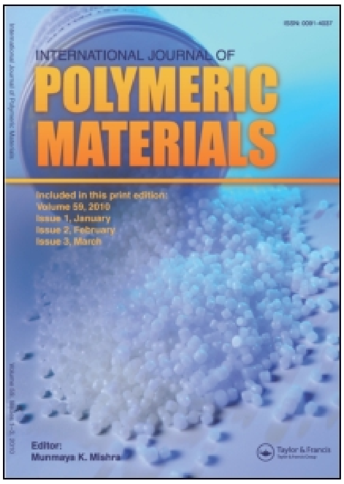

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# The Physical Properties of Oil Palm Empty Fruit Bunch (EFB) Composites Made from Various Thermoplastics

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Oil palm empty fruit bunch (EFB)-based composites were produced using different types of thermoplastic as matrices. The composites were produced by using an internal mixer. The mechanical and water absorption properties of composites were investigated. Overall, the incorporation of EFB into the polymer matrix has resulted in the reduction of flexural strength. The poor performance has been attributed to the poor filler-matrix interaction. Both flexural and tensile modulus of PE and PP composites have been improved upon the addition of fillers, however, both PS and PVC composites showed a decreasing trend. Tensile strength and elongation at break results for all composites have been reduced as the result of incorporation of filler. This has been attributed to the poor filler-matrix interaction or compatibility, size irregularity and also decreased ductile deformation. Water absorption and thickness swelling increased as the filler loading is increased. This has been attributed to the presence of hyrophillic hydroxyl groups of the filler.

*Keywords:* Oil palm empty fruit bunch; lignocellulose; composites; compounding

## INTRODUCTION

Wood–plastic composites have received a lot of attention particularly on the aspect of filler or reinforcing component. The utilization of wood or in general lignocellulosic material, as reinforcing component in polymer composites has become more attractive particularly for

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price driven/high volume applications [1–10]. This development has been attributed to several advantages offered by these types of filler over their inorganic counterparts, such as, lower density, greater deformability, less abrasiveness to expensive moulds and mixing equipments, and of course lower cost. As better understanding of wood–plastic interaction has been gained, the move to find substitutes for wood has been stimulated especially by the abundance of lignocellulosic material. With the increasing pressures on the forest industries, coupled with the scarcity of natural resources, the need for the efficient use of the resources is vital, especially in wood composite industries. Thus, this would mean better conversion, more cost-effective utilization which is environmentally friendly, new technologies or even looking for substitute for wood.

There has been growing interests on the utilization of lignocellulosic, apart from wood. In addition to its advantages over their inorganic counterpart as mentioned earlier, lignocellulosic fillers are derived from a renewable resource, available in abundance and the potential has not been really tapped. These materials have been subjected to various investigations recently, either in replacing existing wood species in making conventional panel products [11] or producing plastics composites [12–16]. The increasing trend in using these non-wood based materials has been induced by the growing demand for light weight, high performance materials coupled with diminishing natural fibre resources (wood in particular) and escalating costs of raw materials and energy.

One of the lignocellulosic materials which is of great relevance to the Malaysian scenario is the large quantity of biomass generated by oil palm industries. The potential utilization of fillers that were derived from oil palm industries, *i.e.*, empty fruit bunch (EFB) and oil palm frond (OPF) for the production of high density polyethylene (HDPE) composites have been reported by several workers [13, 17, 18]. In general, it has been found that the incorporation of fillers into HDPE matrix has to a certain extend reduced both tensile and flexural strength of the composites [13, 17]. Thus it is the purpose of this work to study the properties of EFB derived composites with different thermoplastics as matrices.

Emphasis has been given to EFB instead of OPF for two main reasons. From microstructure-property relationships point of view, both EFB–HDPE and OPF–HDPE composites displayed similar trends and their overall mechanical properties are quite comparable [13, 17]. Secondly, EFB is preferable in terms of availability and cost. EFB is readily available at a typical token price of USD 10.00 per tonne as compared to USD 30.00 per tonne for OPF. In addition, the amount of EFB waste generated by the palm oil industries in Malaysia is very high, *i.e.*, estimated to be about 8 million tonnes per year. Thus, considerable R&D efforts have to be undertaken in finding useful utilization of the EFB.

## EXPERIMENTAL

### Materials

Oil palm empty fruit bunch (EFB) (comprises of a bunch of fibres in which the palm fruit are embedded and consists of about 65% of holocellulose and 25% of lignin) was supplied by Sabutek Sdn. Bhd., Teluk Intan, Perak. The EFB used in this study was ground to the mesh size of 35–60 (270–500 μm). The polyethylene used was of high density polyethylene (PE) (density of 0.96 g/cm$^3$), polypropylene (PP) (density of 0.90 g/cm$^3$), polystyrene (PS) (density of 1.07 g/cm$^3$) and polyvinyl chloride (PVC) (density of 1.20 g/cm$^3$), purchased from The Polyolefin Company (Singapore) Pte. Ltd.

### Preparation of Composite

The filler and thermoplastic were mixed using a Haake Rheocord System consists of a Haake Rheodrive 5000 (drive unit) and Haake Rheomix 600 with roller blade (mixer). The filler and thermoplastic pellets were hand-mixed prior to putting them in the mixer. The mixing was carried out at 180°C for PE, PP and PS, and at 170°C for PVC. The mixture was then transferred to a mould with the dimensions of 160 × 160 × 3 mm. The mixture was preheated for 10 minutes at the same temperature as in mixing process followed by hot-processing at the same temperature for another 10 minutes. Cooling was carried out for 5 minutes under pressure.

## Testing

The sheet produced was cut into 2 types of test samples; *i.e.*, flexural and tensile tests. Tensile tests were carried out according to ASTM D618 on samples with the dimensions of 15 × 1.9 × 0.3 cm (length × width × thickness), using Universal Testing machine Model STM-10 at a cross-head speed of 0.5 cm/min. Flexural test was conducted on the same machine according to ASTM D790, *i.e.*, a three-point bending system. The samples with dimensions of 15 × 1.5 × 0.3 cm, were tested at a cross-head speed of 2.0 mm/min. A minimum of six samples were tested in each test.

The calculations for flexural modulus (modulus of elasticity, $MOE$) and strength (modulus of rupture, $MOR$) are given below.

Modulus of Elasticity ($MOE$):

$$MOE = \frac{L^3 \Delta W}{4bd^3 \Delta S}$$

where;

$L$ = the span between the centers of supports (m)
$\Delta W$ = the increment in load (N)
$b$ = the mean width of the sample (m)
$d$ = the mean thickness of the sample (m)
$\Delta S$ = the increment in deflection (m)

Modulus of Rupture ($MOR$):

$$MOR = \frac{3WL}{2bd^2}$$

where;

$W$ = the ultimate failure load (N)
$L$ = the span between centres of support (m)
$b$ = the mean width of the sample (m)
$d$ = the mean thickness of the sample (m)

## Water Absorption and Thickness Swelling Test

Samples were immersed in distilled water at 30°C. The water absorption were determined by weighing the specimens after immersing in water for 24 hours. A Mettler balance type AJ150 was used, with a precision of 1 mg. The water content at any time $t$, $M_t$, was calculated by;

$$M_t = \frac{W_w - W_d}{W_d}$$

where, $W_d$ and $W_w$ are original dry weight and weight after exposure for 24 hours, respectively. Thickness swelling ($T_t$) is calculated according to the formula given below;

$$T_t = \frac{T_w - T_d}{T_d}$$

where $T_d$ and $T_w$ are original dry weight and weight after exposure for 24 hours, respectively.

## Morphological Study

The fracture surface of the composites (consists of 45% filler loading) from the tensile test were investigated with a Leica Cambridge S-360 Scanning Electron Microscope. The objective is to get some information regarding fibre dispersion, bonding quality between fibre and matrix and to detect the presence of microdefects if any. The fracture ends of the specimens were mounted on aluminum stub and sputter coated with a thin layer of gold to avoid electrostatic charging during examination.

## RESULTS AND DISCUSSION

Results of flexural strength (*MOR*) is shown in Figure 1. As the *MOR* is a calculation of ultimate flexural strength per unit area of the sample, the results show that the strength for all types of thermoplastic composites decrease as the filler loading is increased. Maiti *et al.* [19] reported that lignocellulosic particles could results in the discontinuity in the polymer matrix. This is expected since hydrophillic nature of

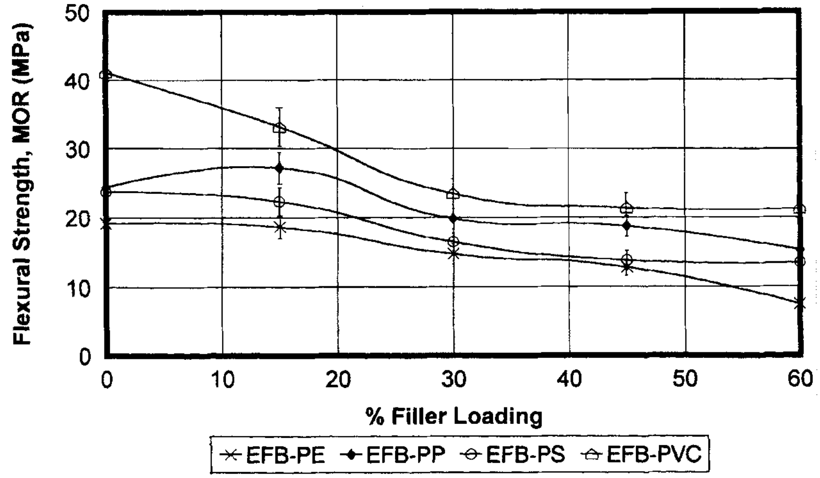

FIGURE 1 The effect of filler loading on the flexural strength of various EFB composites.

the lignocellulosic material could not form a good interaction with hydrophobic thermoplastic matrix. Thus each particle site would serve as the centre of stress concentration, thereby, reducing the ability to transfer stress efficiently. The order of the degree of flexural strength for various thermoplastic composites follows the trend of the pure thermoplastic (without filler); PVC > PP > PS > PE.

The flexural modulus (*MOE*) results are depicted in Figure 2. The modulus for both EFB–PE and EFB–PP composites show an increasing trend as the filler loading is increased. Similar trend was observed by other studies [7, 20–22]. However, the modulus for both EFB–PS and EFB–PVC decrease as the filler loading is increased. As the modulus is a measure of flexural stiffness of a sample, the results show that incorporation of fillers is able to improve the stiffness of composites of HDPE and PP. As PS and PVC are themself are stiffer than HDPE and PP, thus the results indicate that the former have less tolerance to the incorporation of filler with the reference to the stiffness of the material.

Figure 3 shows the effect of filler loading on the tensile strength of EFB-thermoplastic composites. All types of composite show a

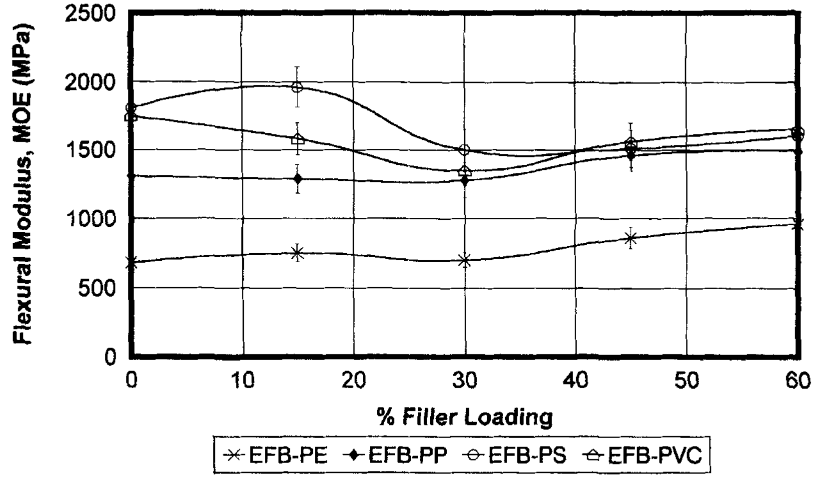

FIGURE 2 The effect of filler loading on the flexural modulus of various EFB composites.

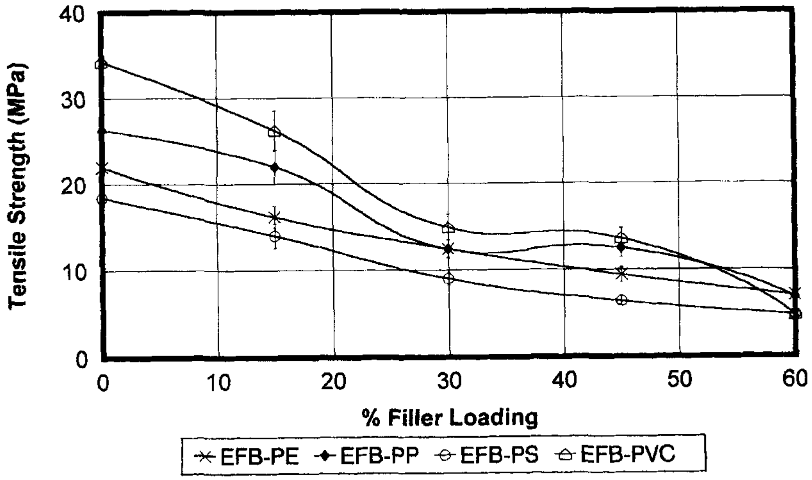

FIGURE 3 Tensile strength as a function of filler loading for various EFB composites.

decreasing trend as the filler loading increases. This is in agreement with the trend observed in other lignocellulosic filled composites [23, 24]. Unlike fibres which have uniform cross-section and relatively high aspect ratio (*i.e.*, the length to diameter ratio, *l*/*d*), for irregular-shaped fillers such as EFB, their capability to transmit stress in the thermoplastic matrix is rather poor. Thus, the strength enhancement in the filled composite is in general much lower than that of fibre reinforced systems. Incorporation of fillers could also increase the degree of the amorphous region, which subsequently reduce the strength of the composites [8]. From the results, it is obvious that the strength of the composites depends on the properties of the polymer matrix. These can be clearly seen from the similarity in the order of the strength of the neat polymers and their respective composites.

Tensile modulus results (Fig. 4) follow similar trend as flexural modulus. Tensile modulus for EFB-PP and EFB-PE is increased as the filler loading increases. On the other hand, both EFB-PS and EFB-PVC show a decreasing trend in their modulus. The results probably show that the presence of fillers could disrupt the crystallinity of the polymers which in turn affecting the modulus of the polymers [8].

As expected, all composites show a decreasing trend in elongation at break (EB) as the level of loading is increased (Fig. 5). This may be contributed by the decreased deformability of a rigid interphase

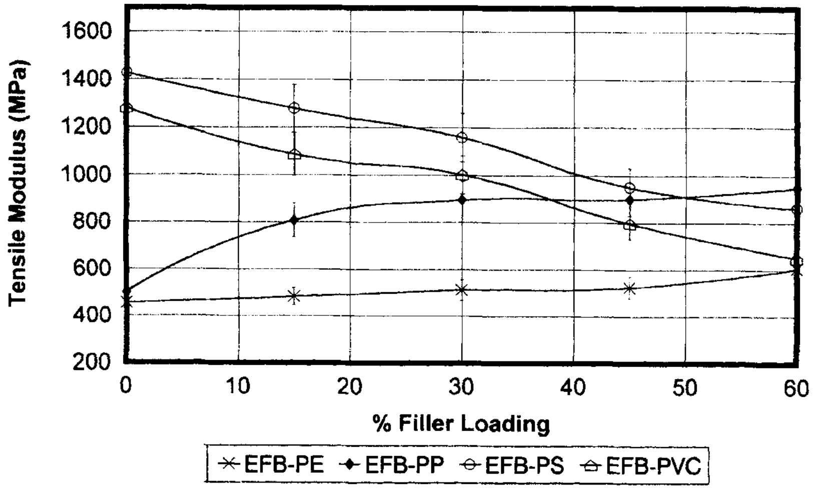

FIGURE 4 Tensile modulus as a function of filler loading for various EFB composites.

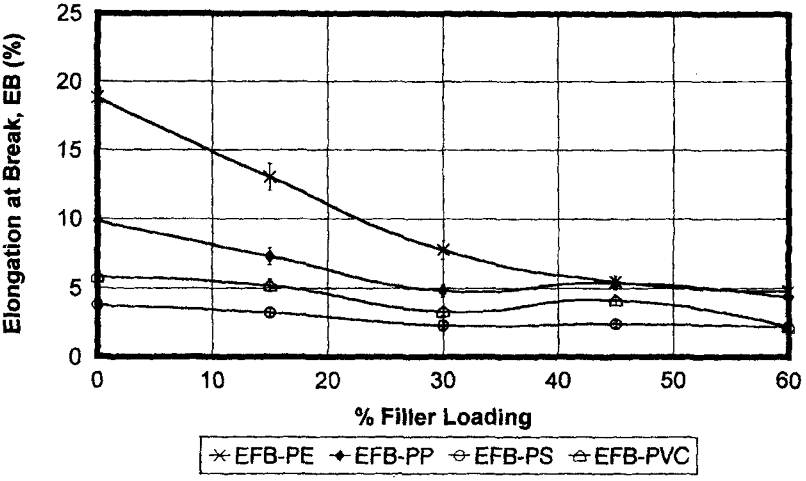

FIGURE 5 The effect of filler loading on the elongation at break for various EFB composites.

between filler and the matrix component. EFB – PE composites exhibit the highest reduction in the EB as compared to the other composites. It is obvious that the order of the performance is the opposite of the tensile modulus results shown earlier. Though both PS and PVC produce composites superior in tensile modulus than PE and PP, their performance in EB are rather low. It can also been seen that the level of EB is dependent on the type of polymer used as matrix.

Figures 6 and 7 depict the effect of filler loading on the water absorption and thickness swelling of various EFB composites, respectively. It can be seen that water absorption increases as the filler loading is increased. This is expected since lignocellulosic materials through their hydroxyl groups could form hydrogen bonding with water [25]. The absorption of water into the cell wall structure would increase the dimension of the cell wall through swelling. Thus, this in turn would increase the water uptake and the thickness of the samples. EFB – Ps composites show the highest water absorption followed by EFB – PVC, EFB – Pe and EFB – PP. The performance of each composites correlate well with the water absorption of their respective polymer, where PS, PVC, PE and PP absorb about 0.05% 0.03%, $< 0.01$ and $< 0.01\%$, respectively [26].

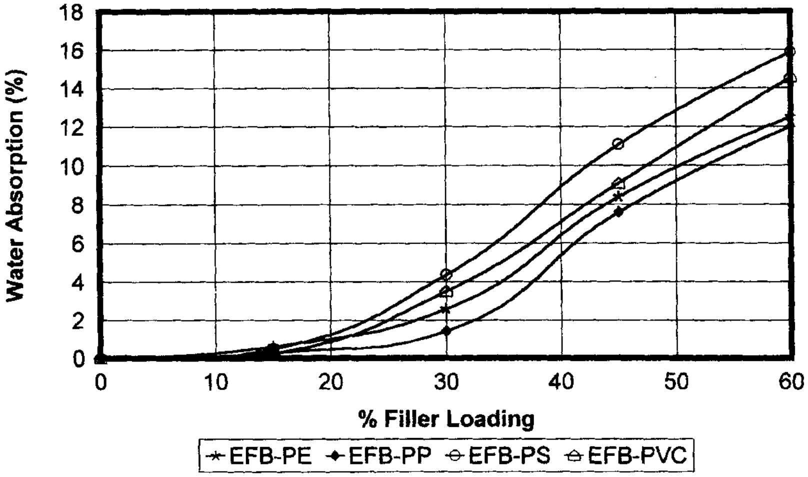

FIGURE 6 The effect of filler loading on the water absorption of various EFB composites.

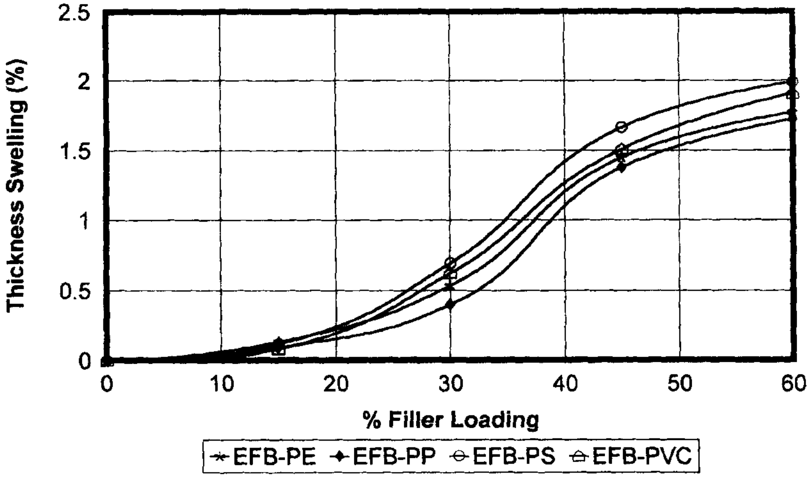

FIGURE 7 The effect of filler loading on the thickness swelling of various EFB composites.

Scanning electron microscopy (SEM) was employed to study the tensile fracture surfaces of various composite samples based on 45% filler loading. The objective is to get some idea on filler dispersion and bonding quality between filler and matrix. Figures 8(a) and (b) show the fracture surface of EFB–PE composite. Figure 8(a) shows holes that indicates the occurrence of fibre pull out. This indirectly implies

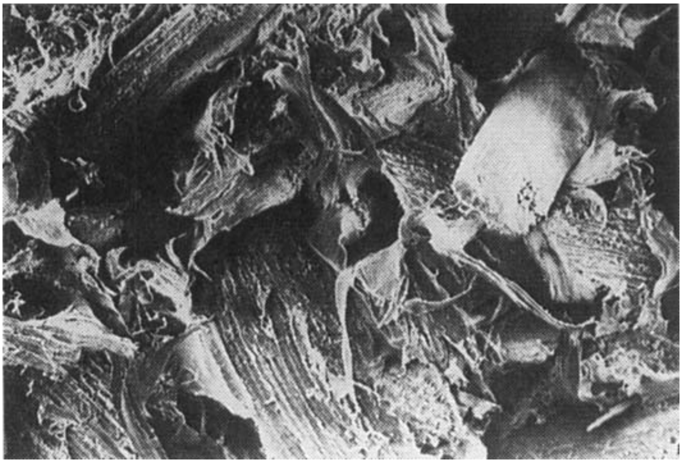

FIGURE 8(a) Scanning electron micrograph of tensile fracture surface of EFB–PE composites (45% EFB) with magnification of 100 X.

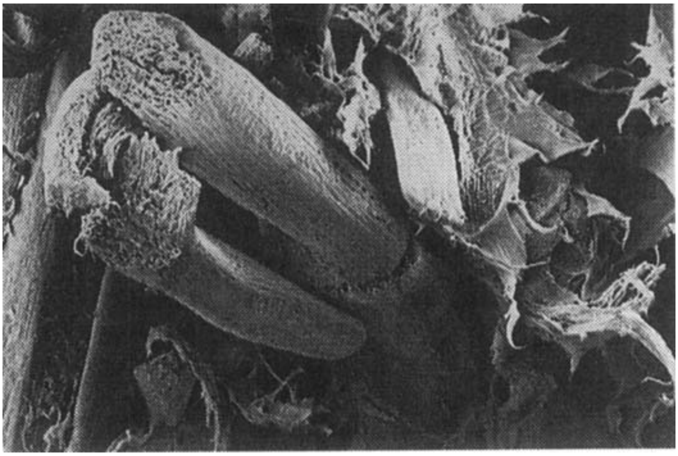

FIGURE 8(b) Scanning electron micrograph of tensile fracture surface of EFB–PE composites (45% EFB) with magnification of 100 X.

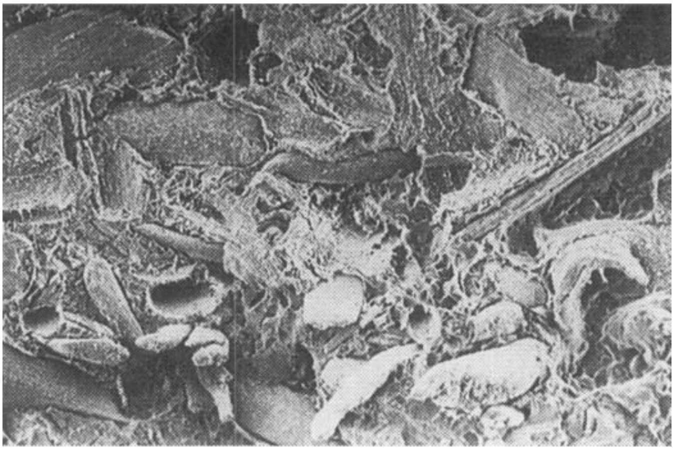

FIGURE 8(c) Scanning electron micrograph of tensile fracture surface of EFB – PE composites (45% EFB) with magnification of 50 X.

that there is poor filler-matrix interactions between untreated fibre and matrix. It can be seen from the micrograph the occurence of feathering, which indicates the ductility of PE matrix. In addition to fibre pull-outs as the mode of fracture, fibre breakage can also be seen in the sample (Fig. 8b), at a lesser extent than the former. Due to hydrogen bonds formed between fibres and the wide difference in polarity between untreated lignocellulosic fibres and the matrix, the fibres tend to agglomerate into bundles and become unevenly distributed throughout the matrix (Fig. 8c). From Figure 9(a) for EFB – PP composite, it is obvious that fibre pull-out is one of the main mode of failure. Fibres are shown to be oriented in a random arrangement (Fig. 9b). Evidence of fibre pull-out can also be observed in the EFB – PS composites. There are also evidence of good interfacial adhesion between EFB surface and matrix (Fig. 10a). The presence of voids as shown in Figure 10b may create stress concentration points which in turn reduce the strength of the samples. It can also be seen that the surface of EFB – PS composites is relatively smooth compared to EFB – PE composites, which indicates that the former is less ductile than the latter. Thus, this also explains the lower EB of EFB – PS composites.

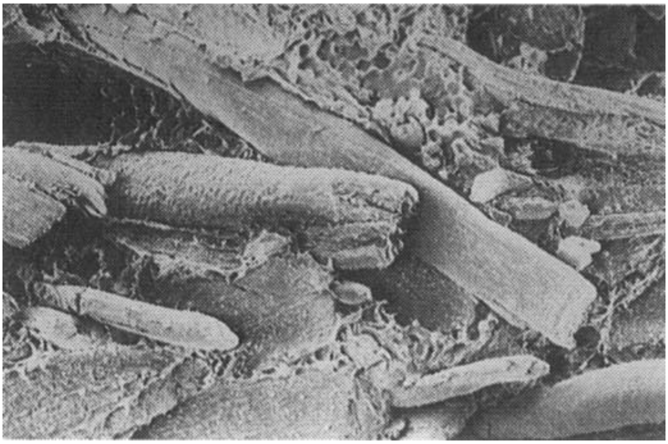

FIGURE 9(a) Scanning electron micrograph of tensile fracture surface of EFB–PP composites (45% EFB) with magnification of 50 X.

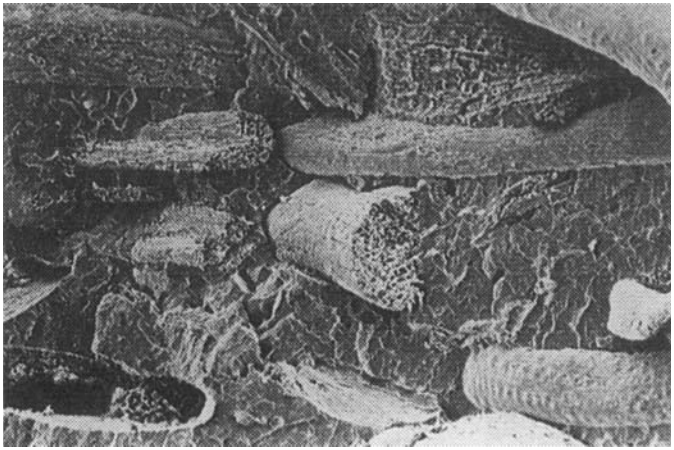

FIGURE 9(b) Scanning electron micrograph of tensile fracture surface of EFB–PP composites (45% EFB) with magnification of 100 X.

From Figures 11(a) and (b), it is clear that the good interfacial adhesion is formed between PVC matrix and EFB. This may be contributed by the polar Cl atom from PVC which produce some degree

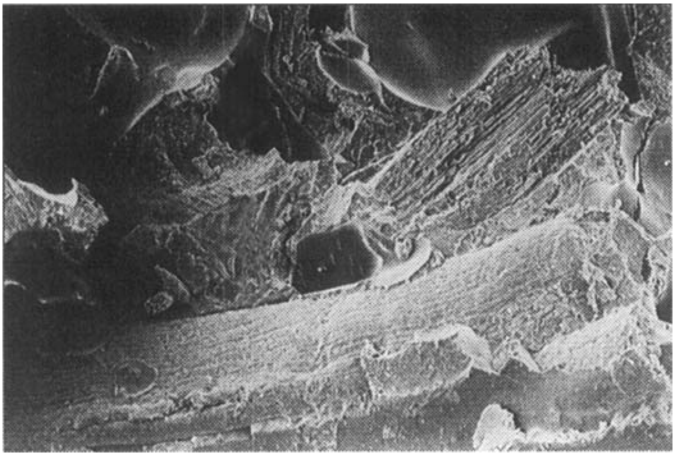

FIGURE 10(a) Scanning electron micrograph of tensile fracture surface of EFB–PS composites (45% EFB) with magnification of 100X.

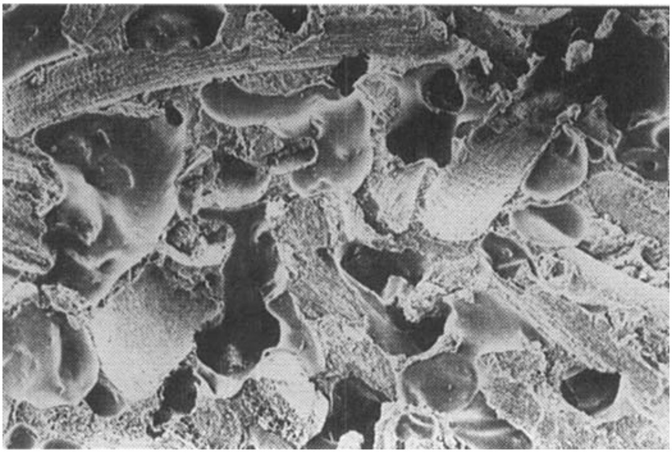

FIGURE 10(b) Scanning electron micrograph of tensile fracture surface of EFB–PS composites (45% EFB) with magnification of 50X.

of compatibility with polar groups of EFB. These observations support the results of tensile strength where EFB–PVC composites display higher strength than the rest of the composites.

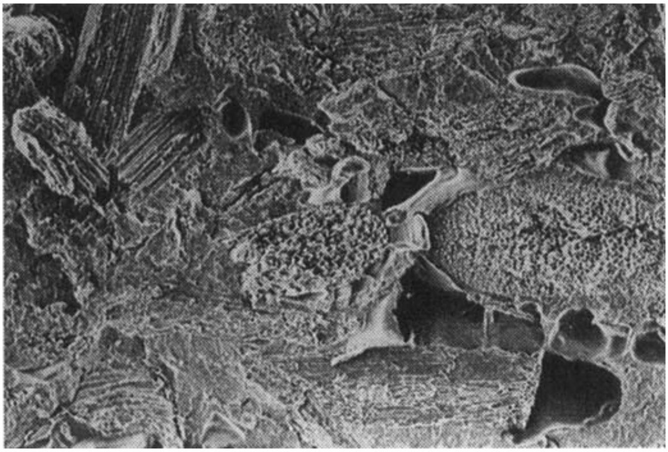

FIGURE 11(a) Scanning electron micrograph of tensile fracture surface of EFB–PVC composites (45% EFB) with magnification of 100X.

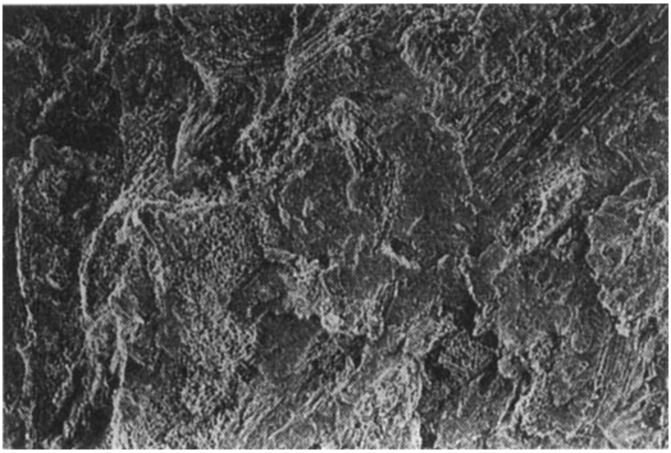

FIGURE 11(b) Scanning electron micrograph of tensile fracture surface of EFB–PVC composites (45% EFB) with magnification of 100X.

## CONCLUSIONS

The main objective of this investigation is to study the effect of various thermoplastics on the properties of EFB-based composites. The conclusions made from this study are as follows:

1. the incorporation of EFB into the polymer matrix has resulted in the reduction of flexural strength. The poor performance has been attributed to the poor filler-matrix interaction.
2. flexural and tensile modulus of PE and PP composites have been improved upon the addition of fillers, however, both PS and PVC composites showed a decreasing trend.
3. tensile strength and elongation at break results for all composites hav been reduced as the result of incorporation of filler. This has been attributed to the poor filler-matrix interaction or compatibility, size irregularity and also decreased ductile deformation.
4. water absorption and thickness swelling increased as the filler loading is increased. This has been attributed to the presence of hydrophillic hydroxyl groups of the filler.

## Acknowledgements

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