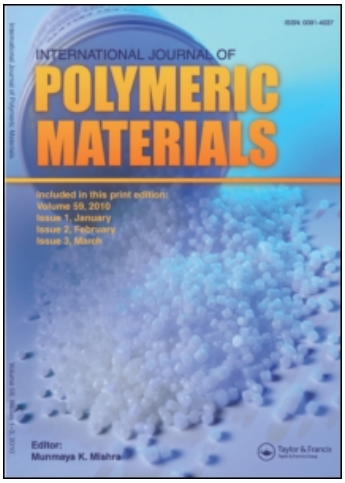

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

A preliminary study on the oil palm empty fruit bunch-polyurethane (EFB-PU) composites

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Online publication date: 27 October 2010

To cite this Article Rozman, H. D. , Tay, G. S. , Abubakar, A. and Kumar, R. N.(2002) 'A preliminary study on the oil palm empty fruit bunch-polyurethane (EFB-PU) composites', International Journal of Polymeric Materials, 51: 12, 1087 — 1194
To link to this Article: DOI: 10.1080/714975695
URL: http://dx.doi.org/10.1080/714975695

International Journal of Polymeric Materials, 51:1087–1094, 2002

0091-4037/02 $12.00 + .00
DOI: 10.1080/00914030290109877

A PRELIMINARY STUDY ON THE OIL PALM EMPTY FRUIT BUNCH-POLYURETHANE (EFB-PU) COMPOSITES

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Empty fruit bunch-polyurethane (EFB-PU) composites were produced by reacting EFB and polyethylene glycol (PEG) with diphenylmethane diisocyanate (MDI). From the results of flexural and impact properties, it was found that these properties were influenced by the percentage of OH groups of EFB, coupled with the reinforcing effect of EFB filler. In addition to that, the formation of PU matrix from PEG and isocyanate proved to be crucial in producing good stress transfer from the matrix to the filler.

Keywords: polyurethane, composites, mechanical properties

INTRODUCTION

Lignocellulosic materials have been the focus of various studies in recent times in making composites, particularly, in thermoplastic composites [1–8]. This has been attributed to several advantages offered by lignocellulosic fillers, such as lower density, greater deformability, less abrasiveness to equipment, biodegradability and lower cost. However, in producing good lignocellulosic-thermoplastic composites, in terms of mechanical and physical properties, the main obstacle to be resolved is the compatibility between them. Various chemical reagents have been employed as coupling agents to enhance the compatibility between the constituent materials [2, 3, 9–12].

There have been attempts to employ lignocellulosic materials as reactive reinforcements in composites, *i.e.*, by involving the functional groups of the lignocellulosic to interact chemically with the matrix. This approach enlarges the scope of incorporation in wider range of polymeric matrix

Received 22 August 2000; in final form 27 August 2000.
The authors would like to thank Universiti Sains Malaysia, Penang, for the research grant and Sabutek Sdn. Bhd., Teluk Intan, for the cooperation and technical support that have made this research work possible.
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materials, thereby widening the potential application. One of the areas of interest is in producing polyurethane-based composites. It is generally accepted that PU is one of the most useful three-dimensional polymers. This is due to its unique features, *i.e.*, it can be produced in the form of sheets, foams, adhesives, *etc.* Many attempts to utilize lignocellulosics as raw materials for PU synthesis have been reported. Natural polymers having more than two hydroxyl groups per molecule can be used as polyols for PU preparation, if the polyols from natural polymers can be reacted efficiently with isocyanates. Glasser *et al.*, had prepared PU from hydroxyalkylated lignin [13]. Hirose *et al.*, found that molasses could be used to produce PU foams and sheets [14]. Hatakeyama *et al.*, attempted several types of lignin, wood meal and wood tar residue for making PU in the form of sheet, foam and composites [15].

In this study, the reinforcing filler used is derived from an oil palm tree (Elais guineensis) component, namely EFB. This material is a by-product of the palm oil industry, a bunch of fibers in which the palm fruit are embedded and consists of about 65% of holocellulose and 25% of lignin [16]. The EFB waste generated by the industry is estimated to be about 8×10^6 tons per year. Thus, finding useful utilization of the EFB will surely alleviate environmental problems related to the disposal of oil palm wastes.

EXPERIMENTAL

Materials

The EFB in fiber form was obtained from Sabutek Sdn. Bhd., Teluk Intan, Perak, Malaysia. Diphenylmethane diisocyanate (MDI) was supplied by Aldrich Chemical Company, Inc. Polyethylene glycol with molecular weight of 200 (PEG 200) was obtained from Fluka Chemika.

Preparation of EFB-PU Composite

EFB filler was obtained in the form of long strands of fibers. The fibers were ground into small particles. Endecotts sieve was used to separate the particles into different sizes. The filler size used in this study were of mesh 35–60, 60–80, 80–100 and 100–270. The fillers were dried in an oven at 105°C for approximately 20 hours. PEG was dried by mixing it with "molecular sieve type 3A" powder. EFB-PU composite was produced by a "one-shot" process. Firstly, EFB filler was mixed with diphenylmethane diisocyanate (MDI) at room temperature, followed by the addition of polyethylene glycol (PEG). Mixing was carried out using a mechanical stirrer. Each of the partially cured EFB-PU mixture was hot-pressed at 125°C for 5 hours at a pressure of 500 kg/cm^2. The sample was then post-cured in an oven at 125°C for 24 hours.

Determination of Hydroxyl (OH) Content of EFB

The OH content was determined by reacting EFB with phthalic anhydride in pyridine, followed by titration with sodium hydroxide. In this study, the overall amount of OH (EFB and PEG) in the system was kept constant. However, the amount of OH from EFB was varied; 20, 40, 60, 80 and 100% from the overall amount of OH.

Testing

The sheet produced was cut into 2 types of test samples; *i.e.*, flexural and impact tests. Flexural test was conducted according to ASTM D790, *i.e.*, a three-point bending system, using Universal Testing machine Model STM-10. The samples with dimensions of $15 \times 1.5 \times 0.3$ cm, were tested at a cross-head speed of 2.0 mm/min. The Izod impact test was carried out according to ASTM D256 on unnotched samples with dimensions of $6.5 \times 1.5 \times 0.3$ cm, using Zwick Impact Pendulum Tester Model 5101. The impact strength was expressed in J/m of sample mean thickness. A minimum of six samples were tested in each case. Flexural toughness was calculated from the area under stress-strain curve. The calculations for flexural modulus and strength are given below.

$$\text{Flexural modulus} = \frac{L^3 \Delta W}{4bd^3 \Delta S}$$

$$\text{Flexural strength} = \frac{3WL}{2bd^2}$$

where;

L = the span between the centers of supports (m)
W = the ultimate failure load (N)
ΔW = the increment in load (N)
b = the mean width of the sample (m)
d = the mean thickness of the sample (m)
ΔS = the increment in deflection (m).

RESULTS AND DISCUSSION

Figure 1 depicts the effect of the % of EFB and particle size on the flexural strength of the EFB-PU composite. Generally, the composites show maximum flexural strength at 40 – 50% EFB. It can be seen that more EFB loading is needed to achieve maximum strength as the size of filler is increased. Generally, it appears that sample with smaller size produce lower flexural strength. This is in contrary to previous works with EFB in

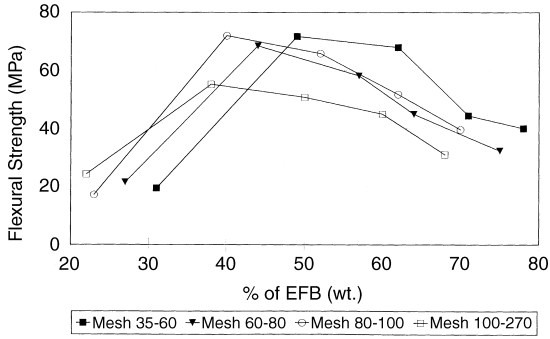

FIGURE 1 The effect of EFB loading on flexural strength.

thermoplastic matrix where the smaller the size the better the strength, where factors other than fiber length such as mode of failure, plasticization and better tendency for consolidation in hot pressing, *etc.*, play significant role [1–6]. It is believed that the deciding factor in the present case appears to be (1) availability of EFB hydroxyl groups (OH) (2) active participation of the OH groups with isocyanate, leading to an integrated thermoset matrix. Figure 2 explains the effect of the % of OH of EFB on the flexural strength. It is obvious that for all samples with different filler sizes, the maximum strength are achieved at 40% accessible OH of EFB.

Results of flexural modulus (Figs. 3 and 4) show similar trend to those of the strength. Figure 5 shows the effect of % of EFB and filler size on the flexural toughness of the composites. As shown by the flexural strength results (Fig. 1), the toughness of samples with larger particle size of filler are higher. The toughness of the samples increase as the % EFB is increased up to an extent, after which it decreases. It seems that the limiting values of toughness of samples with different filler sizes differ from one to another.

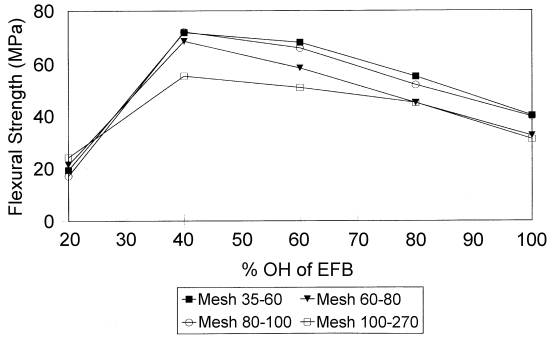

FIGURE 2 The effect of %OH of EFB on flexural strength.

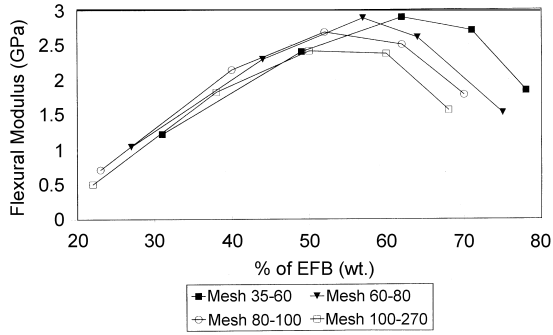

FIGURE 3 The effect of EFB loading on flexural modulus.

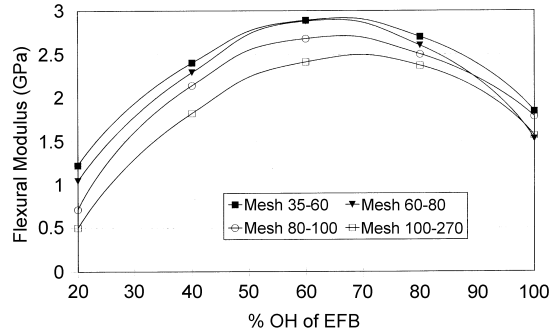

FIGURE 4 The effect of %OH of EFB on flexural modulus.

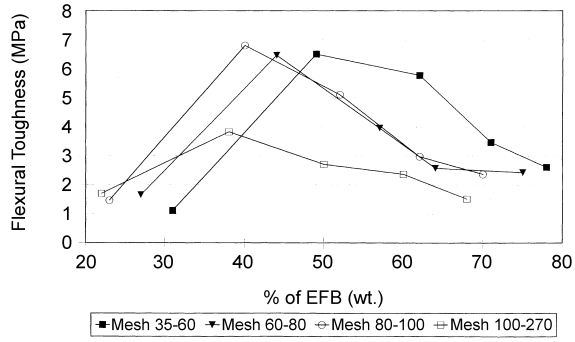

FIGURE 5 The effect of EFB loading on flexural toughness.

However, by looking at Figure 6, it could be seen that the deciding factor is the % of accessible OH groups. For all samples, the limiting toughness is when the % of OH is at 40%. Since the toughness indicates the energy

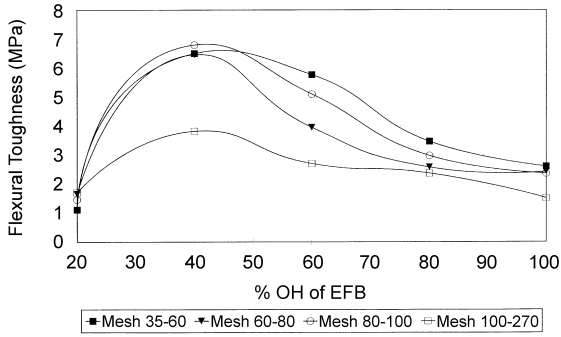

FIGURE 6 The effect of %OH of EFB on flexural toughness.

required to break a sample, the results show that more energy is needed to break samples with bigger filler size. As explained previously, this may be contributed by the active participation of OH groups with isocyanate through the formation of urethane bondings. Samples with smaller filler size (higher surface area) would leave more surface exposed and hence unreacted with isocyanate. This would lead to the creation of more stress points. Thus, that is why the energy needed to bring to failure is lower for sample with smaller size particles compared to those with bigger ones.

From the results of impact strength (Figs. 7 and 8), it is clear that there is a limit on the addition of EFB in improving the strength. Since the total OH content is kept constant, the quantity of PU matrix (reaction of PEG and isocyanate) is expected to be accordingly reduced as the OH content of EFB increases. Hence, it affects the energy required to break the samples. However, the actual strength of the samples are rather high. This clearly shows that an effective interaction has occurred between OH groups of EFB

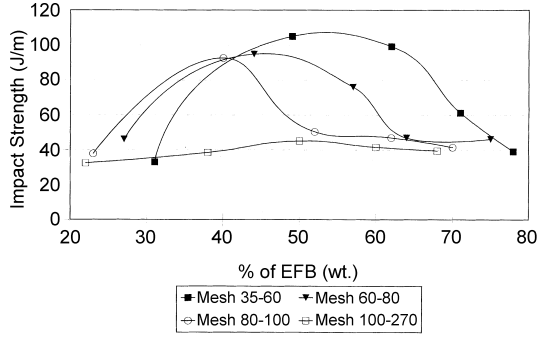

FIGURE 7 The effect of EFB loading on impact strength.

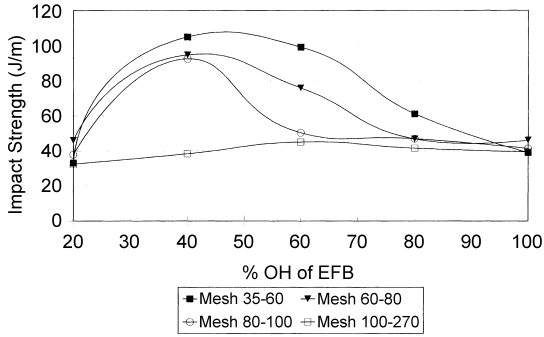

FIGURE 8 The effect of %OH of EFB on impact strength.

and isocyanate to produce sufficient covalent bonds to give rise to higher mechanical strength.

CONCLUSIONS

The study showed that the flexural and impact properties increased as the % of EFB and OH of EFB were increased. However, it was found that a limiting value was achieved at 40–50% EFB loading, after which the strength decreased. The results indicated that the PU matrix also played a significant role in determining the strength. From this study, it can be said that the strength of EFB-PU composites were contributed by,

(1) % OH and reinforcing effect of EFB
(2) the degree of formation of polyurethane matrix from PEG and isocyanate
(3) surface area of filler

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