Research Article

Mechanical Properties of Oil Palm Shell Composites

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The mechanical properties of oil palm shell (OPS) composites were investigated with different volume fraction of OPS such as 0%, 10%, 20%, and 30% using unsaturated polyester (UPE) as a matrix. The results presented that the tensile strength and tensile modulus of the UPE/OPS composites increased as the OPS loading increased. The highest tensile modulus of UPE/OPS was obtained at 30 vol% of OPS with the value of 8.50 GPa. The tensile strength of the composites was 1.15, 1.17, and 1.18 times higher than the pure UPE matrix for 10, 20, and 30 vol% of OPS, respectively. The FTIR spectra showed the change of functional group of composites with different volume fractions of OPS. SEM analysis shows the filler pull-out present in the composites which proved the poor filler-matrix interfacial bonding.

1. Introduction

Over the past few decades, natural fiber composites have gained significant importance in various applications such as automotive components for producing seat backs, door panels, package trays, headliners, interior parts, and dashboards [1, 2]. The idea of the conventional nonrenewable reinforcement substitution such as glass fiber with natural fiber is invented as a response to the environmental legislation as well as consumer pressure. Thus, environmentally friendly natural fiber composites are widely introduced to industries as they possess many advantages over synthetic fibers such as renewable source, biodegradability, low density, low energy consumption, and nonabrasiveness [3, 4]. Natural fiber reinforced polymer composites also have some disadvantages such as incompatibility with petroleum based polymeric matrices, high moisture absorption capability, and insufficient adhesion between hydrophilic fiber and hydrophobic polymer [5].

Recently thermosetting resin such as epoxies, polyester, and phenolic has attracted the attention of the scientist, researchers, and manufacturers. Orthophthalic unsaturated polyester (UPE) has been used due to its advantages over

other thermosetting resins, including good mechanical, thermal, and room temperature cure capability, low cost, and transparency [6, 7]. Utilization of oil palm shell (OPS) as filler materials in the manufacture of biocomposites can solve the agriculture disposal problem in an environmentally friendly manner. OPS are being used as thermal insulator, concrete ingredient in building industry, carbon activation for water purification, fuel for the heat generation, and automobile disk brake pad [8]. Previous finding showed that the usage of OPS in the PP matrix enhanced the tensile strength, elongation at break, and impact strength but reduced the tensile modulus of the PP composites [9]. This contributes a significant role in improving the mechanical properties of the polymer composite.

Malaysia is the world's second largest palm oil producers and exporters after Indonesia. The palm oil industry of Malaysia generates approximately 80 million tons of solid waste biomass annually, including empty fruit bunch, trunk, frond, mesocarp fiber, and oil palm shell. Generally, oil palm industries in Malaysia generate an abundant amount of OPS approximately in 4 million tons per year [10]. Proper utilization not only will be able to solve the disposal problem but also can convert all of these by-products into higher value-added products such as biocomposites [10]. Currently,

the use of oil palm wastes as filler in composite materials has gained attention among researchers and industries owing to today's ecological issues and economic factors. In this study, OPS is chosen as filler due to its lower moisture content (10%) among the other wastes such as EFB and sugar palm fiber [11]. In order to achieve the objectives, the scope of the research is to make a feasibility study on the addition of OPS to the UPE matrix for the improvement of the mechanical properties of composites. Different fiber loadings are used to get the maximum fiber volume fraction to achieve optimum composite strength. Fracture surfaces of the UPE/OPS bio-composites and the presence of functional chemical groups in OPS are examined by scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). The mechanical properties test on composites was carried out according to ASTM standard.

2. Experimental Details

2.1. Materials. Oil palm shell (OPS) with size 1.0–2.8 mm was obtained from Beaufort, Sabah, Malaysia. The orthophthalic unsaturated polyester resin and Methyl ethyl ketone Peroxide (MEKP) with density 1.17 g/cm^3 were supplied from Sepangar Hardware, Kota Kinabalu, Sabah, Malaysia.

2.2. Sample Preparation. Specimens with four different compositions of filler content such as 0, 10, 20, and 30 vol% of OPS in 100, 90, 80, and 70 vol% of an unsaturated polyester matrix were mixed with 1 vol% of MEKP and were prepared. The mixtures were poured into a flat surface mold for preparing specimens of UPE/OPS composites using a compression mold technique. The molds were left to cure in room temperature for 24 hours. After curing time for the composite material, the specimens were taken out and cut into the standard tensile dimension by using a hacksaw.

2.3. Tensile Testing. The tensile test was performed according to ASTM D5083. The test was carried out with a Universal Testing Machine (UTM) model GOTECH AI-7000-M equipped with a load capacity of 10 kN. 10 specimens were cut from the plates by using cutter with the size of specimens for the tensile test being 150 mm (length, L) $\times$ 25 mm (width, W) $\times$ 3 mm (thickness, T).

2.4. Water Absorption Test. Water absorption test was carried out according to ASTM D570. Edges of the samples were sealed with polyester resin and subjected to moisture absorption. The samples were dried at 80°C for 24 hours. The specimens were weighed and recorded using weighing balance. The composite specimens were immersed in distilled water at room temperature until the water content reached saturation [12]. The specimens were periodically taken out of the water, wiped with a clean dry cloth to remove the surface's water, and weighed again within 1 minute of removing them from water in order to avoid any errors due to evaporation. The weight mean of specimens was recorded using standard weighing balance with 3-decimal place [0.001 g] readability.

2.5. Measurement of Density. The density (ρ) of composite was determined using standard formula [3]. Initially, specimens were weighted (m) and then the volume (V), that is,

10 mm (length, L) $\times$ 10 mm (width, W) $\times$ 3 mm (thickness, T), of the specimens was measured.

2.6. Fourier Transform Infrared Spectroscopy. Fourier transform infrared (FTIR) spectroscopy was used in order to detect the presence of the functional groups in the composites. The spectra of the composites were obtained using an IR spectrometer (Perkin-Elmer Spectrum 100). About 2 mg of the sample was pressed into a disc of about 1 mm thick. The FTIR spectra of the sample were collected in the range of $4000\text{--}600 \text{ cm}^{-1}$.

2.7. Scanning Electron Microscope (SEM) Analysis. Morphological studies of the UPE/OPS composites were carried out using an SEM JEOL JSM-5610LV. SEM was used to observe the fracture surface of the composite samples.

2.8. Statistical Analysis. Statistical analysis method was used in order to analyse the result obtained. One-way analysis of variance (1-way ANOVA) test with P value < 0.005 was used to determine whether increasing OPS content gives significant effect on the composite tensile properties such as tensile strength, tensile modulus, and elongation at break.

3. Results and Discussion

3.1. Tensile Properties. Mechanical properties of UPE/OPS were presented in Figure 1 at a different volume fraction of fiber (0, 10, 20, and 30 vol%). It showed that Young's modulus of 10 vol% was higher than pure unsaturated polyester, but it was getting lower when the fiber content was increased to 20 vol% as displayed in Figure 1(a). The highest tensile modulus for UPE/OPS was obtained at 30 vol% with the value of 8.50 MPa. Since the addition of OPS particles to UPE matrix developed a rigid interface, it will inhibit the matrix chain mobility and cause the tensile modulus of UPE/OPS to increase with the addition of OPS to 10 vol%. This is attributed to stiffer and more rigid composites [13]. For 20 vol% of OPS, the value showed lower tensile modulus (stiffness) of the composites which in turn increased the elongation at break as a stiff material reducing deformability of a rigid interface between the OPS and matrix and changed its shape slightly under elastic loads [14].

Figure 1(b) shows the effect of fiber content on the tensile strength of UPE/OPS composites. From the figure, the tensile strength increased with the increasing of filler content due to the strong interfacial bonding between the UPE matrix and OPS particles. A strong bonding between the hydrophilic filler and the hydrophobic matrix polymer increased the stress transfer efficiency and resulted in higher strength [15]. Therefore, the composite can sustain higher load before failure compared to the unreinforced polyester. The tensile strength of the composites was 1.15, 1.17, and 1.18 times higher than the pure matrix for 10 vol%, 20 vol%, and 30 vol%, respectively. Based on the ANOVA analysis, there is significant difference in the tensile strength of the different OPS contents.

The elongation at break increased with the increase of loading up to 20 vol% and then decreased with 30 vol%

FIGURE 1: Mechanical properties results of UPE/OPS composites: (a) Young's modulus, (b) tensile strength, and (c) elongation at break.

FIGURE 2: Water absorption of UPE/OPS composites.

of UPE/OPS composites as presented in Figure 1(c). This showed that addition of OPS up to 30 vol% enhanced the rigidity of the composite formed. This could be attributed to insufficient wetting of the fiber as well as the possibility of increasing fiber-rich or matrix-rich areas within the composite and led to poor interfacial bonding between the fiber and the matrix [16]. According to Azuan [7], the decrement in elongation at break is due to poor interfacial bonding between OPS and matrix. Hence, it can be said that the UPE/OPS composite with 20 vol% OPS has relatively higher or better elasticity.

FIGURE 3: Density of UPE/OPS composites.

FIGURE 4: FTIR of UPE/OPS composites.

3.2. Water Absorption. Based on Figure 2, the water absorption of UPE/OPS composites increased with OPS content, which indicated that water absorption of composite is higher than the UPE matrix. As proposed by Salmah et al. [13], the structure of OPS consists of hydroxyl groups that give the hydrophilic properties of absorbing water which has been proved by pure polyester that shows the lowest percentage in water absorption. Moreover, the presence of microcracks and gaps between OPS and UPE enhance the diffusion of water and thus the water absorption increases with the increase

of OPS content. This result proves that the OPS possess low moisture absorption compared to sugar palm fiber reinforced unsaturated polyester composites which gives high value of water absorption, that is, 1.57% and 3% for EFB reinforced polyester composites [17, 18].

3.3. Density Property. The effects of fiber content on the density of composites are given in Figure 3. The unsaturated polyester (UPE) matrix had a density of 1.29 g/cm³, and the composite density decreased relative to the matrix with the

FIGURE 5: SEM at 1000x magnification of tensile fracture surface of UPE/OPS composites: (a) 0 vol% OPS; (b) 10 vol% OPS; (c) 20 vol% OPS; and (d) 30 vol% OPS.

addition of OPS to the UPE matrix. The density of UPE/OPS composites was 1.26 g/cm^3 , 1.24 g/cm^3 , and 1.20 g/cm^3 for 10, 20, and 30 vol% of OPS content, respectively. Thus, from our finding, it is clearly showed that the density of UPE/OPS composites decreased linearly with the increase of OPS which fulfils the requirement of manufacturer for application in both construction and automotive industries.

3.4. FTIR Analysis. From Figure 4, The FTIR spectra show that the peaks appearing in the 4 spectra were almost the same. In neat unsaturated polyester, the band at 3412.61 cm^{-1} is characteristic of the hydrogen bonded -OH stretching vibration. This is partly because the sample had been exhibited in the open air for days, and, as a consequence, there had been almost continuous absorption of moisture into the unsaturated polyester. Furthermore, this peak is caused by the hydroxyl group from MEKP as well. Neat unsaturated polyester has a peak at 3074.41 cm^{-1} resulting from the =C-H stretch in aromatic and unsaturated hydrocarbon, and a peak at 2932.01 cm^{-1} resulting from the -CH₃ and -CH₂ in aliphatic compounds. The peak at 1726.08 cm^{-1} indicates the presence of C=O stretching and the peaks at 1610.38 cm^{-1} and 1450.19 cm^{-1} can be assigned to aromatic ring stretching. The peak at 1383.44 cm^{-1} was corresponding to the COO- stretching. The absorption bands observed in the 1285.54 cm^{-1} and

1120.89 cm^{-1} are related to the C-O-C stretching in ester. The bands at 1067.49 cm^{-1} are due to the unsaturated in-plane deformation. A doublet at 751.55 cm^{-1} and at 698.15 cm^{-1} might be attributed to C-H out-of-plane deformation for unsaturated, aromatic compound. In addition, the peak at 475.65 cm^{-1} indicates the presence of C-O-C bending in ether.

For OPS reinforced unsaturated polyester, the wavenumber in the range of 3417.06 cm^{-1} to 3421.51 cm^{-1} indicated the O-H stretch of the hydroxyl group from cellulose, hemicellulose, and lignin. The intensity of this -OH group absorption band is increased with increasing OPS content. This indicated that the hydrophilic properties of OPS are increased. The peak in the range of 1726.08 cm^{-1} to 1730.53 cm^{-1} is C=O stretch from hemicellulose and lignin. The band in the range of 1441.29 cm^{-1} to 1454.64 cm^{-1} is due to the presence of O-CH₃ in lignin. The peak at 1276.64 cm^{-1} can be assigned to C-O-C stretching and confirmed the formation of ester bonds. The peak in the range of 1125.34 cm^{-1} to 1129.79 cm^{-1} contributed to C-O-C in ether group from cellulose, hemicellulose, and lignin. The peaks in the range of 1063.04 cm^{-1} to 1071.94 cm^{-1} are due to the C-O stretch in C-OH. Moreover, peak in the range of 471.20 cm^{-1} is referring to C-O-C bending in ether group.

FIGURE 6: SEM micrograph of UPE/OPS composite with 20 vol% OPS at 1000x magnification.

3.5. SEM Analysis. Figure 5 shows the fracture surface of UPE/OPS composites after tensile testing. It shows that the filler detached from the fracture surface in the composites which proved the poor filler-matrix interfacial bonding [17]. The presence of a discontinuity between filler and matrix is mainly caused by the poor wetting of the hydrophilic filler by a hydrophobic polymeric matrix [19]. In Figure 6, it can be seen that some of the fibers broke at the fracture plane.

4. Conclusions

The study found that the increasing of OPS content has increased the tensile strength of UPE/OPS composites. The results showed that the optimum fiber content for the tensile modulus of UPE/OPS was 30 vol% OPS with the value of 8.50 GPa. The tensile strength of the composites were 1.15, 1.17, and 1.18 times higher than the pure UPE matrix for 10 vol%, 20 vol%, and 30 vol%, respectively. For the elongation at break, it was increased with the increasing of OPS loading up to 20 vol%. The water absorption and moisture content of UPE/OPS composites increased with increasing of OPS content due to the hydroxyl groups in the fibers. SEM analysis shows that the filler detached from the fracture surface which proved the poor filler-matrix interfacial bonding.

Competing Interests

The authors declare that they have no competing interests.

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