Effects of Bulk Density, Filler Ratio and Particle Geometry toward Thermoplastic Composite from Oil Palm Residues

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ABSTRACT

Thermoplastic composites were produced from oil palm trunk sawdust and polypropylene. The filler ratio used were 10%, 20% and 30% based on dry weight of oil palm sawdust and the particle size geometry used were 425μm, 250μm, and 150μm. The effect of bulk density, filler ratio and particle geometry toward physical and strength properties of thermoplastic composite were analysed. The results indicate that the smallest particle size geometry has the highest bulk density and vice versa. Higher filler ratio and particle size geometry were found to increase the physical properties of the board and the strength properties of the board decreases, respectively. In general, statistical analysis shows that the bulk density, filler ratio and particle geometry significantly influences the physical and strength properties of thermoplastic composites produced from oil palm residues.

Keywords: *physical properties, strength properties, thermoplastic composite, oil palm residues*

Introduction

Thermoplastic composite or wood plastic composite (WPC) is a composite material that contains thermoplastic (PE-polyethylene, PP-polypropylene, PVC-polyvinyl chloride, PS-polystyrene) and wood flour or fibre. Karmarkar et. al (2007) stated that the wood fibres have gained significant interest as reinforced material for commercial thermoplastics. The applications of thermoplastic composite in the market are most widely used for exterior building components, automotive profiles, building profiles, decking, windows and indoor furniture. This technology becomes more attractive because the manufacturers claim that WPC is more environmentally friendly and requires less maintenance than the alternatives of solid wood treated with preservatives or solid wood of rot-resistant species (Myers et al. 1993). Furthermore, Wechsler & Hiziroglu (2007) agreed that some of the major advantages of WPC include their resistance against biological deterioration for outdoor applications where untreated timber products are not suitable. As a result, this technology, as claimed by those authors above, has great potential to be filler in thermoplastic manufacturing and additionally, it is considered to have low cost and high availability. Thermoplastic composite in this study dealt with PP as a plastic material and oil palm trunk (OPT) residues as a filler.

Previous studies on oil palm residues in form of oil palm wood flour (OPWF) and empty fruit bunch fibre (EFBF) have been reported by several researchers. Zaini et. al (1995) reported changes on the basis of particle size in a study of four sizes of OPWF used as a filler in different concentrations of polypropylene and Hanafi et. al (1997) study on the effect of filler content and size on curing characteristics and mechanical properties of oil palm wood flour (OPWF) reinforced epoxidised natural rubber (ENR) composites. The effects of cellulose and EFB fibres on the mechanical properties of polypropylene are investigated by Khalid et. al (2008). They found that filler content and size of OPWF and EFBF influence mechanical properties of the boards. The size and aspect ratio are believed to influence the rheology or the flow in the mixture and in turn the mechanical performance of the composites (Kulkarni et. al 2002). They expected that fillers and fibres, when used in combination, not only complement each other's performance and result in better properties for the composite but also reduce the extent of matrix polymer required in the system. On the other hand, Stark & Berger (1997) claimed that the effects of particle size on the properties of polypropylene filled with wood flour do not affect specific gravity but do affect some selected mechanical and physical properties of wood plastic composites. They reported that increasing the fibre size improves strength and stiffness, but reduces elongation and energy to break. In addition, Bouafif et. al (in press) stated that aspect ratio, rather than particle size, has the greatest effect on strength and stiffness. However, particle size does not affect specific gravity. According to Clemons (2002), most plastics processors ignore wood fibre because of its low bulk density, low thermal stability, and tendency to absorb moisture. The relatively high bulk density and free-flowing nature of wood flour compared with wood fibres or other longer natural fibres, as well as its low cost, familiarity, and availability, are attractive to WPC manufacturers and users. The moisture absorption by composites containing natural fibres has several adverse effects on their properties and thus, affects their long-term performance. Wang et. al (2006) concluded that low fibre loading prevents the moisture of composites. However, at high fibre loading, for example, 65%, this increases the moisture absorption. Precautions are needed to prevent moisture absorption when high fibre loading is applied. Several researchers suggest that coupling agents, compatibilisers or other chemical modifications are used to improve the moisture resistance of composites (Clemons, 2002; Wang et. al, 2006; Jamaludin, 2006 & Khalid et. al, 2008,).

The research and development into new uses of by-product for OPT residues display an attractive approach as an alternative source of lignocellulosic material for the wood based industries. The OPT residues have a great potential to be converted into value-added product. Sumathi et. al (2008) reported that OPT residues have been successfully utilised as saw-wood and plywood or lumber, core in the production of blackboard, interior furniture, particleboards with chemical binders and some of the trunks are mixed with EFB and oil palm fibres to be combusted and produce energy. The oil palms residues in this study are subjected to the sawdust which remains after converting OPT into the lumber. Exploitation of this material is an effort to reduce waste in oil palm plantation and moreover, to avoid pollution. Thermoplastic composite from OPT residues has been expected to be more durable than other panel products due to less moisture absorption. The purpose of this study was to investigate the potential of OPT particles as a filler in thermoplastic composite. In addition, the effects of bulk density, filler ratio and particle geometry toward the physical and strength properties of OPT sawdust filled PP were also determined.

Materials and Methods

Polypropylene (PP) was supplied by Polypropylene Malaysia Sdn. Bhd (a member of PETRONAS Group and Companies). The OPT was obtained from Malaysian Palm Oil Board (MPOB), Bangi, Selangor. Figure 1 shows the OPT sawdust that is produced from lumber processing residue. Sawdust was ground into particles using Wiley milling machine. Particles were then screened and classified into three geometry sizes (425, 250 and 150 μm) using a Gilson multi deck screener. Then, the particles were oven-dried at 80 °C until they achieved moisture content less than 5%. The particles were then identified using the bulk density measurement. The process to get bulk density was done by sieving the sawdust into the cylinder using free fall method.

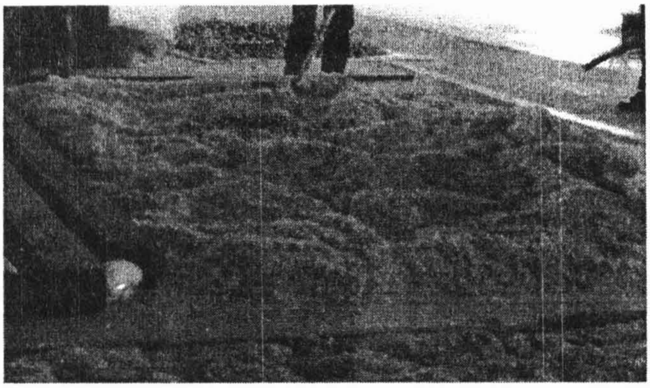

Figure 1. Oil palm trunk residues

Table 1 indicates the proportion of particles filler and PP with capacity of 2 kg. Thermoplastic is manufactured using a dispersion mixer (Figure 2). The mixer was first heated to working temperature of 185 °C and PP was then melted down in about 15 minutes and added to the OPT particles for about 20 minutes until the compounded admixture become granules. After that the granules are fed into a crusher to be palletized. A chrome-plated mould with dimension of 300×240×2 mm was used for tensile, impact and physical testing samples. Approximately 144 g of palletized admixture was placed in the mould. Another chrome-plated mould with dimension of 240×150×6 mm was used for bending testing sample. Approximately, 216 g of palletized admixture was placed in the mould. The boards were given density of 1000 kg/m^3 and hot-pressed at 185 °C temperature for 5 minutes and then cooled to a temperature of 18 °C using a cold press with running water through the platens for 1 minute.

Table 1. Proportional of filler ratio of OPT particles and PP

Particle geometry (µm)	Filler Loading (%)	Particle (g)	PP (g)
425	10%	200	1800
	20%	400	1600
	30%	600	1400
250	10%	200	1800
	20%	400	1600
	30%	600	1400
150	10%	200	1800
	20%	400	1600
	30%	600	1400

Physical properties were conducted to determine thickness swelling (TS) and water absorption (WA) in accordance with ASTM D 570-98 standards (ASTM, 1998). Six samples with a size of 50×50 mm were measured at marked points. Then, the samples were submerged in distilled water for 24 hours before thickness measurements were taken from the same location to calculate swelling values while water absorption measurements were taken from the mass values of the samples. Strength properties were conducted to determine flexural, tensile and impact. The flexural was determined using INSTRON Universal Testing Machine in accordance with ASTM D790 – 03 standards (ASTM, 2003). The support span was 150 mm while the crosshead speed utilized was 5 mm/min. All flexural samples were cut into rectangular specimens (150×25 mm). Tensile tests were conducted in accordance with ASTM D 3039/D 3039M – $00^{\varepsilon 2}$ standards (ASTM, 2000) with specimen type I (150×10 mm). Constant head-speed was 2 mm/min. Unnotched izod impact strengths were measured according to ASTM D 256 – 05a standard (ASTM, 2005) on Ceast make pendulum impact tester. Impact samples were cut with a size of 80×10 mm. Six samples were presented as the average for all strength tested specimens. The analyses was performed by SPSS 16.0 to determine a comparison of the means using Duncan and Waller-Duncan tests and a relationship between each source of variation using Pearson correlation analysis at a 95% confidence level.

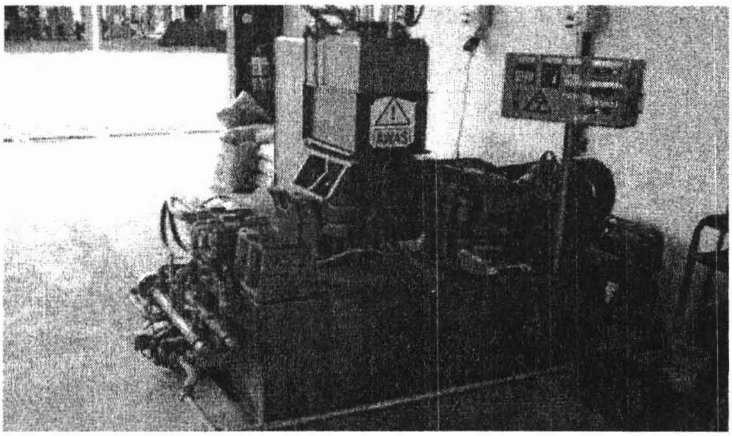

Figure 2. Dispersion mixer

Results and Discussion

Figure 3 shows the effect of bulk density on OPT particle geometry. Bulk density has significantly influenced the particle geometry. From the figure, it displays that the highest bulk density of OPT sawdust was 161 g/l for particle geometry of 150 µm followed by 250 µm (155 g/l) and 425µm (140 g/l). The trend shows that the smaller particle geometry produces the higher bulk density and vice versa. This could due to smaller particle geometry gave denser volume than the bigger particle geometry. Therefore, they gave a large surface and compacted, and then they increase the density of particle geometry. Dai et al. (2004) studied on the bulk density of mats of wood particles, hammer milled straw and refined straw particles. They found that the wood particles are much denser than straw particles because wood particles contain little fine particles compared to straw particles that they are very much are like mini-flakes. An effect of particle geometry on strength properties of rattan-cement composite has been investigated by Olorunnisola (2007). He reported that an inverse relationship was observed between rattan particle size and loose bulk density. The density of the composites increased with a decrease in rattan particle size because it is attributable to the reduction in air volume with decreasing particle size.

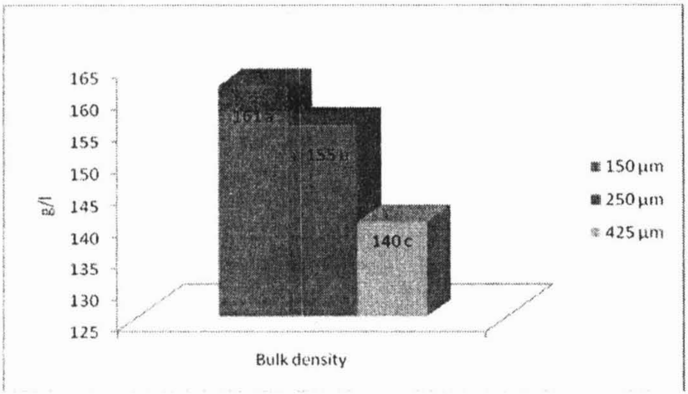

Figure 3. Effect of particle geometry on bulk density

Table 2 reveals the relationships between bulk density, filler ratio and particle geometry to the physical and strength properties of OPT filled thermoplastic. From Pearson correlation analysis, the filler ratio gave highly significant relationship with tensile and impact strength meanwhile, both bulk density and particle geometry gave significant effect at the 0.05 level on the bending strength. A strong positive correlation was found at relationship between filler ratio against impact strength (0.73) and moderate relationship (-0.54 and 0.63) against tensile strength. This showed that the variables were only affected on strength properties but not on physical properties of thermoplastic composite. Generally, all variables have week correction against physical and strength properties of OPT particles filled thermoplastic.

Table 2. Pearson correlation analysis between variation and thermoplastic composite properties

Variable	Physical properties		Strength properties				
	TS	WA	Flexure		Tensile		Impact
			FMOR	FMOE	TMOR	TMOE	
Bulk density	0.074	0.128	0.320*	-0.300*	0.208	-0.049	0.024
Filler ratio	0.205	0.031	-0.051	-0.031	-0.538**	0.628**	-0.727**
Particle geometry	0.074	0.128	0.320*	-0.300*	0.208	-0.049	0.024

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

The results of the analysis of variance (ANOVA) are shown in Table 3. The ANOVA shows that all corrected model were highly significant with physical and strength properties except for water absorption (WA). Physical properties vary insignificantly with filler ratio and particle geometry but the interaction between filler ratio and particle geometry was highly significant. This result suggests that physical properties are dependent on interaction between particle geometry and filler ratio. Mechanical properties also were significantly different with interaction between filler ratio and geometry particle. However, they were not significant for impact strength. Both flexural modulus and TMOE were not significant with filler ratio while impact strength was not significant with particle geometry.

Table 3. Results of the analysis of variance (*F* values) for physical and strength properties of OPT particles filled PP

Source	Physical properties		Strength properties				
	TS	WA	Flexure		Tensile		Impact
			FMOR	FMOE	TMOR	TMOE	
Corrected model	6.187**	1.894ns	7.144**	13.412**	11.231**	11.916**	15.372**
Ratio	2.965ns	0.248ns	1.993ns	0.073ns	20.868**	30.880ns	56.422**
Geometry	0.356ns	0.592ns	14.225**	38.855**	6.504**	0.478ns	1.196ns
Ratio ×geometry	10.713**	3.368*	6.178**	7.360**	8.776**	8.152**	1.935ns

* Significant at 0.05; ** Significant at 0.01; ns not significant at 0.05

The results of filler ratio toward thickness swelling (TS) and water absorption (WA) are given in Figure 4. It reveals that filler ratio significantly affected TS while it is comparable in WA. The TS thermoplastic composite increases with the WA and thus, has similar trend to the water absorption regarding the impacts of particles to plastics ratio. The impact of OPT particles to plastics ratio on water uptake can be explained by the presence of vascular bundles, parenchyma tissues and hydrogen bonding sites in the OPT particles. According to Adhikary et al (2008), some researchers explained that this situation was influenced by the gaps and flaws at the interfaces, and the micro-cracks in the matrix formed during the compounding process resulted in poor compatibility between the hydrophilic wood flour and the hydrophobic plastics, which increases the water absorption depending on the number of free hydroxyl groups, thus, the amorphous regions are accessible by water. On the other hand, plastics are water repellent and have much lower water sorption capability than wood. Wang et. al (2006) reported that moisture only penetrate into plastic composites through natural fibre (rice hulls) after one year submersed in the distilled water at room temperature. Samples made with lower ratio of OPT particles have lower TS (1.4%) and WA (0.78%) while the higher TS and WA were approximately 2.0% and 1.0%, respectively. This finding indicates similar dimensional stability properties without adding the coupling agent which is consistent with previous findings by Chen et al. (2006) and Adhikary et al. (2008).

As shown in Figure 4, the effect of filler ratio is significant for selected properties i.e. tensile modulus of rupture (TMOR), tensile modulus of elasticity (TMOE) and impact strength of PP-OPT particles composites. In general, an increase of filler ratio increases both tensile and flexural MOE but it decreases the MOR and impact strength. However, Khalid et al. (2008) found that the effect of impact strength of PP-cellulose and PP-EFBF composites for notched samples increased with the filler loading. The highest values of strength properties for MOR was 29.79 MPa with 10% filler ratio, for MOE was 2813 MPa with 30% filler ratio and for unnotched impact was 8.93 k/J with 10% filler ratio. In previous study, it was that reported that high particle ratio attributed to high rigidity and strength. Related to that statement, Adhikary et al. (2008) found that TMOE and FMOE of wood fibre increased steadily with wood fibre content. The results obtained are in agreement with the finding in this study. In the other study, PP-cellulose EFBF composites appeared to have slightly lower TMOE at lower filler loading; however, as the filler loading was increased, the TMOE increased significantly. This is a common phenomenon, i.e. filler addition results in greater modulus, but the PP-EFBF composite modulus is still lower than PP-cellulose composite (Khalid et al., 2008). By adding filler ratio, it is expected to change the viscoelastic behaviour of PP to a more ductile behaviour. The study on OPWF showed the increasing filler content declined strength properties but they increased flexibility strength (Zaini et al., 1995).

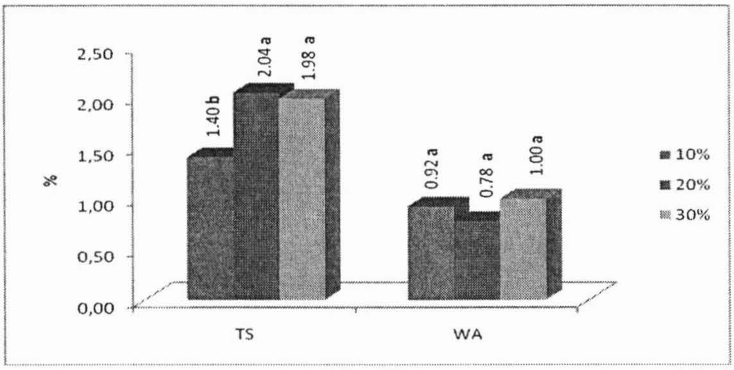

Figure 4. Effect of filler ratio on physical properties

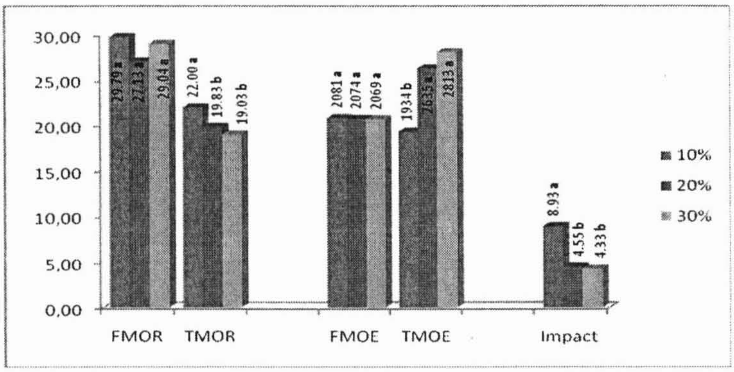

Figure 5. Effect of filler ratio on strength properties

The effect of particle geometry on physical properties of PP-OPT particle composites was also investigated. The results show that the additional dimension changes in TS and WA were dependent with smaller particle geometry. In other words, the smaller the particle size, the higher the water absorption would be, where it was probably due to the huge amount of parenchyma tissues in fine particles. According to Lim & Khoo (1986), parenchymatous cells in OPT structure retained more moisture than vascular bundles. The effect of particle geometry on water uptake was not significant but the interaction between particle geometry and filler content was significant as mentioned earlier. Figure 6 illustrates the highest TS and WA were 1.95% and 1.10%, particularly at finest particle geometry and vice versa.

The effect of particle geometry has been reported to influence the strength properties of thermoplastic composite. According to the results, the MOR strength was inversely related to the particle geometry while the MOE was directly related to the particle geometry. However, impact strength was comparable at different particle geometry. The highest value for MOR, MOE and impact were obtained at particle geometry of 250 µm. Figure 7 demonstrates the effect of OPT particle geometry towards strength properties of PP composites. Bouafif et al. (in press) found that an increasing fibre size improves the modulus of elasticity and maximum strength in both tensile and flexure tests. Meanwhile, Hanafi et al. (1997) reported that OPWF-ENR composites with the smallest particle size show the best overall mechanical properties, i.e. tensile strength, tensile modulus and tear strength than larger particle size. They have evident from SEM study that showed the poor strength properties may be attributed to the geometry of OPWF fillers. Zaini et al. (1995) reported that the composites filled with larger-sized filler showed higher modulus, tensile and impact strengths, particularly at high filler loadings. In related study by using oil palm residues, the effect of impact strength of PP-cellulose and PP-EFBF for notched samples increases with the filler loading (Khalid et al., 2008).

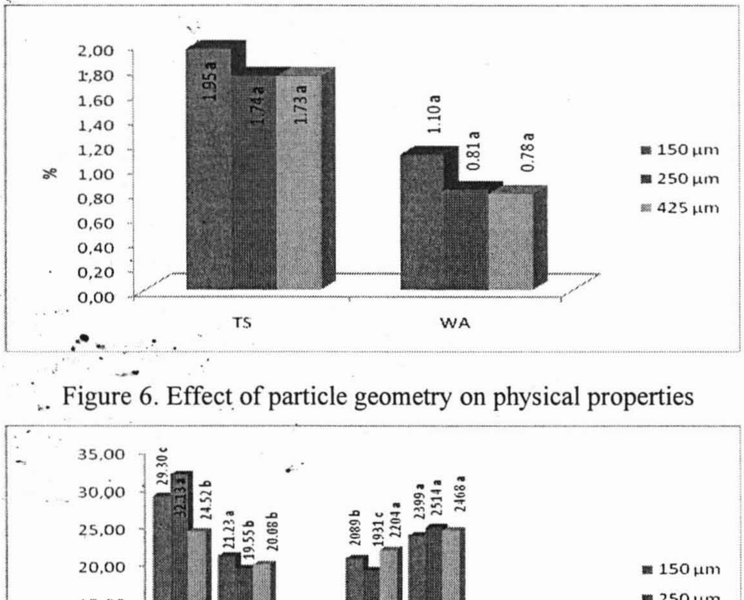

Figure 6. Effect of particle geometry on physical properties

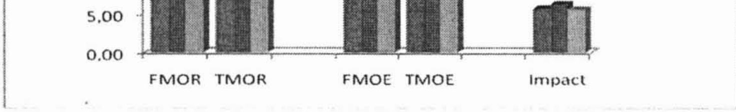

Figure 7. Effect of particle geometry on strength properties

Conclusion

A study on physical and strength properties has been carried out to understand the basic characteristics of wood plastic composite from oil palm trunk residues. The strength properties of oil palm residues –filled polypropylene composite are significantly influenced by the main factor of filler ratio and particle geometry but those effects are not related to physical properties. The physical and strength properties of this composite may be further improved by using suitable coupling or bonding agents. Successive studies will be conducted using various types of coupling agent namely maleic anhydride grafted polypropylene (MAPP) and multi functional acrylates (MFA) to improve the bonding between the cellulose and polymer matrix. This study suggests that OPT particles is a potentially attractive thermoplastic filler due to optimising the utilization of oil palm residues to be a value-added product in wood-based industry.

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