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Physico-mechanical Characteristics Enhancement of Oil Palm Wood After Treatment with Polymerised Merbau Extractives Resin

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***Abstract*—Study of Polymerised Merbau Extractives (PME) applications for modified wood products was carried out on oil palm wood. The tests of physical and mechanical properties were conducted using an Instron® UTM following the relevant standards. Thermal properties were investigated using differential scanning calorimeter (DSC) analysis representing the mechanical characteristic alterations of the treated wood. Allied treatment of impregnation and hot-compression (compregnation) using PME resin can improve the quality of oil palm wood into the strength class of III with an increase of density by 250% and hardness by 456.45%. The treatment also improved the dimensional stability of the samples due to decreasing thickness swelling by 73% in normal water temperature (23°C) and by 75 % in boiling water. Increasing temperature of glass transition (Tg) of compregnated palm wood resulted in the wood structure to be stronger. The thermogram also showed that crystal point of the control at the temperature of 324.49°C, lower than that of the compregnated samples (327.85°C). This explain why the compregnation treatment of the palm oil wood increases its strength. The compregnated lignocellulose material could be a potential material for furniture products.**

Keywords—oil palm wood, PME resin, treatment, physico-mechanical

I. INTRODUCTION

Indonesia is the only one country which has the largest oil palm (*Elaeis guineensis* Jacq.) plantation in the world with the area of 9.3 million hectares. The oil palm plantations are replanted around 150,000 hectares and tend to increase every year. From the replanting program there will be about 128 oil palm trees that equivalent to the volume of oil palm timber around 220 m^3/hectare. Thus, every year there will be 81.5 million m^3 of oil palm wood [1]. However, the huge potential with millions cubic-meters of palm oil trunk is still presumed as a problematic waste. If it is left in the garden area, the palm stem will rot and become the nest of pests. If destroyed by chopping and then burning, it requires high costs and produces smoke which in turn results in other problems.

Oil palm trees are basically lignocellulose which can be used as a substitute for wood. The weaknesses of the wood properties can be enhanced by making suitable products, giving treatment or modification. Shaari et.al. [2] show that oil palm wood has basic characteristics which is very diverse compared to conventional wood. Balfas [3] conducted a trial to make plywood from oil palm trunk and found that there is a positive correlation between the density and bonding strength in the panel. Plywood panels produced could meet the qualifications of interior products. A study conducted by Darwis et al [4] on the glue laminated timber (glulam) manufactured from oil palm trunks (OPT) wood showed a different results on the mechanical characteristics. Based on their study, the Modulus of Elasticity (MOE) increased by more than 50% compared to that of the initial or OPT solid wood. However, generally, the mechanical properties of OPT glulam did not meet to satisfy the requirement of Japan Agricultural Standard for Glued Laminated although the bonding strength increased by 100% or 0% wood damage in shear and delamination test, respectively.

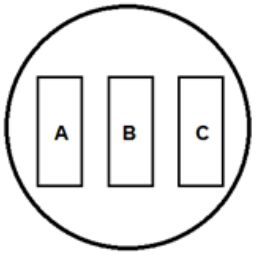
Since the major content of Merbau Extractives (ME) is revealed as resorcinol, the use of this phenolic compound has been developed for various application in quality enhancement of lignocellulosic materials. ME can be polymerised to produce phenolic/resorcinolic resin and applied for composites or modified wood products. Polymerised Merbau Extractives (PME) has been formulated in base condition with formaldehyde and resorcinol addition as the copolymer to produce polymer or resin [5]. This paper presents another option to enhance the oil palm wood properties through coating and compregnation treatment using polymerised Merbau extractives.

II. EXPERIMENTAL

A. Material

The material used in this study is 25-year-old palm oil stem (*Elaeis guineensis* Jacq). The samples measuring l×w×t = 10 × 8 × 5 cm were cut from two sides – left and right – and the

middle parts of the trunk following cutting-pattern shown in Fig. 1. All samples were dried to reach moisture content of 10%. The drying samples will be treated using resin of polymerised Merbau extractives (PME) which has been polymerised in base condition with formaldehyde and resorcinol addition as the copolymer [6].



Remarks: A = left, B = middle, C = right

Fig. 1. Cutting-pattern for taking samples of palm oil stem.

B. Resin Treatment and Compregnation

All of samples were measured and weighed, then treated with the resin evenly on the entire surface. The resin spreading applied for the samples was 0.018 g/cm^2. After resinning all of samples were allowed for conditioning for ± 10 minutes and then were weighed. For compregnation treatment, cold compression was done on the treated and untreated samples for 20 minutes with the pressure of 120 kg, then hot pressing with a temperature of 120˚C for 10 minutes and the pressure of 40 kg. Compressed samples were then conditioned at room temperature.

C. Physico-Mechanical Tests

1) Density: The oil palm wood samples that have been compregnated then conditioned for 6-7 days until the constant weight obtained. The dimensions all of samples were measured.

2) Hardness: The representing values of hardness was taken from the test that has been done on all surfaces of the specimens to obtain side-hardness (4 sides) and 2 cross-sections. The tests were done using an Instron® Universal Testing Machine following SNI 03-6842-2002: Methods of testing wood hardness in the laboratory [7].

3) Thickness swelling: Thickness swelling (TS) was measured by two soaking-test methods in which the samples (3x3x3 cm) were soaked in a water bath for 24h using normal water and 3h using hot water. After that, the samples were drained on a rack in atmospheric condition for 24h. All samples were the conditioned in oven at 60°C for 3 days before being oven-dried at 100±3^{o}C until constant weight was obtained. The thickness and weight of the samples were measured at the oven dried condition before and after soaking treatment. The thickness swelling affected by water was calculated using the following equation:

$$TS = \frac{t_1 - t_0}{t_0} x100\% \quad (1)$$

where, t_0 is initial thickness before soaking test and t_1 is final thickness (after soaking test).

A 100% of TS means a complete recovery of compressive deformation, while 0% reflects the perfect fixation or complete dimensional stability as the effect of the impregnation and compression treatment on the samples.

4) Thermal properties: Investigation on thermal properties of treated and untreated (control) oil palm wood samples were carried out using a differential scanning calorimeter DSC 6220 apparatus (Seiko Instruments Inc., Japan). It is done in order to examine the thermal transition behaviour (e.g. glass transition and melting of the samples) using a heating rate of 30°C/min to reach the temperature of 550 in nitrogen atmosphere [8, 9]. This DSC determined the glass transition temperature, melting point, and crystallization point of the samples.

D. Data Analysis

The effect of compregnation treatment using poymerised Merbau extractives (PME) on oil palm wood will be represented by ANOVA (Analysis of Variance) on the data of density, hardness, thickness swelling in normal and hot water. The data of thermal properties were analysed by interpreting the thermogram.

III. Results and Discussion

Results of the tests for density, thickness swelling in normal and hot water, and hardness test are presented in Table 1. According to Rowell [10], improvements in physical and mechanical properties of treated wood with polymer are related to polymer loading. The polymer loading depends not only on the penetration level of the polymeric material on the wood but also on which part of wood being treated. Penetration in sapwood is much greater than heartwood for most species.

A. Density

The density increment of the samples of oil palm wood using polymerised merbau extractives (PME) was caused by deposition of the compound in wood's structure [11]. The amount of deposited impregnating compound in wood can be estimated by increasing weight after impregnation. Overall, the results showed that the coating treatment using PME is effective in improving the density of Oil Palm wood. According to Hill [12] the effectiveness of impregnation treatment can be obtained by using non leachable impregnating compound.

Compregnation treatment increased much higher the density of oil palm wood by 250% compared to untreated (control) samples (Table 1). This is because empty cavities on the stem were filled by PME resin accompanied by a strong pressure and high temperature. As a result, the resin penetrated the cell wall and was maximised by the compression treatment.

According to the Indonesian wood class strength classification (PKKI, 1961), the compregnation was able to increase the wood class from V (density <0.3 g/cm^3) to III (density 0.4 - 0.6 g/cm^3). Regarding this strength classification, the compregnated oil palm wood could be used for furniture material.

TABLE I. DENSITY, THICKNESS SWELLING AND HARDNESS OF TREATED AND UNTREATED OIL PALM WOOD

Parameters	Origin of samples	Treatment		
		Untreated (Control)	*Coating*	*Compreg nation*
Density (g/cm^3)	Left	0.35[a]	0.36[d]	0.48[g]
	Middle	0.17 [b]	0.19 [e]	0.29[h]
	Right	0.21[c]	0.245[f]	0.52[i]
Thickness swelling, normal water, 24h (%)	Left	82.63[a]	46.99[d]	21.19[f]
	Middle	92.63[b]	92.28[b]	24.29[g]
	Right	97.19[c]	95.45[e]	28.44[h]
Thickness swelling, hot water, 24h (%)	Left	93.65 [a]	55.80[c]	22.14[e]
	Middle	107.25[b]	64.33[d]	24.32[e]
	Right	106.23 [b]	56.75[c]	28.56[f]
Hardness (kg/cm^2)	Left	74.00 [bc]	248.25[de]	297.25[e]
	Middle	24.75[a]	102.50 [bc]	142.50[bc]
	Right	84.00[bc]	167.00 [cd]	235.25[de]

[a.] The numbers on the same raw followed by the same letter are not significantly different at α = 5%

B. Thickness Swelling

Soaking tests in hot water revealed that there are significant differences of thickness swelling (TS) between compregnated samples and controls. The TS of the compregnated samples reached much lower (4 times) than those untreated oil palm wood samples, both in normal and hot water tests. This indicates that the effect of compregnation resulted in optimum resin penetration and the formation of a strong specific bond between the resin and the oil palm wood, in turns the wood becomes more stable. Thickness swelling resulted from hot water test is a bit higher than that cold water due to swelling or stretching of wood cellulose bonding. However, these test results meet the SNI ISO 1683:2010 standard [13] in which requires the thickness swelling no more than 25% of the original thickness.

Reduction in the thickness swelling is due to the structural change of wood component and a potential cross-linking in the cell wall polymers [14,15]. In this study, the reduction in TS for oil palm wood samples is presumed to be caused mainly as the effect of the PME resin that contains cross-linking compound. This compound has similar properties as phenol resorcinol formaldehyde (PRF) resin. In the polymerised merbau extractive, polymerisation reaction occurs between merbau extract and formaldehyde, while in copolymerisation the reaction is between the extract with resorcinol and formaldehyde. These reactions involve functional aldehyde (CHO) groups from formaldehyde as the cross-linker that can result in hydrogen bonding between the formed polymer and wood cell wall. This reaction results in an un-leachable material that makes cross-linking with wood cellular-structure after impregnation. According to Shams and Yano [16], penetration of resin into wood contributes to high dimensional stability of the impregnated wood. Fukuta et al [17] stated that the permeation of the resin into the cell wall greatly contributes to deformation fixation.

C. Hardness

Hardness of palm oil wood increased up to 4 times after compregnation treatment. For instance, the hardness increased from 74.000 kg/cm^2 to 297.250 kg/cm^2 on the left part of the stem after compregnation treatment. The increment of hardness also significantly occurred on the samples with coating treatment with the PME resin. The resin molecules interacted with wood cellulose to form copolymers with cellulose molecules. As the results, the lignocellulose material becomes heavier, denser, harder, and less brittle. Other researcher the increment of hardness after compregnation treatment. Nandika et al. [18] demonstrated that compregnation can increase Albizzia wood hardness up to 54.61%.

An indication of how well the wood performs in relation to wear and denting is provided by its hardness. Therefore, for various applications such as for flooring, furniture and some structural uses, hardness contributes to the important properties of the timber [19]. As revealed by many researchers, the hardness can be improved by impregnation treatment using appropriate resin or polymeric material. Hamdan and Islam [20] reported that after impregnation using benzene diazonium salt, the hardness of five types of selected tropical light hardwoods had higher hardness, compared to their corresponding non-impregnated control wood. In addition, the increase of wood hardness is due to the increase of interfacial adhesion between the polymer and wood. This leads to improves water exclusion, decreases the rate of swelling, and increases hardness of wood polymer composites [21]. In-situ polymerization can also generally enhance the hardness through impregnation [22,23]. The wood hardness increases with the increasing density [24]. According to Rowell [25], the increase in hardness was more than proportional to the increase in specific gravity.

D. Thermal Properties

Thermal properties of compregnated and untreated oil palm wood samples have been investigated by means differential scanning calorimeter (DSC). The analysis is used to determine the temperature of material transformation by quantifying the heat. The results of thermal properties of treated and untreated oil palm wood samples are presented in Figure 2. Figure 2 exhibits thermal characteristics of untreated (a) and compregnated (b) oil palm wood samples. Within the temperature range of 30 to 500°C at heating rate of 30°C/min in nitrogen atmosphere, the DSC curves of untreated samples exhibited endothermic change from 50 to 300°C. The treated samples showed higher temperature changes than that untreated samples. These revealed thermal characteristics of the polymeric material such as the beginning of the transition (Tb), onset temperature (T_{onset}), glass transition temperature (Tg), melting temperature (Tm), and heat capacity (Cp). The glass transition temperature (Tg) is one of the most important

properties of any resin/polymer and is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material. In relation with this case, Tg can be defined as the temperature at which the heat capacity is midway between that of the liquid and glassy states [26,27].

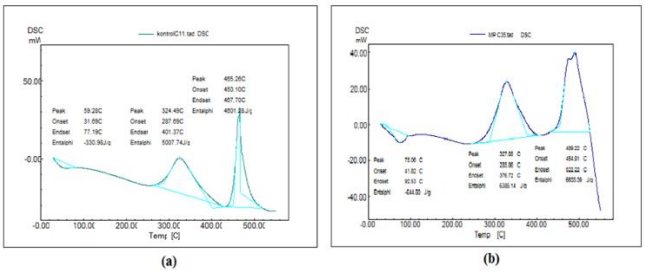


Fig. 2. The thermogram of the control (a) and compregnated (b) oil palm wood samples using PME resin.

The control samples of oil palm wood resulted in a glass transition at the temperature of 31.69°C (Fig. 2a). Increasing temperature of glass transisition (Tg) of compregnated palm wood - compared to control - indicated the formation of more rigid and branched polymers due to crosslinking that occurs between components of PME resin and wood cellulose. It resulted in the wood structure to be stronger. The thermogram also showed that crystal point of the control at the temperature of 324.49°C, lower than that of the compregnated samples (327.85°C). This explain why the compregnation treatment of the palm oil wood increases its strength. The appearance of the exothermic peak at 489.22ºC accompanied by a decrease in enthalpy from the previous exothermic peak, indicates a change to a more stable structure. As the thermal rate increases, an exothermic reaction takes place with the peak temperature of 489.22°C and to be permanent despite the addition of thermal to the temperature of 550°C.

IV. Conclusion

The compregnation treatment using PME resin can improve the quality of oil palm wood on all parts of the cross section of the stem into the strenght class of III with an increase in density by 250%, hardness by 456.45%. The treatment also improve the dimensional stability of the samples due to decreasing thickness swelling by 73% in normal water temperature (23˚C) and by 75 % in boiling water.

Increasing temperature of glass transisition (Tg) of compregnated palm wood resulted in the wood structure to be stronger. The thermogram also showed that crystal point of the control at the temperature of 324.49 ºC, lower than that of the compregnated samples (327.85°C). This explain why the compregnation treatment of the palm oil wood increases its strength. The compregnated lignocellulose material could be a potential material for furniture products.

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