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Effect of Phthalic Anhydride on Tensile Properties and Thermal Stability of Recycled High Density Polyethylene / Wood Fiber Composites

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Abstract –*The effect of phthalic anhydride as a coupling agent on the tensile properties and thermal stability of recycled high density polyethylene/wood fiber (rHDPE/WF) composites were studied. Both composites rHDPE/WF and rHDPE/WF/PAH (modified with phthalic anhydride) were prepared using Brabender Plasticorder at temperature of 160°C and rotor speed of 50 rpm. The result indicated that rHDPE/WF/PAH composites exhibit higher tensile strength and modulus of elasticity than rHDPE/WF composites. It was also found that the addition of phthalic anhydride offers better thermal stability in rHDPE/WF/PAH composites than rHDPE/WF composites.*

Keywords: Recycled high density polyethylene, Wood fiber, Phthalic anhydride

1.0 INTRODUCTION

A renewable natural organic fibers act as reinforcing materials which are biodegradable and ecofriendly for the use of glass or carbon fiber and inorganic fillers. These fibers have advantages which are high specific strength modulus, low cost, low density, renewable organic, nonhazardous, malleable, wide availability, and relatively no abrasiveness [1]. Aina et al. [2] reported that the different types of wood species (funtumia elastic, brachystegia kennedy and milica excels) in rHDPE matrix at different ratio of fiber will reduce the tensile strength but improve the modulus of elasticity of composites. Through studies and research, thermoplastic or natural fibers composites like wood plastic composites (WPC) are proven to have high qualities in technical application fields, for example in load-bearing applications. Polyethylene which is a polymer has wide applications in our modern world. These polymers are frequently used thermoplastic for the production of natural fiber to prepare composites and compounded with natural minerals so as to improve their properties. This is due to its lower melting point, and general availability [3].

In America, the commercial use of natural fibers in plastics has been limited to wood fiber because the use of this wood fiber as filler in the composites increases stiffness and reduces toughness. The composites are brittle due to stress concentrations at fiber ends and poor interfacial adhesion between wood and synthetic polymer. Researches have been done in developing new coupling agents, compatibilizers [4] and to improve processing methods [5].

Supri et al. [6] presented that vinyl alcohol-phthalic anhydride as a coupling agent have enhanced the interfacial adhesion between Low Density Polyethylene (LDPE) and tyre dust improving compatibility of the composites, as evidenced by the thermal stability using X-ray Diffraction (XRD). Supri et al. [7] also approved that chicken feather fiber more widely dispersed in the LDPE matrix with addition of polyethylene grafted maleic anhydride as a coupling agent. This paper reports the effect of phthalic anhydride on tensile properties and thermal degradation of rHDPE/WF composites.

2.0 METHODOLOGY

Materials. The recycled high density polyethylene (rHDPE) with a melt flow index of 0.7 g/min at 190 °C, density of 939.9 kg/m^3, glass transition temperature of -80 °C, melting temperature of 126 °C and water absorption content less than 0.01 % was supplied by Mega Makmur Sdn. Bhd., Penang, Malaysia. The wood fibers with size of 199 µm and types Pulverised Wood Fiber with grade mix wood was obtained from Titan Petchem (M) Sdn. Bhd., Pasir Gudang, Johor, Malaysia. PAH ($C_6H_4(CO)_2O$ with molar mass=148.12 g/mol was used as coupling agents and obtained from AR Alatan Sdn. Bhd., Alor Setar, Kedah, Malaysia.

Sample Preparation. The formulation of recycled high density polyethylene/wood fiber (rHDPE/WF) composites with and without phthalic anhydride is given in Table 1. The compounding of the composite was carried out by using the Brabender Plasticorder was set at temperature 160 °C rotor speed of 50 rpm. Two types of composites were prepared, rHDPE/WF and rHDPE/WF/PAH with modified phthalic anhydride. rHDPE was then charged into Brabender Plasticorder to start the melt mixing. rHDPE was preheat for 2 minutes in the mixing chamber. Next, wood fiber with or without phthalic anhydride were added to the soften rHDPE. The mixing process was allowed for another 8 minutes to obtain homogeneous composites. The composites was discharged from the mixing chamber and pressed into thick round pieces. The discharged composites were then allowed to cool under ambient temperature.

Table 1: Formulations of rHDPE/WF with and without phthalic anhydride at different fiber loading.

Codes	rHDPE (phr)	Wood Fiber (phr)	Phthalic Anhydride (phr)
rHDPE/WF0	100	-	-
rHDPE/WF5	100	5	-
rHDPE/WF10	100	10	-
rHDPE/WF15	100	15	-
rHDPE/WF20	100	20	-
rHDPE/WF30	100	30	-
rHDPE/WF5/PAH	100	5	6
rHDPE/WF10/PAH	100	10	6
rHDPE/WF15/PAH	100	15	6
rHDPE/WF20/PAH	100	20	6
rHDPE/WF30/PAH	100	30	6

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Compression Molding. Samples of rHDPE/WF and rHDPE/WF/PAH with phthalic anhydride composites were compressed via an electrical heated hydraulic press to produce the composites in plate form. The hot and cool press was set at the temperature of 160 °C for both top and bottom platen. Then, the composites were put into the mold, preheated for 6 minutes followed by compression for 2 minutes at the same temperature and subsequently cooled under pressure for 4 minutes.

Characterization and Measurements. Tensile tests were conducted based on ASTM D638 by using Instron 5569 with crosshead speed 10 mm/min. Dumbbell shaped specimens were conditioned at ambient temperature (25±3) °C and relative humidity (30±2) % before conduct the testing. Five dumbbell shaped samples were used for each blend composition. The tensile strength and modulus of elasticity of each composition were obtained from the test. Thermogravimetry analysis of rHDPE/WF composites with and without phthalic anhydride was done by using a Perkin Elmer Pyris 6 TGA analyzer. Samples of about 10 mg were scanned from 30 to 650 °C with a heating rate of 10 °C/min by using constant nitrogen gas flow of 50 ml/min to prevent thermal oxidation process of polymer sample. The temperature at 50% weight loss ($T_{-50\%WT}$), final decomposition temperature (FDT) and the residual mass of TG curve were calculated.

3.0 RESULTS AND DISCUSSION

Tensile Properties. The effect fiber loading on tensile strength of rHDPE/WF composites with and without phthalic anhydride is shown in Fig. 1. The result shows that as the loading of fiber increased, tensile strength of rHDPE/WF composites decreased due to incompatibility of rHDPE and wood fiber. This incompatibility reduced the tensile strength because fractured would be initiated from the weak interface of the composites due to their poor interfacial adhesion [8]. In the previous study, it was found that the strength of rHDPE that is used here is similar to those of virgin HDPE [9]. At a similar fiber loading, rHDPE/WF/PAH composites exhibits higher tensile strength compared to rHDPE/WF composites. This was due to the presence of PAH which help enhanced the interaction between the rHDPE and wood fiber and also effects of the stress transfer, hence reduced the chance of interfacial de-bonding and lead to improve their properties [6].

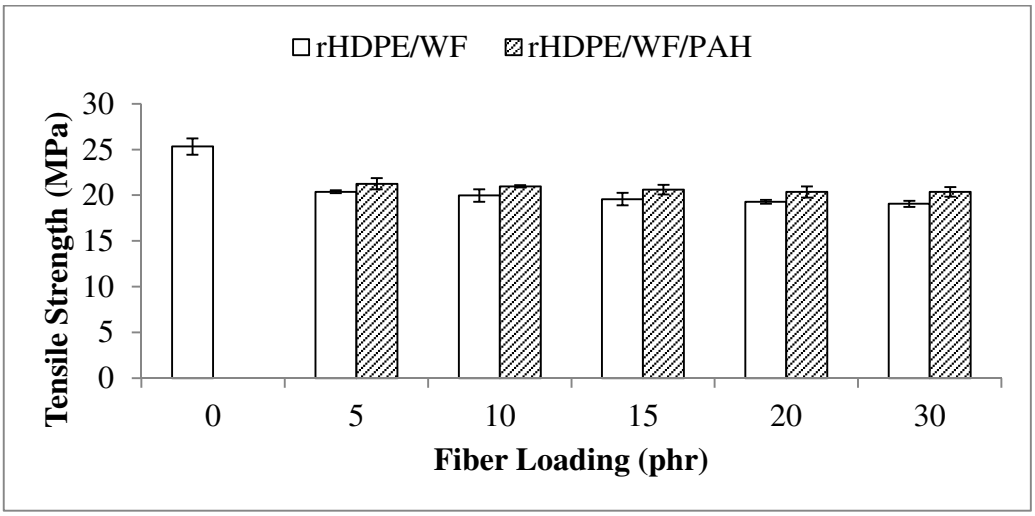

Figure 1: Tensile strength versus fiber loading of rHDPE/WF and rHDPE/WF/PAH composites.

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The effect of fiber loading on modulus of elasticity of rHDPE/WF composites and rHDPE/WF/PAH composites with phthalic anhydride is shown in Fig. 2. The modulus of elasticity of rHDPE/WF and rHDPE/WF/PAH composites tend to increase as filer loading increased. This was due to the presence of the fibers that provide the strength and stiffness in the composites. This result agrees with the finding of Supri et al. [7]. This indicated that the presence of fibers has reduced ductility of the rHDPE/WF composite and increased stiffness. It can be observed that the modulus of elasticity of rHDPE/WF/PAH composites exhibit a higher modulus of elasticity than rHDPE/WF composite. Again this was due to better interfacial adhesion between rHDPE and wood fiber with the presence of phthalic anhydride as a coupling agent [10].

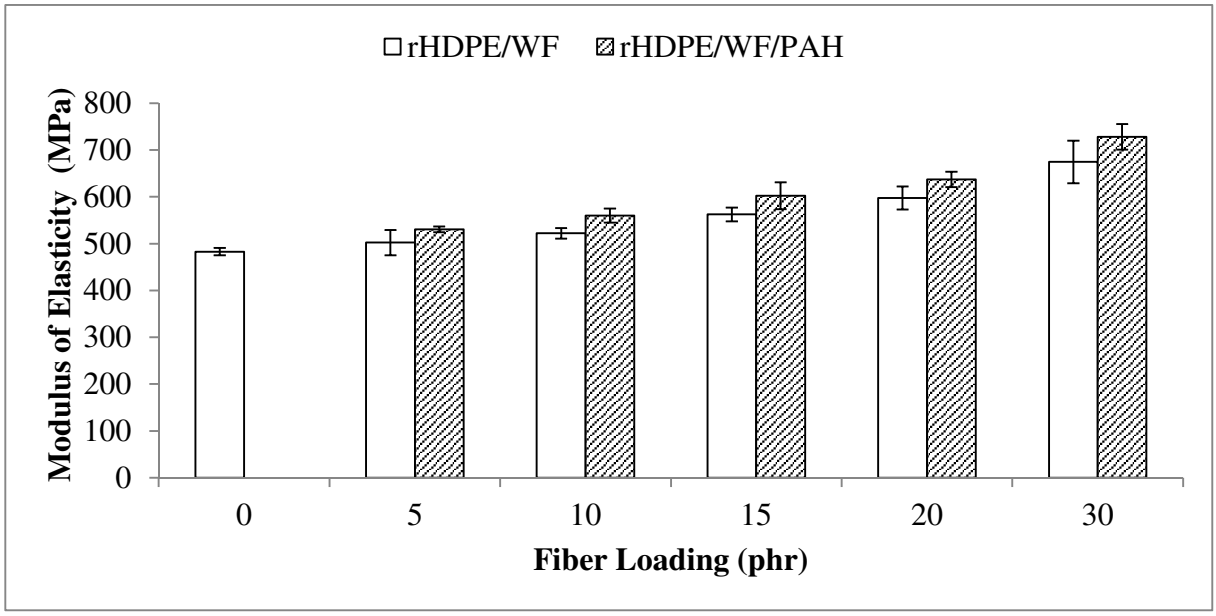

Figure 2: Modulus of elasticity versus filler loading of rHDPE/WF and rHDPE/WF/PAH composites.

Thermal Degradation. Figs. 3 and 4 show the typical thermal degradation curves of the effect on PAH of rHDPE/WF composites at different fiber loading. Table 2 shows the temperature of 50 % weight loss ($T\text{-}_{50\%wt}$) decreased with increasing fiber loading for both composites. This was due to lower degradation temperature at $T\text{-}_{50\%wt}$ weight loss than rHDPE matrix due to the degradation of WF at lower temperature causes of reduction thermal stability [11]. However, FDT and residual mass of both composites increased with increasing of WF loading, which indicated the residue mainly consists of decomposition products of the fiber reinforcement [12]. By comparing both sets of the composites with the same fiber loading, rHDPE/WF/PAH composites showed lower value of $T\text{-}_{50\%wt}$ and FDT due to wood fiber modified with PAH were less thermal resistance. However, the higher residual mass indicated enhanced thermal stability of rHDPE/WF/PAH composites compared to rHDPE/WF composites. In addition, the PAH might be due to the presence of good interfacial adhesion between fiber and matrix as a result of uniform dispersion of fiber throughout the matrix. This indicated that presence of acrylic anhydride (RCO-O-COR) group as coupling agent has increased the thermal stability of rHDPE/WF composites. According to Reddy et al. [13], these results clearly illustrate that the thermal stability of the extracted cellulose microfibrils was higher than that of the raw fibers. This was attributed to the removal of hemicellulose and lignin from the raw fibers on several chemical treatments.

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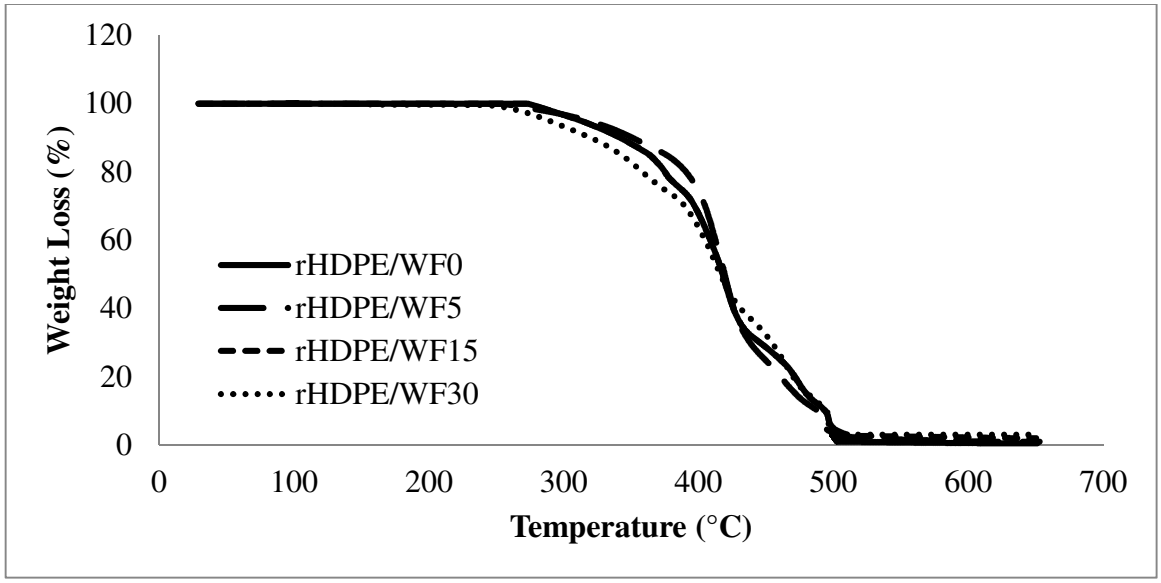

Figure 3: Thermogravimetric curves of rHDPE/WF composites at different fiber loading.

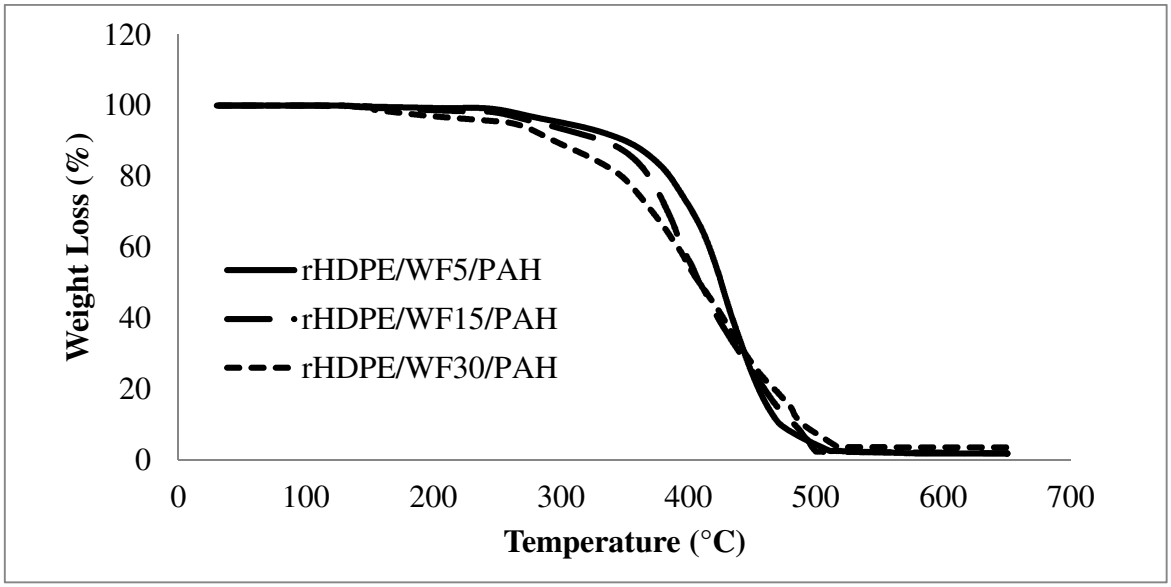

Figure 4: Thermogravimetric curves of rHDPE/WF/PAH composites at different fiber loading.

Table 2: Temperature of 50% weight loss ($T_{-50\%\ wt}$), final decomposition temperature and residual mass for rHDPE/WF with and without modified phthalic anhydride composites at different fiber loading.

Codes	T_{50} %wt (°C)	FDT (°C)	Residual mass (%wt)
rHDPE/WF	434.52	520.34	0.269
rHDPE/WF5	419.17	522.38	0.284
rHDPE/WF15	417.59	529.46	0.604
rHDPE/WF30	415.86	530.96	1.063
rHDPE/WF5/PAH	424.87	530.53	1.435
rHDPE/WF15/PAH	420.28	539.85	1.688
rHDPE/WF30/PAH	419.90	548.14	2.417

4.0 CONCLUSSION

The addition of phthalic anhydride as a coupling agent in the tensile properties and thermal degradation were evaluated. Recycled high density polyethylene, rHDPE modified wood fiber (rHDPE/WF/PAH) showed higher tensile strength, modulus of elasticity, and thermal stability compared to rHDPE/WF composites.

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