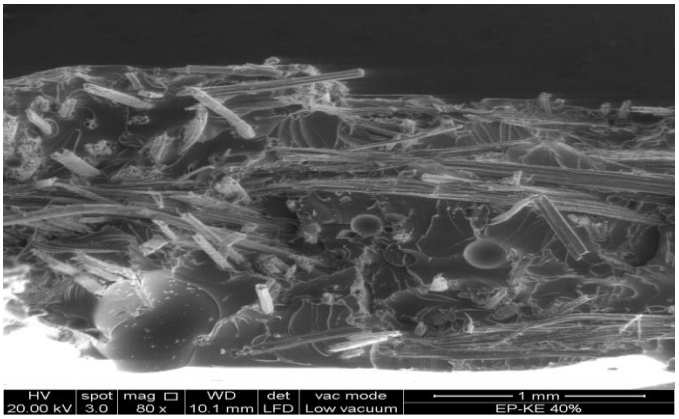

Fig. 5: SEM micrograph of tensile fracture of EP-EFB at 40% fiber loading

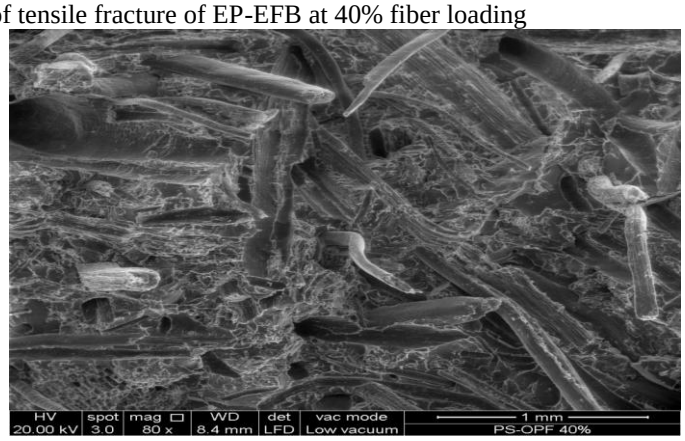

Fig. 6: SEM micrograph of tensile fracture of PS-EFB at 40% fiber loading

Conclusion:

The mechanical properties of natural fibre reinforced thermoplastics and thermoset composites were investigated. In general, the tested composites showed improvement by adding natural fibre as reinforcement. PLA composites demonstrated significant improvement in both tensile and flexural strength while PS and EP composites were hardly been affected or only a slight improvement in mechanical properties were observed. KE fibre was stronger than EFB fibre due to the KE superiority in higher aspect ratio. KE fibre also exhibited comparable strength to E-glass fibre. The SEM analysis showed the interaction between fibre and matrix. Natural fibre reinforced PLA composites possessed excellent adhesion leading to the observed higher strength compared to PS and EP composites. Poor adhesion was observed for PS and EP composites. In future, more research works can be conducted on the modification of the natural fibre, particularly to use as reinforcement in PLA to further enhance the properties of the green composites.

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REFERENCES

[1] Akil, H.M., M.F. Omar, A.A.M. Mazuki, S. Safiee, Z.A.M. Ishak, A. Abu Bakar, 2011. Kenaf fiber reinforced composites: A review. Material and Design, 32: 4107-4121.
[2] Alamri, H., I.M. Low, 2012. Effect of water absorption on the mechanical properties of n-SiC filled recycled cellulose fibre reinforced epoxy eco-nanocomposites. Polymer Testing, 31: 810-818.
[3] Baley, C., 2002. Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase. Composites: Part A, 33: 939-948.
[4] Du, Y.C., J.L. Zhang, J.S. Yu, T. Lacy, Y.B. Xue, H. Toghiani, M. Horstemeyer, C. Pittman, 2010. Kenaf bast fiber bundle-reinforced unsaturated polyester composites IV: effect of fiber loadings and aspect ratios on composite tensile properties. Forest Products Journal, 60: 582-591.
[5] Kabir, M.M., H. Wang, K.T. Lau, F. Cardona, 2012. Chemical treatments on plant-based natural fibre reinforced polymer composites. Composites: Part B, 43: 2883-2892.
[6] Ku, H., H. Wang, N. Pattarachaiyakoop, M. Trade, 2011. A review on the tensile properties of natural fiber reinforced polymer composites. Composites Part B: Engineering, 42(4): 856-873.
[7] Lim, L.T., R. Auras, M. Rubino, 2008. Processing technologies for poly(lactic acid). Progress in Polymer Science, 33(8): 820-852.
[8] Mohamad Haafiz, M.K., A. Hassan, Z. Zakaria, I.M. Inuwa, M.S. Islam, M. Jawaid, 2013. Properties of polylactic acid composites reinforced with oil palm biomass microcrystalline cellulose. Carbohydrate Polymers, 98: 139-145.
[9] Mohanty, A.K., A. Wibowo, M. Misra and L.T. Drzal, 2003. Effect of process engineering on the performance of natural fiber reinforced cellulose acetate biocomposites. Composites: Part A, 35: 363-370.
[10] Nakagaito, A.N., A. Fujimura, T. Sakai, Y. Hama, H. Yano, 2009. Production of microfibrillated cellulose (MFC)-reinforced polylactic acid (PLA) nanocomposites from sheet obtained by a papermaking-like process. Composites Science and Technology, 69: 1293-1297.
[11] Sathishkumar, T.P., P. Navaneethakrishnan, S. Shankar, 2012. Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites. Composites Science and Technology, 72(10): 1183-1190.
[12] Toldy, A., B. Szolnoki, Gy. Marosi, 2011. Flame retardancy of fibre-reinforced epoxy resin composites for aerospace application. Polymer Degradation and Stability, 96: 371-376.
[13] Van Voorn, B.V., H.H.G. Smit, R.J. Sinke, B. de Klert, 2001. Natural fibre reinforced sheet moulding compound. Composites: Part A, 32: 1271-1279.