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MECHANICAL CHARACTERISTICS OF IMPREGNATED WHITE JABON WOOD (*Anthocephalus cadamba*) USING MERBAU EXTRACTIVES AND SELECTED POLYMERISED MERBAU EXTRACTIVES

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ABSTRACT

This paper presents results of a study on the mechanical characteristics of impregnated Jabon wood (*Anthocephalus cadamba)* using Merbau extractives (ME) and two types of polymerised Merbau extractives (PME), i.e PME22 and PME33. A set of tests on hardness, shear, modulus of elasticity (MOE) and modulus of rupture (MOR) was conducted according to the relevant standards. Two types qualitative analysis by means of FTIR spectra and XRD analysis were carried out to explore relationship between the mechanical characteristics alteration with physico-chemical characteristics. The results indicated that a positive improvement in mechanical characteristics was obtained for Jabon wood impregnated with PME22 and PME33. Surface hardness of modified wood samples exhibited higher values compared to the non-impregnated samples for end and side hardness, by 20,04 and 30,54 % (PME22), and 32,73 and 39,89 (PME33),respectively. Shear strength increased by 41,87 and 49,58 % (PME22) and 74,02 and 79,10 %(PME) for radial (T) and tangential (T) sections, respectively. MOE increased by 23,52%(PME22) and by 40,12% (PME33), MOR values also increased by 28,50 and 41,19 % after impregnation with PME22 and PME33, respectively. The increment of mechanical properties of treated Jabon wood after impregnation treatment using polymerised Merbau extractives were confirmed by FTIR spectra and crystallinity (XRD) analysis.

Keywords: Bending strength, crystallinity, FTIR-spectra, hardness, impregnation treatment, shear strength.

INTRODUCTION

Wood production from natural forest resources is significantly decreasing all over the world. One of the solutions which are being investigated is the utilisation of fast-growing plantation wood which provides environmental and economic benefits (Chen *et al.* 2013). Jabon wood (*Anthocephalus cadamba*) is one of potential species to contribute to wood industry as it has a wide range of distribution, is easy to cultivate and is adaptive to Indonesia's natural condition (Mansur and Tuheteru 2010). Jabon also grows rapidly, has high cylindricity, not many knots and its wood is easy to work with (Soerianegara and Lemmens 1993, Krisnawati *et al*. 2011). However, this species also has some weaknesses of physical and mechanical properties (Martawijaya *et al*. 1989). One of the aims of wood modification is to improve the wood–moisture relationship. There are many examples of wood modifications which resulted in reduction in equilibrium moisture content at a given relative humidity. Consequently, the mechanical properties of wood were changed, since it is well known that a reduction in the cell wall moisture content results in an increase in the MOE and strength (Dinwoodie 2000). Physical and mechanical properties of low quality wood can be improved by treatment with chemicals (Hill 2006).This can

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be accomplished by depositing a bulking agent within the swollen structure of the wood fibres through impregnation using bulking agents. Most successful bulking agents that have been commercially applied are highly water-soluble, thermosetting, phenol-formaldehyde resin-forming systems (Rowell 1999). Much earlier wood treatment research conducted in 1950-1960 has found phenol-formaldehyde resins to be effective wood treatment agents (Stamm and Seborg 1951, Stamm and Seborg 1962). Since then, research on wood treatment using phenol and phenolicformaldehyde has been continued (Sakai *et al.* 1999, Deka and Saikia 2000). The Indurite™ Process from New Zealand is another treatment for wood hardening using carbohydrate oligomers and cross-linking condensation polymerisation which resulted in higher density and increased compressive strength, as well as enhanced surface hardness. The performance of the modified wood met the furniture manufacturers requirements (Franich 2007, Cox 2006, Singh *et al*. 1999). Treatment of either solid or composites wood using polymer can also improve various physical and mechanical properties, such as water repellency, dimensional stability, abrasion resistance, surface hardness and fire resistance (Rowell and Konkol 1987, Ibach and Ellis 2005). Improvements in the physical properties of wood polymer composites (WPCs) relate to polymer loading, which depends upon the permeability of the wood species and particular pieces of wood (Rowell 1999). For most species, sapwood usually is more easily impregnated than heartwood (Bergman *et al.* 2009). It has been scientifically proven that wood with high density also has high hardness.

The relationship between these two parameters has been extensively published in several studies (Bustos *et al.* 2009, Doyle and Walker 1985, Dumail and P. Caste´ra 1998, Green *et al*. 1999, USDA Forest Serv. 2006, Herajarvi 2004, USDA Forest Serv. 2007). In comparison with the mature wood, young timber or timber of fast growing species have lower density, as pointed out by Panshin and De Zeeuw (1980). It can be stated that the properties of juvenile wood are characterised by a lower density. The few latewood cells in the juvenile zone and a high proportion of cells with thin wall layers result in a low density and a corresponding low strength in comparison with mature wood (Shmulsky *et al.* 2011). However, young, fast-growing wood can be modified to be denser with various treatment methods.

Previously, Deka and Saikia (2000) impregnated a fast- growing softwood, *Anthocephalus cadamba* Miq. using thermosetting resins: phenol formaldehyde (PF), melamine formaldehyde (MF) and urea formaldehyde (UF). The effects on dimensional stability and strength property of the treatment were studied. The results show dimensional stability increases of 70,59%; 68,23% and 48,5% with about 33 - 35 % of weight gain (WPG) for PF, MF and UF resins, respectively, when wood samples were treated with 30% resin concentration at 90 - 100°C and 5,27 KG/cm^2 air pressure. The levels of 33 - 35 % WPG resulted in 9 - 15% Bulking Coefficient (BC) and 31 - 47% Moisture Excluding Efficiency (MEE) of treated wood. Repeated wetting and drying does not change the value of BC and anti-shrink efficiency (ASE) of treated samples. The treatment also increased MOR and MOE by 12 - 20 % and 5 - 12 %, respectively, at 33 – 35% WPG. Information regarding bending characteristics i.e. MOE and MOR are important for the engineering design and manufacture of structural lumber and for high value uses of wooden furniture components to ensure time-based performance in service (Ozarska 2009). In a floor joist, MOE is very important because it determines the amount the joist will bend or deflect under load and thus how the floor will perform in service (Shmulsky *et al.* 2011). The aim of this study is to investigate the effect of the impregnation treatment using Merbau extractives (ME) and selected polymerised Merbau extractives (PME22 and PME33) on selected mechanical characteristics of impregnated Jabon wood. The mechanical characteristics evaluated were: hardness, shear and bending stiffness/strength (MOE/MOR).

MATERIAL AND METHOD

Specimen preparation

The specimens used in the study were prepared according to Australian Standards for mechanically testing small clear specimens of timber (Mack 1979) and were of the following sizes:

- 20 x 20 x 20 mm for density and moisture content tests.
- 30 x 30 x 90 mm for hardness test.

- 20 x 20 x 60 mm for shear test.
- 20 x 20 x 300 mm for bending strength (MOE & MOR).

The samples were taken from the sapwood of 5 years old back-sawn Jabon wood (*Anthochepalus cadamba* (Roxb) Miq) from West Java Province, Indonesia. As the Jabon wood was only 5 years old the heartwood part was very small. The test samples were prepared from "clear" and "straight grained" wood which did not contain unfavourable features such as knots, cross grain, checks, and splits (Green *et al.* 1999). A total of 768 specimens were prepared and divided into 4 groups based on the type of treatment applied, as follows:

- UT = Non-impregnated samples (controls)
- ME = Impregnated samples using Merbau extractives
- PME22 = Impregnated samples using PME22
- PME33 = Impregnated samples using PME33.

Impregnating material and treatment

Impregnation material included Merbau extractives (ME) which were prepared using the following method.

Merbau wood powder, with a moisture content of 18%, was prepared using a grinding machine. Extraction was done by maceration, in which 500 mL of the powder passed through a 40-mesh screen, was dispersed in hot water of 80 °C, and stirred every 3 h at room temperature for two 24-h periods. The mixture was filtered with a glass filter, resulting in the separation of the first filtrate (1) and the residue. This maceration procedure was repeated for the residue, resulting in a second filtrate (2). The first (1) and the second (2) extracts were combined to make a concentrate (with the use of a rotary evaporator), which was freeze-dried to powder. The properties the ME have been thoroughly investigated by Malik *et al.* (2016). Hot water was used as the solvent in this study because according to Kislik (2012), water is the best alternative for organic solvent. It is environmentally friendly, relatively cheaper, safe, nontoxic, imflammable, and recyclable. Merbau extractive (ME), being a water soluble material, is easy to extract by water. The polymerised Merbau extractives (PME22 and PME33) were made from the ME which has been polymerised in base condition with formaldehyde and resorcinol addition as the copolymer. The resin is classified as a resole because the mole ratio of R/F should be <1 or F/R ≥1, and polymerisation can be done at room temperature. Impregnation treatment was done in a vacuum-pressure vessel where the wood samples were placed into open-top container of a vacuum-pressure unit where connected by a hose to the container of liquid of polymerized Merbau extract (PME) that has been prepared. The open-top container containing the samples was vacuumed using the compressor at the power of 0,1 kg/cm^2 for 30 minutes. The vacuum was then released and the container was allowed to be filled by the liquid of impregnant, so the liquid level was 20 cm higher than the submerged wood samples. Pressure was then applied and maintained at 15 kg/cm^2 for 1 hour. This procedure was applied for the samples of the three impregnating solutions (ME, PME22 and PME33). After that, all specimens were drained and then put into a conditioning room until a constant weight was reached (Malik *et al*. 2015, Malik *et al*. 2016, Malik *et al*. 2018). The moisture content of all tested samples was 12% to avoid – according to Rowell (1996) – a misleading or even invalid values if the samples were tested at different moisture levels.

The test procedures for mechanical properties assessment

Hardness

Thirty two replicate samples measuring 30 x 30 x 90 mm (ratio 1 : 1 : 3) were prepared from each

treatment. According to the "Australian Standards for Mechanically Testing Small Clear Specimens of Timber" (Mack 1979), the dimensions of hardness specimens are 50 x 50 x 150 mm, but the test may also be made on a specimen of any other size, as long as the thickness is at least 25 mm and the ratio of 1:1:3 is maintained. In this study specimen dimensions were 30 x 30 x 90 mm as it was impossible to obtain 50 mm thickness. The hardness was tested using an Instron® Universal Testing Machine according to the above standard. The hardness test was done on all faces of the specimens to obtain side-hardness (4 sides) and 2 cross-sections. The reason for testing all faces of each specimen was to ensure a more representative hardness value (Green *et al.* 2006). Before and after testing, the weight and dimensions of each specimen were measured for determination of wood density and moisture content.

Shear

The shear strength test was carried out according to the procedure of Mack (1979). The loading was applied continuously throughout the test at a rate of motion of the movable crosshead of 0,6 mm/min until a break or separation occurred on the surface of the test samples. The test was done on 256 specimens with 32 repetitions for each treatment on radial and tangential sections.

MOE and MOR

A number of 128 specimens were prepared for bending strength tests (MOE and MOR) using an Instron® Universal Testing Machine according to The Australian Standards Procedure for Mechanically Testing Small Clear Specimens of Timber (Mack 1979) for specimen size adjustment. The loading rate was 1,0 mm per-minute and the specimens were loaded on the radial face.

Physico-chemical test

The physico-chemical analysis was employed to determine whether there is a chemical change on Jabon wood after impregnation treatment that affect the mechanical characteristics. Two methods were used: Fourier Transform Infrared Spectroscopy (FT-IR) that aimed to analysis functional groups and finger print alteration and X-Ray Diffraction (XRD) Analysis to determine degree of crystallinity of the samples from untreated and treated wood. The amount of 15 mg of treated and untreated samples of 120 mesh size were directly used in the FTIR spectroscopy measurement. They were then embedded in kalium bromide (KBr) pellets and analysed using a MB3000 (ABB, Canada) spectrometer. They were scanned in the absorption mode in the range of 4000 to 500 cm^{-1} with the resolution of 2 cm^{-1}. The crystallinity of the samples from untreated and treated wood was measured using X-Ray Diffraction (XRD) (MAXima_X Shimadzu® XRD-7000). The X-ray beam was powered with a 40kV, 30mA source and scans made in the range from 0-40 degrees at a scan speed of two degrees per minute. The degree of crystallinity was calculated as the ratio of the intensity differences in the peak positions.

Data analysis

The changes in mechanical properties of impregnated Jabon wood samples were qualitatively analysed by comparing through the changes of physico-chemical characteristics of impregnated and non-impregnated samples. All data of mechanical properties changes were then analysed by one-way analysis of variance to determine if there were any significant differences between the samples. Then, a post-hoc multiple comparison by Tukey was done to determine whether there was a significant difference between the groups.

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RESULT AND DISCUSSION

Changes in mechanical properties

The changes of physical and mechanical properties of wood can occur by chemical modification due to changes in the chemistry of the wood cell wall polymers. These properties can vary from simple colour change in the wood to major changes in brittleness, hardness, strength, stiffness, density, and moisture sorption (Rowell 1996). The changes may include decreasing, increasing, or even no effect on the properties, depending on the type of chemical used in the treatment. The results of tests of mechanical properties of impregnated Jabon wood i.e hardness, shear and bending strength are presented in Table 1. The analysis showed that the density values of the samples were significantly different for different treatments (Sig = 0,000) (Table 2). As reported by Malik *et al.* (2015), the density of Jabon wood after impregnating treatment using polymerise merbau extractives – PME22 and PME33 – increased by 26and 30 %, consecutively. Generally, almost all mechanical properties of wood are known to be closely associated with wood density (Brown *et al.* 1952, Panshin *et al*. 1964, Sharp 2003). Table 1 shows that there are increments in mechanical properties after impregnation treatment with PME22 and PME33, but not in the samples impregnated with merbau extractives (ME).

Table 1: Mechanical characteristics of treated and untreated Jabon wood.

Treatment	MC (%)	Density (kg/m^3)	Hardness (N)		Shear (kPa)		Bending strength (MPa)	
			End (He)	Side (Hs)	Radial	Tangential	MOE	MOR
			Mean ± SD					
UT	12,09±0,09	340 ± 1	3277,58 ± 543,68	2127,45 ± 626,45	6213,49 ± 381,48	6635,18 ± 704,12	4888,62 ± 734,93	42,79 ± 8,80
ME	12,15±1,48	330 ± 1	3246,88 ± 366,18	2345,36 ± 480,33	6185,05 ± 762,96	6655,77 ± 722,75	4837,65 ± 805,24	44,19 ± 8,92
PME22	12,03±0,21	430 ± 2	3934,43 ± 667,44	2777,24 ± 418,16	8815,20 ± 1367,05	9925,31 ± 1668,11	6038,47 ± 658,06	54,98 ± 6,09
PME33	12,07± 0,05	440 ± 1	4350,52 ± 655,87	2976,12 ± 727,85	10812,81 ± 1234,66	11883,70 ± 1289,57	6849,99 ± 597,26	60,41 ± 8,29

Remarks: MC = Moisture content; UT = Non-impregnated samples (controls); ME = Impregnated samples using Merbau extractives; PME22 = Impregnated samples using PME22; PME33 = Impregnated samples using PME33.

Table 2: Analysis of variance of and density of treated and untreated Jabon wood samples.

Parameter		Sum of Squares	df	Mean Square	F	Sig.
Density	Between Groups	0,324	3	0,108	738,923	0,000
	Within Groups	0,018	124	0,000		
	Total	0,342	127			

The increment of mechanical properties of treated Jabon wood after impregnation treatment have been confirmed by FTIR spectra and crystallinity (XRD) analysis (Malik *et al.* 2018). A coupling reaction between wood and the impregnant can be confirmed by FTIR spectra. The reaction of treated Jabon wood by impregnation using polymerised Merbau extractives (PME22 and PME33) was shown by the presence of the peaks at 2922,16 (PME22) and 2895,15 (PME33), 2002,11 (PME22) and 1928,82 (PME33), 1327,03 (PME22) and 1330,88 (PME33), 1033,85 and 1041,56 for C–H and CH_3 stretching in polymerized Merbau extractives (PME), aromatic combination bands, C–H deformation in polymers (aromatic aldehyde) and C–O ether bond stretching vibrations in PME reaction, respectively, where they do not exist in untreated (UT) Jabon wood samples (Malik *et al.* 2018). This permanent chemical presence has not only resulted in the colour change but also in increased mechanical properties. Using FTIR spectra analysis to confirm the coupling reaction between solid wood and impregnating material and its effect on the wood mechanical characteristics was also carried out by other researchers (Hamdan and Islam 2012, Dong *et al.* 2016). Hamdan and Islam (2012) showed an optimistic improvement in physical and mechanical properties that were confirmed by FTIR spectra. The results revealed the reaction of wood based hydroxyl groups with diazonium salt woods which were modified by benzene diazonium salt formulation. Using rosin as impregnant, from FTIR analysis Dong *et al.* (2016) stated that there may be hydrogen bonds formed by the reason of the affinity between hydroxyl groups in wood and carboxyl groups in rosin, which could improve the interaction between the resin and wood. In addition, results of X-ray diffractometer (XRD) analysis showed that the crystallinity of both PME22 and PME33 was very low by 8,76 and 10,03%, respectively. However, this resulted in increased crystallinity of the impregnated Jabon wood from 46,55% (UT) to 48,25% (impregnated by PME22) and 50,84 % (impregnated by PME22). In contrast, a decrement of the crystallinity occurred in the samples impregnated with ME by 1,02%. According to Santoso (2014), these would have an implication on hardness, shear and bending strengths. The changes of crystallinity values are shown in Figure 1.

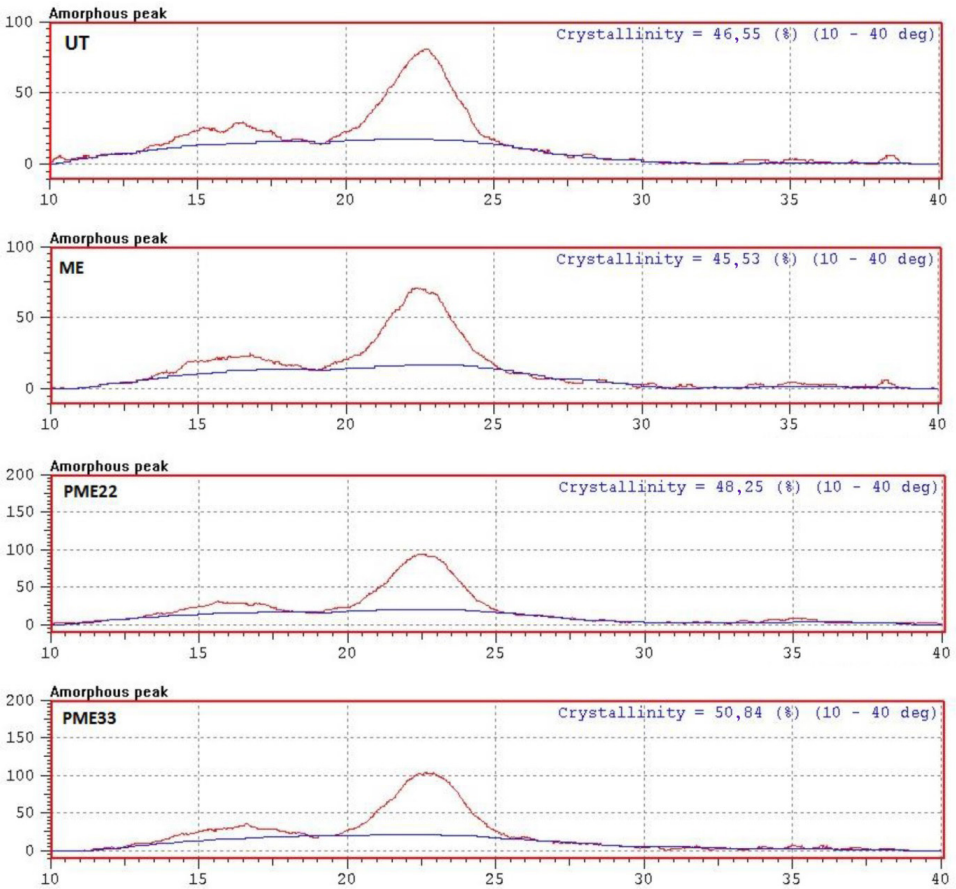

Figure 1: Diffractograph of untreated (UT) and treated Jabon wood samples using ME, PME22 and PME33. Remarks: UT, ME, PME22 and PME33 refers to Table 1.

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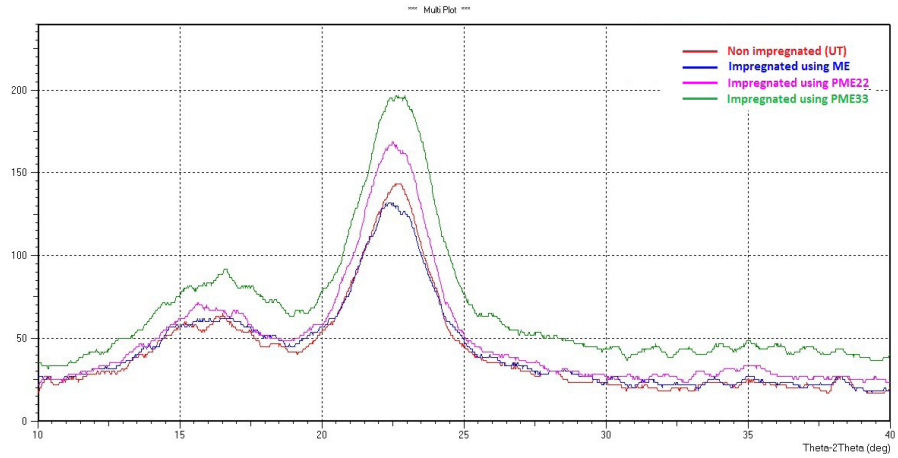

Figure 2: Overlaying diffractograph of the increment of crystallinity treated Jabon wood samples using PME22 and PME33.

Table 3: Crystallinity and molecular weight of treated and untreated Jabon wood samples.

Treatment	Crystallinity (%)	Crystallinity values change (%)
UT	46,55	-
ME	45,53	-1,02
PME22	48,25	+1,70
PME33	50,84	+4,29

PME22 and PME33 can be classified in low molecular weight (MW) polymerized material (PME22 = 3164 and PME33 = 3615). Due to the low MW, these materials can penetrate the cell wall of the treated wood. Thus, crystallinity of the treated wood with PME22 and PME33 increased, or in other words, the increments of crystallinity of the treated wood samples is an evidence that both PMEs penetrated the cell wall. Crosslinking reaction occurred between functional groups of PMEs and the cell wall material. This finding is in line with Wu *et al.* (2011), who stated that a quasi-crystalline was formed as the result of the crosslinking reaction. The crosslinking material not only entered the cell cavity and cell gap, but also filled in the cell walls and the micro-fibrils (Wang *et al.* 2003, Liu *et al*. 2009, Ma *et al*. 2013). This led to the polymerization between the functional groups of wood and the chemicals which resulted in increase of physical and mechanical properties of the impregnated (Chen *et al.* 2013). These results have been confirmed by this current study as presented in the following sections.

Hardness

Hardness is an important property of timber for various applications such as for flooring, furniture and some structural uses. It provides an indication of how well the wood performs in relation to wear and denting (Thomas *et al.* 2009.). Impregnation treatment can improve the hardness, as revealed by many researchers. Hamdan and Islam (2012) reported that the hardness of five types of selected tropical light hardwoods had higher hardness after impregnation using benzene diazonium salt, compared to their corresponding non- impregnated control wood. The increase of wood hardness is due to the increase of interfacial adhesion between the polymer and wood that improves water exclusion, decreases the

rate of swelling, and increases hardness of WPC (Ellis and O'Dell 1999). Hardness can be also generally enhanced through impregnation and in-situ polymerization (Zhang *et al*. 2006, Keskin *et al*. 2004). The wood hardness increases with the increasing density (Forest Product Laboratory 1940). According to Rowell (1999), the increase in hardness is more than proportional to the increase in specific gravity. In present study, as shown in Table 1 and Figure 3 both end- and side- hardness increased following the increment in the density from 340 kg/cm^3 (UT) to 430 kg/cm^3 (PME22) and 440 kg/cm^3 (PME33). Statistically, the differences in hardness increments after impregnating treatment using PME22 and PME33 were significant as determined by one-way Anova at $\alpha = 0,05$ ($F(3119) = 26,386$ Sig = 0,000). Post-hoc analysis by Tukey showed that the hardness resulted from impregnating 300 treatment using PME22 (He = 3934,43 ± 667,44 N; Hs = 2777,24 ± 418,16 N, Sig = 0,000) 301 and PME33 (He = 4350,52 ± 655,87 N, Hs = 2976,12 ± 727,85 N, Sig = 0,000) were significantly different from non-impregnated samples/ UT (He = 3277,58 ± 543,68 N, Hs = 2127,45 ± 626,45 N) and from samples impregnated with ME (He = 3246,0 2345,36 ± 480,33 N). Even, the hardness of impregnated samples using PME22 and PME33 were significantly different from each other. There was no significant difference between the hardness of UT and ME, as well as their density.

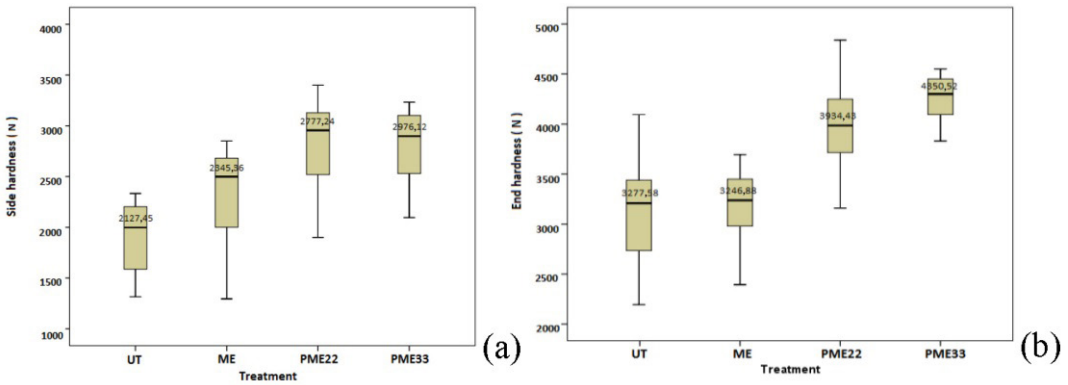

Figure 3: Hardness increment of Jabon wood after impregnating treatment using PME22 and PME33: (a) End-hardness; (b) Side-hardness.

Shear strength

Shear strength is defined as an ability to resist internal slipping of one part upon another horizontally along the wood fibre (Green *et al.* 1999, Shmulsky *et al*. 2011). As well as hardness, shear also increased with increased density due to the impregnating treatment (Chow 1966, Rowell 1999). Table 1 and Figure 4 shows that both radial (R)- and tangential (T)- shear strength increased after impregnating treatment using polymerised Merbau extractives (PME22 and PME33) from 6213,49 ± 381,48 kPa (R) and 6635,18 ± 704,12 kPa (T) at UT to 8815,20 ± 1367,05 kPa (R) and 9925,31 ± 1668,11 kPa (T) at PME22 and to 10812,81 ± 1234,66 kPa (R) and 11883,70 ± 1289,57 kPa (T) at PME33 Jabon wood samples. Meanwhile, there was no significant improvement of the shear strength of Jabon wood samples after impregnating treatment with ME; the shear slightly decreased on radial section. Statistically, the shear strength changed after impregnating treatment using PME22 and PME33. The shear values were significantly different as determined by one-way Anova at $\alpha = 0,05$ ($F(7248) = 143,460$ Sig = 0,000). Further, post-hoc analysis by Tukey method showed that the shear values resulted from impregnating treatment using PME22 and PME33 were significant different from UT and ME samples both on radial and tangen-

tial sides. This analysis also revealed that there was a significant difference in the shear strength between radial and tangential sides of UT samples. However, there was no significant difference between radial- and tangential- shear strength of ME samples.

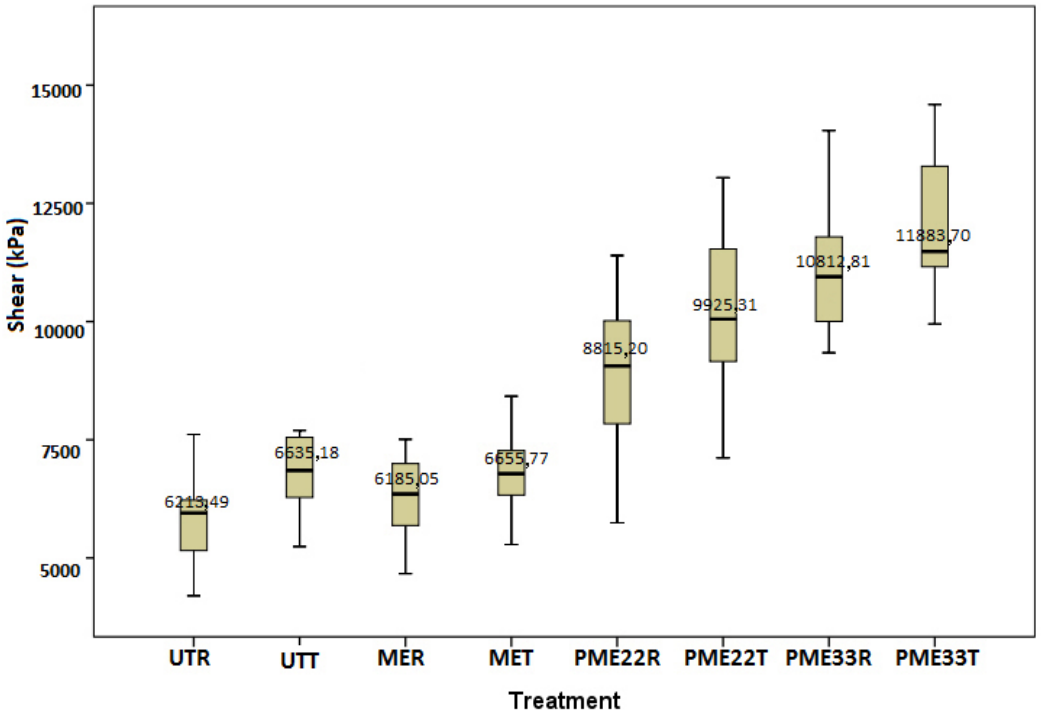

Figure 4: Shear increment of Jabon wood after impregnating treatment using PME22 and PME33.
UTR = Non-impregnated samples (controls) on Radial section; UTT = Non-impregnated samples (controls) on Tangential section: MER = Impregnated samples using Merbau extractives on Radial section; MET = Impregnated samples using Merbau extractives on Tangential section; PME22R = Impregnated samples using PME22 on Radial section; PME22T = Impregnated samples using PME22 on Tangential section; PME33R = Impregnated samples using PME33 on Radial section;.PME33T = Impregnated samples using PME33 on Tangential section.

Bending strength

Impregnation treatment generally improves flexure characteristics of impregnated wood. In regards to using polymeric material as the impregnant, Zhang *et al*. (2006) concluded that modulus of elasticity was enhanced through impregnation and in-situ polymerization. Moreover, the increase of modulus of rupture (MOR) and modulus of elasticity (MOE) was related with weight percent gain of the impregnated wood (Deka and Saikia 2000). In line with these earlier studies, it should be pointed out that the increments of the flexure characteristics have been also observed in impregnated Jabon wood, as shown in Table 1 and Figure 5. From the results presented in Table 1, it can be seen that MOE increased from 4888,62 ± 734,93 MPa (UT) to 6038,47 ± 658,06 MPa in PME22 samples (23,52%) and to 6849,99 ± 597,26 MPa in PME33 samples (40,12%). MOE value decreased by -1,04% on impregnated samples using ME. MOR values increase by 3,27; 28,50 and 41,19 % after impregnated with ME, PME22 and PME33, respectively. Statistical analysis indicate that the increments of MOE and MOR were significantly different (F(3124)= 6038,47 MPa, Sig = 0,000 for MOE; F(3124)= 54,98 MPa, Sig = 0,000 for MOR). Furthermore, post-hoc analysis by Tukey showed that MOE and MOR values of the impregnated samples using PME22 and PME33 samples were significant different compared to UT and ME samples. The MOE values of PME22 and PME33 samples were also significant different. However, the MOR values of PME22 and PME33 samples were not significantly different as well as MOR of UT and ME samples and be amorphous area or by para-crystallin of microfibril. In addition by para-crystallin can be related to crystallization process of cellulose in In addition, Yunianti (2012) reported that there is a strong linear correlation (r=0,83) between MOE with- in certain limit - crystallinity. In the present study,

as demonstrated in Figure 2 and Table 3, it could be assumed that the increment of the bending strength of impregnated Jabon wood is related to the crystallinity increment. Chen *et al.* (2013) stated that there is no doubt that the mechanical properties are closely related with the strength of the wood cell wall.

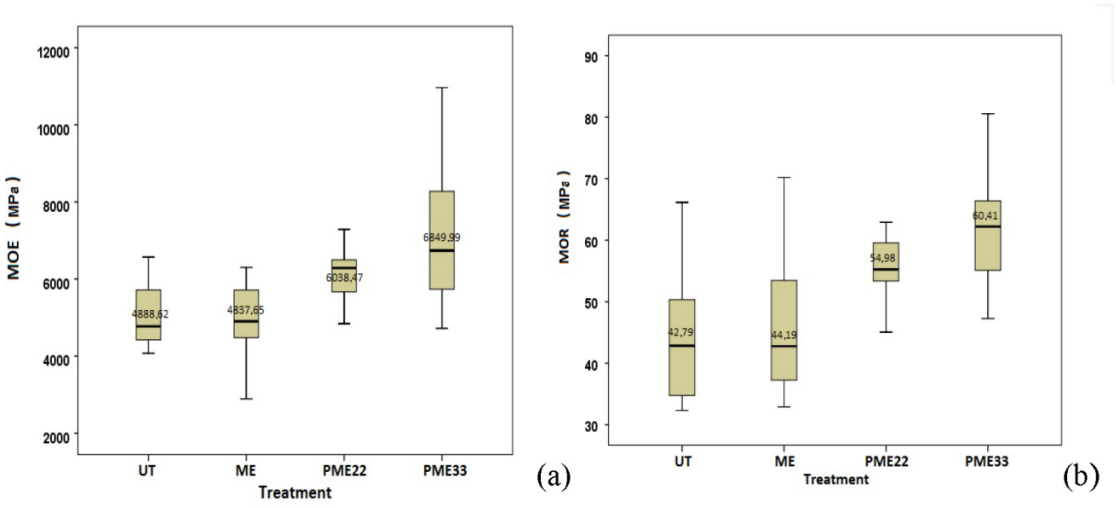

Figure 5: The increment of bending strength of Jabon wood after impregnating treatment using PME22 and PME33: (a) MOE and (b) MOR.

CONCLUSIONS

Positive results in improvement of mechanical properties are obtained for Jabon wood which has been impregnated by polymerised Merbau extractives (PME22 and PME22) following the increment of the density. Surface hardness of modified wood samples exhibites higher values compared to the non-impregnated samples by 20,04 and 30,54 % (PME22) and 32,73 and 39,89% (PME33) -0,94 and 10,24 (ME) for the end and side hardness, respectively. Shear strength increases by 41,87 and 49,58 % (PME22) and 74,02 and 79,10 % (PME) for radial (T) and tangential (T) sections, respectively, compared to non-impregnated samples. MOE increases by 23,52% for PME22 impregnated samples and by 40,12% for PME33 samples; meanwhile MOE value decreases by -1,04% on ME impregnated samples. MOR values increased by 3,27 28,50 and 41,19 % after impregnation with ME, PME22 and PME33, respectively. The increment of mechanical properties on treated Jabon wood after impregnation treatment using polymerised Merbau extractives are confirmed by FTIR spectra and crystallinity (XRD) analysis. The increment occurres due to the penetration of the PMEs into the cell wall by crosslinking reaction between functional groups of PMEs and the cell wall material and the formation of a quasi-crystalline which is shown by increasing crystallinity of the treated Jabon wood.

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