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Physico-Mechanical Properties of Thermoplastic Composite Reinforced with Kelempayan, Oil Palm Trunk and Bamboo as Fillers

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ABSTRACT

Thermoplastic composite panel can be used for a variety of applications. The wide distribution, renewability and recyclability of lignocelluloses can expand the market for low-cost thermoplastic composites. Lignocellulosic materials from fast growing and plantation species such as lesser-known timber, bamboo and palm tree are promising materials for particulate filler for the production of thermoplastic composite panel due to its accessibility, great substrate behaviour and high yield resources. This study was to determine the physico-mechanical properties of thermoplastic composite panel reinforced with particulate fillers from kelempayan (Neolamarckia cadamba), oil palm (Elaeis guineensis) and betong bamboo (Dendrocalamus asper). This study focused on the effect of particle size and three percent additive to dimensional stability and strength properties of a panel. The polypropylene plastic has been blended with the particulate fillers in a dispersion mixture at the temperature of 180 °C. Then, it was hot pressed for five to nine minutes and the mold was cold pressed for three minutes before the panel was conditioned for testing performance. Preliminary results indicated that smaller particles size with a filler loading ratio of 10 % was easier to disperse in melted polypropylene to produce composite plastic panels as compared to larger particles size which resulted in minimum *dimensional changes and higher tensile strength. Statistical analysis has proven that different particle sizes and the supplementary of three percent additive significantly influenced the physico-mechanical properties of the thermoplastic composite panel.*

Keywords: wood plastic composite; particle size; filler loading; dimensional stability; strength properties; lignocellulosic material

INTRODUCTION

Renewable lignocellulosic resources from timber and non-timber incorporates the sturdy potential for the lessening of manufacturing costs. It is also valuable for mitigating environment climate change and improving carbon absorption, hence beneficial to the producers to reduce raw material cost. Lignocellulosic materials can be used for particulate filler of the plastic industry. The construction division is one of the major plastic consumers in developed countries. The main plastic categories in the division are polyethylene, polypropylene, and polyvinyl chloride, entirely of which can be applied in the manufacture of thermoplastic composites [1]. Polypropylene is generally used as a raw material for thermoplastic composite. A part of this coupling agent to improve the compatibility between polymer matrix and filler is maleic anhydride grafted polypropylene (MAPP). Çavuş and Mengeloğlu [2] reported that the ideal quantity of MAPP ranged between 2 to 6 %. The wood filler of thermoplastic composite has no specific size because it is generally applied to characterize the shape of the wood used [3]. The key returns of the wood filler are its low density, cheaper cost, good strength, renewability, biodegradability, and wide accessibility. Thermoplastic composite has a good opportunity to be a commercial export product. The Malaysian Timber Council [4] reported a stable performance of RM19.8 billion in Malaysia's timber and timber-related exports although there was a decrease of 3.3 % compared to the previous year. The previous year's export related to this sector was RM 23 billion. Therefore, this situation forecast that the thermoplastic composite industry could contribute to a global demand that would provide a return to the national income.

This study focusses on the utilization of lignocellulosic resources from fast growing and plantation species which are kelempayan (*Neolamarckia cadamba*), oil palm (Elaeis guineensis) and betong bamboo (*Dendrocalamus asper*). Kelempayan is a supplementary rapid growing timber species that is suggested in the government policy to track a hostile program for the expansion of forest plantations in Malaysia [5]. Kelempayan is a non-commercial light hardwood. It is easily found in secondary forests and it can be planted as field crops [6]. Articles published in the past 5 years have reported scientific findings on the timber and composite panel from kelempayan [7-12]. No findings have been reported on reinforced kelempayan filler for thermoplastic manufacturing. Therefore, kelempayan particles provide continued and sustainable source of raw materials in the future as compared to the commercial tropical timber species. Timber possesses intermediate strength and is less flexible due to its grains pattern and natural defect. Likewise, these timbers need an extensive period of up to 10 years in order to attain the strength and ready to be collected, whereas the bamboo requires less time to mature; around 3 years to attain its essential strength. Non matured timber will result in the decrease of strength properties. Furthermore, the exploration on the new mixture of organic and synthetic materials has become an important issue especially from oil palm plantation waste. Considering that the economic life of the oil palm is about 25-30 years, many of the oil palm stands are now being considered for replanting. At replanting age, the oil palm stem has a height that ranges between 7 to 13 m and the diameter between 45 cm and 65 cm, measured 1.5 m above ground level [13]. Suhaily et al. [14] stated that there were 40 million tons of residual oil palm biomass excess from oil palm trees; essentially empty fruit bunch, trunk and frond which were formed each year in Malaysia. Apart from this, only 10 % of the total oil palm biomass is being used, whereas the residual 90 % is not being unused. Recently, there has been very little scientific findings on oil palm trunk biomass reinforced with resin polymer [15-17]. However, many of the findings were on by-products biomass. Subsequently, bamboo exhibits excellent mechanical properties as a natural fibrous material for composite panel. There was a study on betong bamboo (*D. asper*) that caused the utilization of this species to be deserted especially in Malaysia. Betong bamboo, commonly known as giant bamboo, is a large bamboo that grows in dense tufts with culms of up to 30 m tall with an average diameter of 8-20 cm. It has relatively thick walls (11 – 20 mm) and the lower culms show aerial roots from the nodes

[18]. It exhibits higher tensile strength when compared to other commercial bamboo species [19]. Apart from this, it is relatively inexpensive compared to other building materials because it is a versatile plant and can be found in rural settlements [20]. Recently, several studies elucidated bamboo as a great vision for the reinforcement of thermoplastic composites and would be a capable alternative for wood-polymer composites products [20-25]. Consequently, the utilization of the betong bamboo for thermoplastic composites will reduce the demand for plastics and the environmental impact associated with their production and disposal.

The intention of this study was to determine physico-mechanical properties of thermoplastic composite panel reinforced with particulate fillers from kelempayan branches, oil palm trunk residues and betong bamboo culms. Moreover, this study analyzed the effect of different particulate filler sizes, filler ratio loading and the supplementary of MAPP on the physico-mechanical properties of the panel. The remarkable natural fibers that can be potentially used in the biobased composite production because of its lower price, good properties, and fast-growing characteristic [26]. They are abundant, renewable and biodegradable. Indeed, the use of lignocellulosic resources as the organic filler in thermoplastic composites would enable the production of more environmental-friendly products with huge additional values for developing countries.

MATERIALS AND METHODS

This study was performed to evaluate the effect of different particulate fillers, different filler ratio and three percent additive on physico-mechanical properties of thermoplastic composite panel (Table 1). The materials used in this study for the particulate filler were kelempayan branches, oil palm trunk residues and betong bamboo culms. Meanwhile, the thermoplastic matrix and additive were polypropylene and MAPP, respectively.

Table 1: Experimental parameters to produce thermoplastic composite panel

Filler Type	Filler Size (μm)	Filler:PP	Additive
Kelempayan branches	150	10:90	No
	250	20:80	
	425	30:70	
Oil palam trunk residues	150	10:90	No
	250	20:80	
	425	30:70	
Betong bamboo culms	150	10:87	3 % MAPP
	180		
	425		

Manufactured of thermoplastic composite panel

The process of filler production is different for each lignocellulosic species. Kelempayan branches must be debarked first before chipped using a chipper machine and flaked using a knife ring flaker. Meanwhile, oil palm trunk residues were resaw into the flitches then cut using a strand machine. Betong bamboo culms were split into the strips using a cleaver before chipped and flaked. After that, the unscreened sawdust particles were ground into fine particle size using a grinder machine. Finally, the grinded particles were separated using a wire mesh screener and dried using an oven at the temperature of 70 °C until they reached moisture content below 5 %.

Furthermore, the production of thermoplastic composite panel is started by mixing the polypropylene pellets and the dried screened particulate fillers in a dispersion mixture machine at the temperature setting of 180 °C. Then, the cold composites were brokendown into an even granule size using a crusher machine. The granules were formed into two different mold volume according to the testing sample measurement. Usually, the bar platen mold available at the laboratory for the bending test can load granules about 216 g, while for tensile and dimensional stability tests can be loaded with granules of about 144 g. After that, the platen molds were pressed under heat at 180 °C and pressure at 1000 psi respectively for nine minutes for the bending testing samples and five minutes for tensile and dimensional stability testing samples. Lastly, the platen molds were cold pressed at 20 °C and pressured at 1000 psi for three minutes. Conditioned panels were trimmed and cut into the required cutting samples before testing was performed. Figure 1 demonstrates the flow process of making the thermoplastic composite.

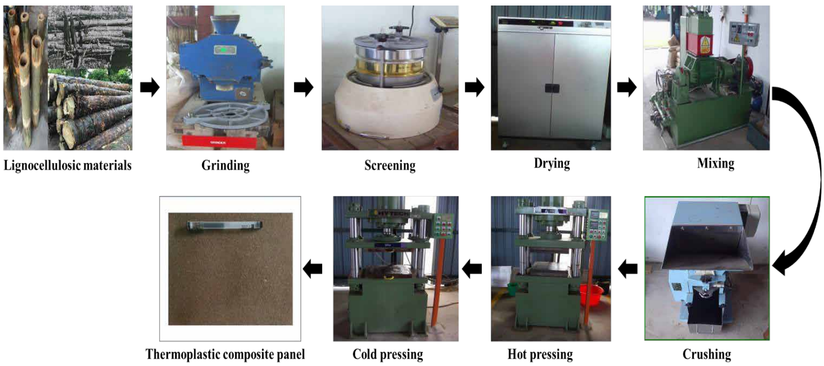

Figure 1: The process flow of thermoplastic composite panel reinforced particulate filler from kelempayan branches, betong bamboo culms and oil palm trunk residues

Testing Performance

Physico-mechanical testing consisted of the physical and mechanical data collection. The physical testing referred to the experiment on the dimensional stability of the panel through water absorption and thickness swelling changes before and after soaking in the water for 24 hours. The sample size for dimensional changes was 50 mm x 50 mm which is in accordance to the standard test method ASTM D570 (2003) [27]. Meanwhile, mechanical testing consisted of bending, tensile and impact resistance analysis that were performed via the universal testing machine. The sample size for flexural test was 150 mm x 25 mm following the standard test method ASTM D6272 (2003) [28]. Sample size for tensile test was 150 mm x 10 mm (ASTM D638, 2003) [29] and sample size for impact test was 80 mm x 10 mm (ASTM D256, 2003)[30]. The data was analyzed using significance one-way variance.

RESULTS AND DISCUSSION

Analysis of physico-mechanical properties

Table 2 shows the physico-mechanical properties of the thermoplastic composite panel reinforced kelempayan branches filler. The effect of the different particulate filler geometries has significantly influenced the physico-mechanical properties except for the modulus of rupture and thickness swelling. The results presented found that the smaller the particulate filler is, the higher the properties in dimensional stability. The best performance of dimensional stability has been found at particulate filler of 150 μm which percentage change of water absorption was 4.01 %, while thickness swelling was 5.98 %. Consequently, the results of the strength properties revealed that the smaller particulate filler improved the modulus of elasticity for flexural (2096 MPa) and tensile (26.39 MPa), whereas the larger particulate filler improved the modulus of rupture for flexural (2776 MPa) and tensile (16.83 MPa) as well as for impact resistance (4.78 MPa). Statistical analysis of different filler ratios significantly affected the physico-mechanical properties of thermoplastic composite panel. The more filler loading would result in decreased dimensional consistency, modulus of rupture and impact strength but increased modulus of elasticity. As stated, the best results scored at filler loading 10 % which water absorption was 3.55 %, thickness swelling was 4.54 %, impact strength was 5.67 MPa and modulus of rupture for flexural and tensile were 30.87 MPa and 20.03 MPa, respectively.

Table 2: Physico-mechanical properties of thermoplastic composite panel reinforced kelempayan branches filler

Particle size (µm)	FMOR (MPa)	FMOE (MPa)	TMOR (MPa)	TMOE (MPa)	Impact (kJ/mm²)	WA (%)	TS (%)
150	26.79	2096	16.68	2639	3.74	4.01	5.98
250	27.26	2059	16.65	2484	3.83	4.16	6.29
425	27.76	1992	16.83	2386	4.78	5.45	6.99
Significant level	NS	HS	NS	HS	HS	HS	NS
Filler ratio (%)							
10:90	30.87	1970	20.03	2071	5.67	3.55	4.54
20:80	26.10	2034	16.42	2528	3.53	3.95	5.42
30:70	24.84	2143	13.70	2910	3.16	6.11	7.29
Significant level	HS	HS	HS	HS	HS	HS	NS

Notes: F = flexural, T = tensile, MOR = modulus of rupture, MOE = modulus of elasticity, WA = water absorption, TS = thickness swelling, HS = has significant, NS = not significant

The physico-mechanical properties of thermoplastic composite panel reinforced oil palm trunk residues filler are presented in Table 3. Apparently, different particulate filler sizes have slightly significantly affected the modulus of rupture for flexural and tensile. The results showed that the panel composed of particulate filler size of 150 µm has given good physico-mechanical properties. Meanwhile, different filler ratios significantly influenced tensile and impact strength. The best physico-mechanical properties recorded for panel manufactured with 10 % filler ratio of oil palm trunk residues.

Table 3: Physico-mechanical properties of thermoplastic composite panel reinforced oil palm

Particle size (µm)	FMOR (MPa)	FMOE (MPa)	TMOR (MPa)	TMOE (MPa)	Impact (KJ/mm²)	WA (%)	TS (%)
150	31.62	2193	21.23	2514	6.35	0.78	1.74
250	29.17	2089	20.07	2468	5.79	0.81	1.78
425	25.79	1927	19.55	2399	5.66	1.10	1.95
Significant level	HS	NS	HS	NS	NS	NS	NS
Filler ratio (%)							
10:90	29.80	2079	22.00	2813	8.92	0.78	1.40
20:80	29.50	2065	19.83	2635	4.55	0.92	2.04
30:70	27.29	2064	19.02	1934	4.33	0.99	2.65
Significant level	NS	NS	HS	HS	HS	NS	NS

Notes: F = flexural, T = tensile, MOR = modulus of rupture, MOE = modulus of elasticity, WA = water absorption, TS = thickness swelling, HS = has significant, NS = not significant

The physico-mechanical for thermoplastic panel composed with particulate filler from betong bamboo culms is recorded in Table 4. Generally, physico-mechanical properties of the test samples showed an improvement from the control samples. Comparison of filler size was significantly different in dimensional stability and strength properties of the panels. Plus, the extended 3 % of MAPP in the composite upgrading the physico-mechanical properties of the panels. As specified, the highest flexural strength was the panels from particulate filler size of 150 µm with MAPP, tensile and impact strength was the panels reinforced filler size of 425 µm without MAPP and the dimensional consistency found from particulate filler size of 180 µm with MAPP. The analysis of the physico-mechanical properties showed an improvement matrix by adding MAPP due to its function as the bridging agent between the hydrophilic of betong bamboo particles and hydrophobic of polypropylene. Conversely, the incompatibility of hydrophilic filler and hydrophobic polymer matrix was the main drawback of natural particle utilization in thermoplastic composite production [2].

Table 4: Physico-mechanical properties of thermoplastic composite panel reinforced betong bamboo culms filler

Filler size (µm)	MAPP (%)	FMOR (MPa)	FMOE (MPa)	TMOR (MPa)	TMOE (MPa)	Impact (kJ/mm²)	WA (%)	TS (%)
150	0	40.26	2027	8.90	27.7	0.33	2.24	5.80
	3	46.76	2164	12.42	40.9	0.47	1.95	5.13
180	0	41.85	2014	5.56	14.9	0.43	2.74	6.07
	3	41.29	1986	5.53	13.9	0.49	1.57	4.44
425	0	34.45	2317	18.91	80.2	0.54	2.81	7.42
	3	43.40	1948	15.61	54.3	0.50	1.90	6.50
Control	0	54.65	1800	28.26	40.3	0.02	0.05	0.03
Significant level		HS	HS	HS	HS	HS	HS	NS

Notes : F = flexural, T = tensile, MOR = modulus of rupture, MOE = modulus of elasticity, WA = water absorption, TS = thickness swelling, HS = has significant, NS = not significant

In general, the effect of particulate filler size from different lignocellulosic species gave off different deduced findings. Dimensional stability represents compatible trend for all species where larger particulate size possess greater changes in water uptake and volume of the panels. Bahari and Krause (2016) reported water uptake of bamboo particles of 1 mm to be greater than 75 µm. This could be due to more area of the larger particles embedded in the composites with more hydrophilic area and voids which allowed water absorption. Nevertheless, particulate filler size variation distinguished mechanical properties of the composite panel manufactured by different lignocellulosic species. Fine particles always revealed good stiffness and elasticity of the composite as compared to coarse particles. This is because the larger the size of the particle, the more brittle it becomes and less interface with matrix bonding while the small size is stronger to grip with each particle and plastic. Kassim [31] reported that the better mechanical properties filled by fine bamboo particles had compatibility with polypropylene whereas the coarse particles yielded huge stress with polypropylene, reducing the strength of composites. Furthermore, the effect of the filler ratio on the physico-mechanical properties demonstrated that higher filler declines the composite panels. Mohammad et al. [32] stated that more eucalyptus filler loading composed with thermoplastic cause brittleness and reduced the elongation at break. A bulky agglomeration was designed once high wood ratio adheres to each other which meant with higher wood ratio, the structure of the composite was not soundly mixed. On the other hand, several reasons influenced the strength properties of the thermoplastic such as the filler loading, fiber-matrix adhesion, stress transmission at the interface and blending temperature [33]. Other than that, additional compatibilizer of MAPP acted as mechanisms of anhydride reaction with a cell wall polymer hydroxyl group to form an ester bond and they intertangled into the melting polymer [34]. Therefore, MAPP could help improve polymer matrix with bamboo filler to form stronger interfacial bonding which later increased the physico-mechanical properties of the composite.

Comparison properties of lignocellulosic materials

Figure 2 indicates the mean values of the physico-mechanical properties of thermoplastic composite panel reinforced with different lignocellulosic particulate fillers of 10 % ratio. The results presented that kelempayan branches filler possessed the average physico-mechanical properties in contrast to other fillers. The formation of the fiber in the branches of a kelempayan is similar to the formation of the young tree stem. Mahmud et al. [7] reported that the density of the young kelempayan tree was influenced by the presence of sapwood fiber formation around the pith in vertical variation. Therefore, tremendous cellulosic fiber formed gives a great matrix polymer to the young fiber particles. Moreover, oil palm trunk residues filler revealed the highest mean values in tensile, impact and dimensional stability but had the lowest mean value in flexural strength. Abdul Khalil et al. [15] found that the addition of OPT fiber increased the strength and concurrently improved the elongation at breakage of the samples. This phenomenon was due to the good adhesion between the filler and matrix, which permitted the samples to elongate during testing by a scanning electron microscope (SEM) that was reported by Abdul Khalil et al. [15]. Figure 3 presents the SEM images of polypropylene-virgin wood filler composite with couplers that improved mechanical properties, unfortunately it possibly increased the cost of manufacture [35]. Whereas betong bamboo filler gave the largest value in stiffness flexural and tensile elasticity but the lowest mean value in impact strength. Yeh and Yang [24] revealed that the bamboo cellulose had a tight stiffness crystalline edifice owing to a complex network of hydrogen bonds. This meant that the lignin in bamboo provided strength and stiffness to fiber walls and transferred stress between the cellulose fibers and the matrix.

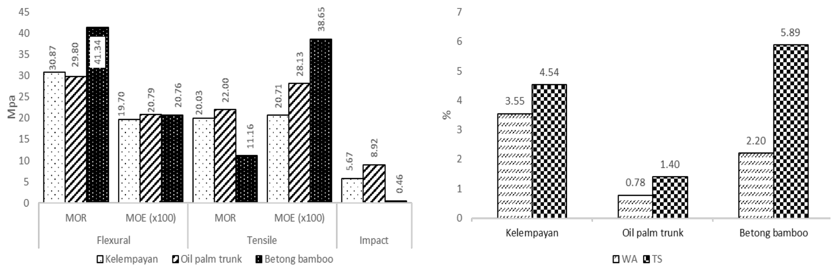

Figure 2: Physico-mechanical properties of thermoplastic composite reinforced variation of lignocellulosic materials

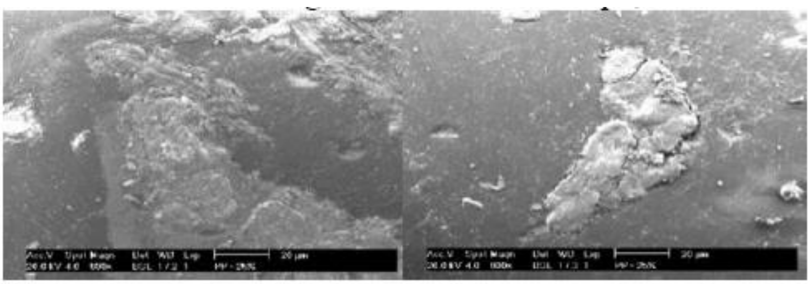

Figure 3: Scanning electron microscopy of polypropylene composite reinforced with virgin wood filler Source: Sosa (2021)

CONCLUSION

The manufacture of thermoplastic composite panel with standard laboratory scale was successfully produced. It has opened an opportunity of exploiting various lignocellulosic materials from secondary forest and plantation species due to the great cellulosic matrix behavior. The results from this study presented a similar trend with other studies on natural particle composite as mentioned above. Determination of physico-mechanical properties has contributed knowledge for industrial practice. The particulate filler size, filler ratio and compatibilizer addition indeed influenced the physico-mechanical properties of the plastic composite panels. It can be concluded that all lignocellulosic materials in this study have great physico-mechanical properties using filler size of 150 μm, while the filler ratio of 10 % presented the good physico-mechanical properties for both kelempayan and oil palm panels. The sufficient and uniform dispersion of polymer matrix of fine filler can be improved by adding MAPP compatibilizer which could enhance the interfacial adhesion between matrix and fiber. Hence, further study on other properties is recommended to overcome the flaws of the thermoplastic composite in this study.

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