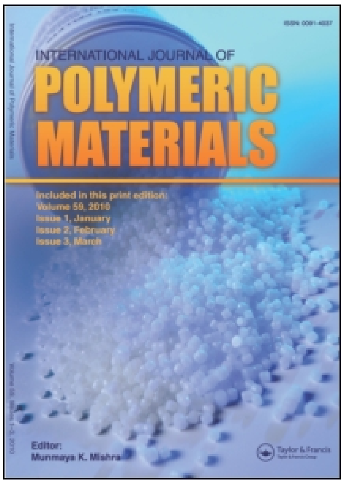

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Polyethylene-Oil Palm Frond Composites-A Preliminary Study on Mechanical Properties

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Polyethylene-Oil Palm Frond Composites-A Preliminary Study on Mechanical Properties

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The mechanical properties of composites consisting of high density polyethylene (HDPE) and oil palm frond (OPF) have been investigated. Three sizes of OPF at different filler loadings were compounded using a single screw compounder. Modulus of rupture (MOR) of the OPF-HDPE composites decreased with increasing filler loading. Samples with smaller size particles displayed higher MOR as compared to the larger ones. The incorporation of OPF into polymer matrix has also reduced the tensile and impact properties of the composites. This has been attributed to poor filler dispersion and increasing tendency for filler-filler interactions as filler loading increases. Scanning electron microscopy (SEM) has revealed that the OPF particles embedded in the matrix were in the form of irregular shaped-fibre bundles and the failure occurred through extensive fibre bundle pull-out and debonding. This failure mechanism has provided qualitative evidence for the poor tensile and impact strengths of the composites.

Keywords: Polyethylene; oil palm frond; filler; composite; scanning electron microscope

INTRODUCTION

The utilization of lignocellulosic material in the production of plastic composites is becoming more attractive particularly for low cost/high volume applications. There are several factors which are responsible for the observed trend. Lignocellulosics-derived fillers possess several advantages compared to inorganic fillers, i.e., lower density, greater deformability, less abrasiveness to equipment, and of course lower cost. Moreover, lignocellulosic-based fillers are derived from a renewable resource.

Lignocellulosic-derived fillers can be obtained either from wood or non-wood based materials. Of these two, the latter has been subjected to various investigations recently, either in replacing existing wood species in making conventional panel products [1] or producing plastics composites [2]. 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.

Malaysia in particular, has a large quantity of biomass generated by oil palm industries. Recent investigations have shown that valuable products could be produced from various biofibres of oil palm tree. Examples of such products are oil palm component-plastic composites [2], oil palm component-rubber composites [3], sheet moulding compounds [4], composites [1], and pulp and paper [5]. Since the chemical composition of oil palm is similar to that of timber, these wastes could be turned into new raw materials with expanding potentials.

The aim of this study is to investigate the effect of high filler loadings and particle sizes on the mechanical properties of oil palm frond-polyethylene (OPF-PE) composites. The high filler loading is of interest in this study for two main reasons. Firstly, the incorporation of high loading, low cost lignocellulosic fillers into relatively expensive thermoplastics will be an effective strategy to reduce the cost of the composite products. In this study, the filler used is derived from oil palm tree (*Elais guineensis*) component, namely, oil palm frond (OPF) and used in meal form. This material is the byproduct of the palm oil industry and consists of about 80.5% of holocellulose and 18.3% of lignin [6]. OPF is readily available at a typical token price of $30.00 per tonne. In spite of further costs needed to grind the material to the required size, the overall cost is still cheap. Secondly, the OPF waste generated by the oil palm industry in Malaysia is estimated to be about 13 million tonnes per year. Thus, finding useful applications for the OPF will surely alleviate environmental problems related to the disposal of the oil palm wastes.

EXPERIMENTAL

Materials

Oil palm fronds (OPF) in fibre were obtained from Sabutek Sdn. Bhd., Teluk Intan, Perak, Malaysia. The polyethylene used was of high density polyethylene (HDPE) purchased from The Polyolefin Company (Singapore) Pte. Ltd.

Preparation of composite

OPF fibres were ground into three sizes; 270–500, 180–270 and 75–180 μm. The OPF was compounded with HDPE in a Betol single screw extruder (Model 116) at a screw speed of 20 rpm, with barrel temperature range of 150 to 160°C, from feeding zone to the die zone, respectively. The average moisture content of the OPF samples was about 10%. The mixture was extruded and pelletized.

The compounded samples in pellet form were compression moulded into a sheet of dimensions of 18.5 × 13.5 × 0.5 cm. The moulding process involved preheating, followed by heating at 160°C and subsequent cooling under pressure. The total moulding time was 15 minutes; 5 minutes for each step.

Testing

The sheet produced was cut into 3 types of test samples; i.e. flexural, tensile and impact tests. Tensile tests were carried out on samples with dimensions of 16.5 × 1.9 × 0.5 cm, using Instron machine Model 1114 at a cross-head speed of 0.5 cm/min. Flexural tests were conducted according to ASTM D790, i.e. a three-point bending system, using Universal Testing machine Model STM-10. The samples, with dimensions of 13.5 × 1.5 × 0.5 cm, were tested at a cross-head speed of 2.0 mm/min. The Izod impact tests were carried out on unnotched samples with dimensions of 6.5 × 1.5 × 0.5 cm, using an Impact Pendulum Tester (Zwick) Model 5101. A minimum of six samples were tested in each case.

The fracture surfaces of the composites from the tensile test were investigated with a Leica Cambridge S-360 Scanning Electron

Microscope. All fractured surfaces were sputter coated with gold to avoid electrostatic charging and poor image resolution at 35 X and 100 X magnifications.

RESULTS AND DISCUSSION

It is well known that the size of fillers plays an important role in determining the mechanical properties of filled-thermoplastic composites and this is perfectly true even for lignocellulosic fillers. Thus, the present study was confined to three different sizes of OPF particles; 270–500, 180–270 and 75–180 μm.

Figure 1 shows the results of flexural modulus of rupture (MOR). In general, all samples with different sizes of filler show a decreasing trend with increasing filler loading. The higher MOR for the samples with smaller filler size implies that the samples are capable of withstanding higher stress before failure than the ones with larger particle size. Samples with fillers of size 75–180 μm show the highest MOR as compared to other samples with larger size. This may be attributed to the greater interaction and/or better dispersion of the finer OPF particles in the PE matrix. A similar observation has been reported by Maldas *et. al*[7] in the case of wood fibre-polystyrene composites.

In OPF-PF composites, poor wetting is expected due to poor compatibility between polar nature of OPF and non-polar of polyethylene matrix, giving way for weak interfacial regions. The effect is further magnified by further addition of filler. The weak interfacial regions will reduce the efficiency of stress transfer from the matrix to the reinforcement component, thus poor strength properties can be anticipated. As highlighted by several workers[8,9,10], the quality of interfacial bonding is determined by several factors, such as the nature of lignocellulosic and thermoplastic as well as their compositions, the fibre aspect ratio, the types of incorporation procedures, processing conditions employed and on the treatment of the polymer or fibre with various chemicals, compatabilizers, coupling agents, etc.

Figures 2 and 3 show the effect of filler loading and filler size on the tensile strength and tensile modulus of OPF-PE composites, respectively. Incorporation of filler into a thermoplastic matrix may not necessarily increase the tensile strength of a composite. Fibres with

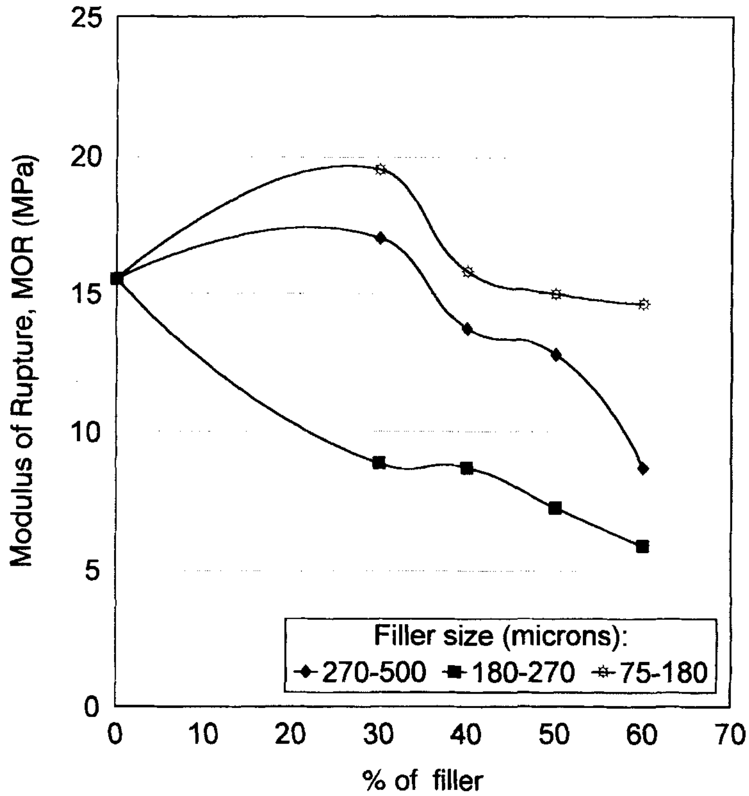

FIGURE 1 Effect of filler loading and particle size on MOR.

uniform circular cross-section and certain aspect ratio normally improve the strength. However, for irregular-shaped fillers with low aspect ratio as in this study, the capability to support stresses transferred from the polymer matrix is significantly reduced. As a result, the stiffness and strength enhancements in the filled composites are lower than fibre reinforced systems. In the present study, tensile strength of the composites decreases gradually with filler loading.

In general, significant improvement in tensile modulus was observed with increasing filler loading. Composites with smaller filler size display better modulus than the larger filler size samples. Similar observations have been reported by Hanafi *et. al.*[3] for oil palm wood flour reinforced epoxidized natural rubber composites. Smaller

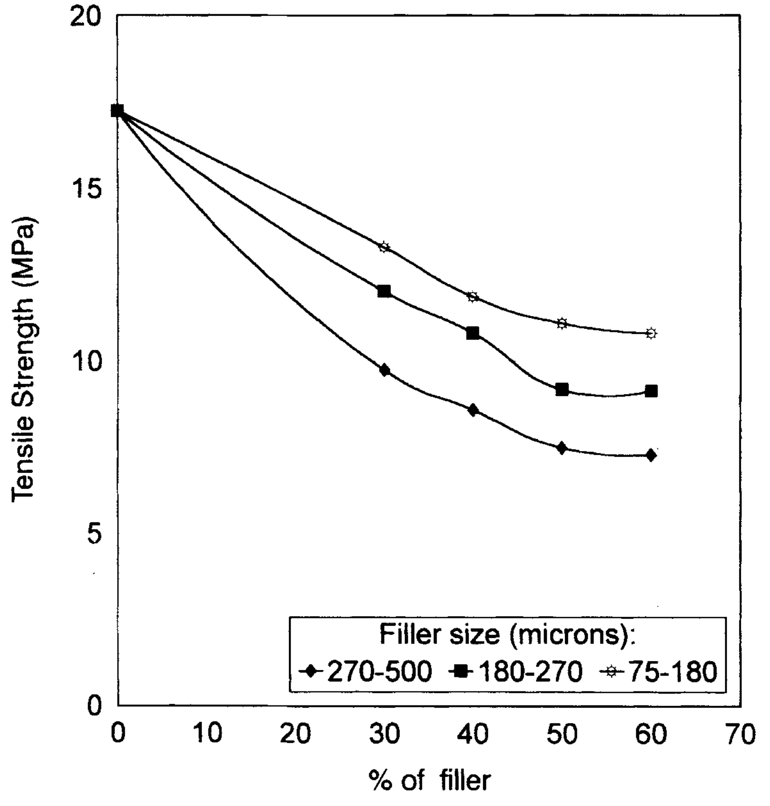

FIGURE 2 Effect of filler loading and particle size on tensile strength.

or finer particles with larger specific area may impart greater interaction with the polymer matrix and can result in uniform filler dispersion in the composite.

The impact strength of composites decreases as the filler loading is increased (Fig. 4). This reflects the reduction in energy absorption at the crack tip. The poor bonding quality between the fibres and polymer matrix creates weak interfacial regions which will result in debonding and frictional pull out of fibre bundles. These failure mechanisms which inhibit the ductile deformation and mobility of the matrix will obviously lower the ability of the composite system to absorb energy during fracture propagation[13]. The extensive fibre bundle pull out as observed from the SEM micrograph (Fig. 5), clearly provides

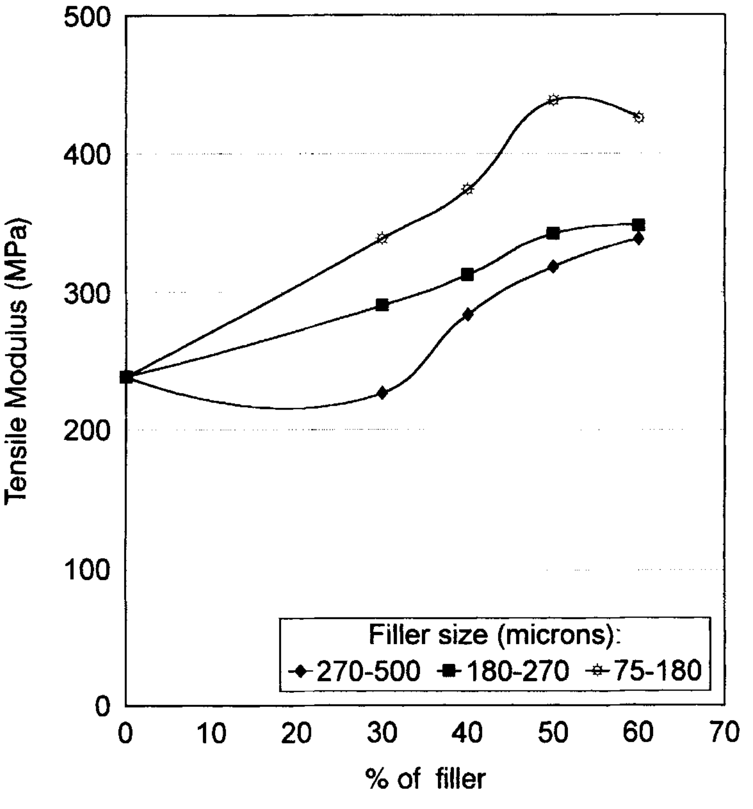

FIGURE 3 Effect of filler loading and particle size on tensile modulus.

supportive evidence for the poor impact properties of the composites. The results in Figure 5 also show that, samples with smaller particle size demonstrate greater impact strength than the larger ones. This is expected since, samples with smaller size filler not only possess better homogeneity (i. e. higher filler-matrix interactions) than the larger ones [7], but also relatively higher absorption energy during the fracture process.

Scanning electron microscopy (SEM) was employed to study the tensile fracture surfaces of composite samples based on 40 and 60% fibres of sizes 270–500 µm. The objective is to get some idea on filler dispersion and bonding quality between filler and matrix and also to detect the presence of microdefects if any. SEM micrographs of the

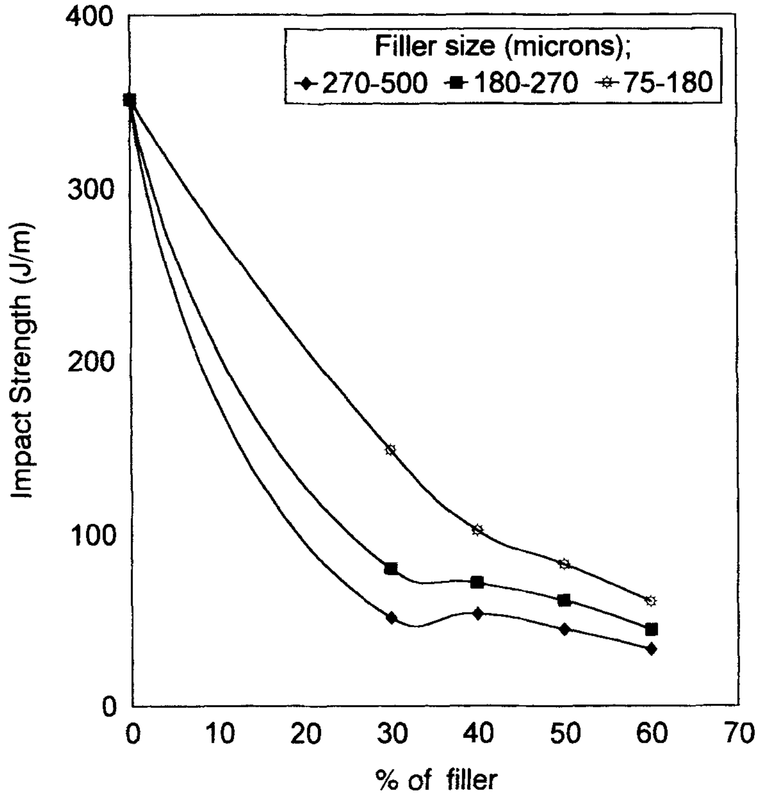

FIGURE 4 Effect of filler loading and particle size on impact strength.

fracture surfaces are shown in Figures 5(A) and (B) with a magnification of X 35, and Figures 5(C) and (D) with a magnification of X 100.

It is known that composite materials with satisfactory mechanical properties can only be achieved if there is a good dispersion and wetting of fibres in the matrix that will give rise to strong interfacial adhesion. However, this is not the case when OPF fillers are used in PE. The polarity of lignocellulose OPF fillers is obviously not capable of forming a good filler-matrix interaction with the non-polar PE. On the contrary, due to hydrogen bonding, these fillers have a greater tendency to agglomerate into fibre bundles. These fibre bundles can be observed by SEM to be distributed unevenly throughout the matrix.

FIGURE 5 (A) – Scanning electron micrograph of tensile fracture surface of 40% OPF-PE composite. Magnification: 35 X.

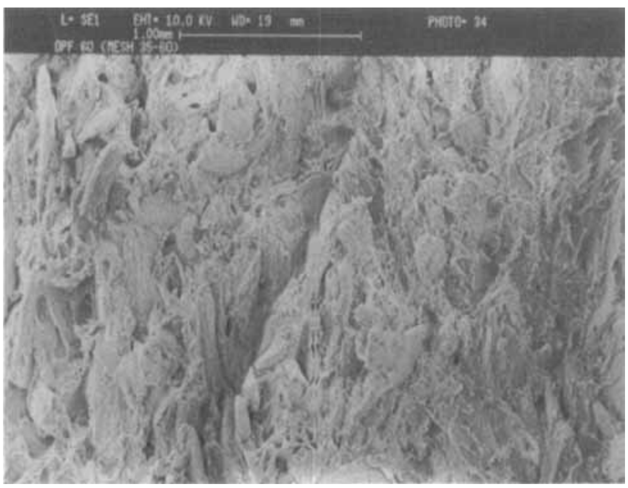

FIGURE 5 (B) – Scanning electron micrograph of tensile fracture surface of 60% OPF-PE composite. Magnification: 35 X.

Figure 5 (A) and (B) illustrate the SEM micrographs of composites filled with 40 and 60% fibres of sizes 270–500 μm, respectively. In Figure 5(C), fibre bundles of diameter about 500 μm can be seen on

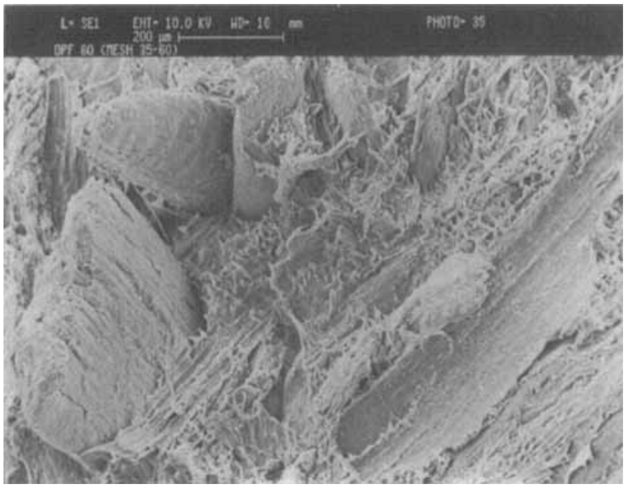

FIGURE 5 (C) – Scanning electron micrograph of tensile fracture surface of 60% OPF-PE composite. Magnification: 100 X.

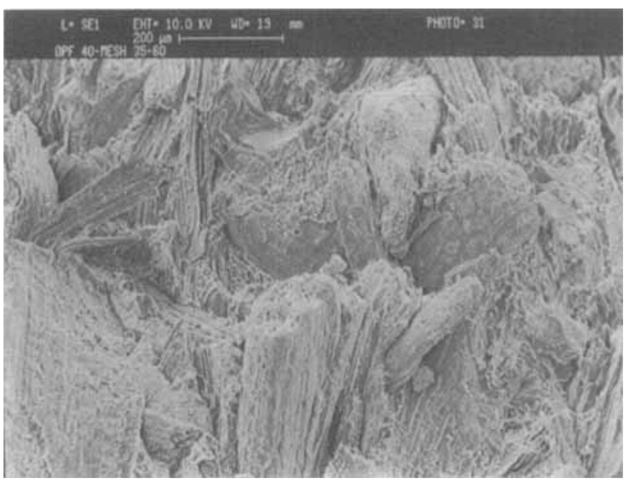

FIGURE 5 (D) – Scanning electron micrograph of tensile fracture surface of 40% OPF-PE composite. Magnification: 100 X.

the crack plane. The presence of such fibre bundles is expected to give a detrimental contribution to the tensile and impact strengths of the PE composites. Perhaps a significant improvement in strength properties could be achieved if the fibres were to be dispersed uniformly as fine fibres (i. e. much smaller in diameter) in the matrix. The efficiency of filler dispersion can be enhanced by using coupling agents and also high shearing compounding equipment such as a twin screw extruder. The role of coupling agent is not merely as a dispersing agent but more importantly to improve the bonding quality between the filler and the polymer matrix. Figure 5(B) also shows holes that indicate the occurrence of fibre bundle pull out. This may be due to poor interfacial bonding between untreated fibre and matrix. Further evidence for the poor bonding can be obtained from the SEM micrograph shown in Figure 5(D). A trace of a fibre surface with its bordered-pits printed in the matrix clearly indicates that the OPF fibres were merely imbedded in the PE matrix without a good bonding at the interface.

CONCLUSIONS

This paper reports on the effect of filler size and filler loading of OPF on the mechanical properties of PE composites. The conclusions from this study are summarized as follows:

1. The incorporation of the OPF fillers into PE matrix has resulted in the reduction of tensile and impact properties. This has been attributed to the geometry of the OPF whereby the irregular shaped fibre bundles reduce the capability of the composites to support stress transfer from the polymer matrix. Extensive fibre bundle pull out and debonding have been observed to be the dominant mode of failure.
2. In general, OPF-PE composites with smaller filler sizes displayed superior tensile and impact properties than the larger ones. It is believed that better filler dispersion is the main factor responsible for the observed trend.

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