COLOUR CHANGES AND MORPHOLOGICAL PERFORMANCE OF IMPREGNATED JABON WOOD USING POLYMERISED MERBAU EXTRACTIVES

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ABSTRACT

Colour can be one of the preferencial factors prior to making a decision when people want to make a purchase of a wood product. Impregnation treatment can alter the wood colour. This study investigated the colour change of young plantation Jabon wood due to impregnation using Polymerised Merbau Extractives. Colour evaluation was done using the *CIEL*a*b** system. Investigations also included morphological appearance by Scanning Electron Microscopic and chemical change by Fourier Transform Infrared analysis.

The results demonstrated that impregnation treatment using selected Polymerised Merbau Extractives i.e. PME22 and PME33, resulted in the colour change of the wood. Appearance of the impregnated wood was different from the original wood; it was like a 'new wood'. The colour was changed permanently. PME33 caused Jabon wood samples to be darker. The SEM results of untreated and treated Jabon wood showed apparent difference due to deposited cured polymerised Merbau extractives (PME) in wood vessels. Obviously, a certain amount of cured PME precipitated on the surface of wood vessels and filled in the cell wall illustrated by the cross section of treated wood. FTIR spectra revealed that impregnating treatment using polymerised Merbau extractives made chemical changes in the wood of new functional groups bonded to Jabon wood.

Keywords: *Anthocephalus cadamba*, chemical changes, CIELab color, treated wood, wood appearance.

INTRODUCTION

One of the physical properties of wood that influences aesthetic values is the wood colour. In the modern era, colour takes an important place in regard to human's need and style. Colour can be one of the preferencial factors prior to making a decision when people want to make a purchase, design a property and manufacture a product. For those reasons, colour becomes an important consideration in a marketing strategy. Furthermore, colour has a psychological influence on people (Whitfield and Wiltshire 1990, Babin *et al.* 2003, Miller and Kahn 2005, Aslam 2006, Skorinko *et al.* 2006, Deng *et al.* 2010, Piotrowski and Armstrong 2012, Schloss and Palmer 2011). Colour can determine a marketing value (Warner and Raymond 1947). These days, the average consumer will not accept colour ranges that were industry standard ten years ago. They are always searching for a better product; a product that gives them desired properties with a minimum variation (Konica-Minolta 2007).

Wood is available in a range of colours from almost white, as in the sapwood of many species, to almost black, as in the heartwood of black ebony (Hon and Minemura 2001). It can influence the market price of this ligno-cellulosic material. As compared with the colour of other materials such as plastic and concrete, wood conveys peace of mind and a feeling of natural mildness (Hon and Minemura 2001, Esteves *et al.* 2008, Rosu *et al.* 2010, Dubey *et al.* 2010).

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In comparison to wood species with pale or light colour, darker wood colour is preferable in many countries due to a 'tropical' appearance or value. As a result, woods which are naturally pale or light in colour are usually treated to darken the colour (Esteves *et al.* 2008). However, colour preference is different depending on culture, final consumer, and country. The preference also changes with time. Some markets, such as Scandinavia and Japan, prefer light-coloured wood for certain end uses (Wahl *et al.* 2002, Esteves *et al.* 2008), whereas in South Asia, people like dark-coloured wood as it gives the impression of a strong, stable and durable wood (Dubey *et al.* 2010). Similarly, in South-western countries, darker-coloured woods are also preferred because it is associated with tropical species of high-quality (Esteves *et al.* 2008).

To create a darkened effect in wood, many studies have been carried out by means of various methods, either physical or chemical treatment. Most studies that have been undertaken and applied to industrial production including heat treatment (Sundqvist 2004, Hill 2006, Esteves *et al.* 2008, Pena and Hale 2009a, Pena and Hale 2009b, Dubey *et al.* 2010, Esteves and Pereira 2009, Dubey *et al.* 2012, Cermák and Dejmal 2013, Garcia *et al.* 2014, Kamperidou and Barmpoutis 2015, Tuong and Li 2010). Hill (2006) stated that a darkening of the wood occurs with the colour change being related to the temperature and time of treatment.

Colour alterations can also occur after an impregnation treatment even though the treatment is initially not intended to change the wood colour. Recent studies revealed this visible and aesthetical characteristic of the treated wood. A study on the effects of boric acid, borax and ammonium acetate treatments on total colour values was carried out by Aydin and Colakoglu (2005). They manufactured rotary cut veneers from Alder (*Alnus glutinosa* subsp. *barbata*) and Beech (*Fagus orientalis*) logs and investigated colour change after the treatment. Their study revealed that ammonium acetate caused the highest total colour change while treatment with borax caused the lowest total colour change. Simsek and Baysal (2012) investigated colour change values using the CIELAB method on Oriental Beech and Scots Pine after being impregnated using borate. They show that the chemical caused negative values ΔL^* for both wood species. Furthermore, the values of Δa^* and Δb^* of the Scots Pine impregnated wood were found to be much higher than that of the Oriental Beech. The increase in the chromaticity coordinates, Δa^* and Δb^* for the Scots Pine indicated the yellowing and reddishness due to impregnation. The results also showed that the total colour changes (ΔE) of the Scots Pine were higher than those of the Oriental Beech. Borate impregnation caused remarkable loss in gloss of the Oriental Beech and Scots Pine (Simsek and Baysal 2012).

Wood besides being naturally composed mainly of lingo-cellulose compounds; cellulose, hemicellulose and lignin, another material also can be found in wood or bark that is called extractive, because it can be extracted using polar and non-polar or neutral solvents. Due to its colour, the employment of natural dyestuffs dates back to antiquity, and many of these probably arose from wood or bark (Hillis 1987). Experiments using natural dyes were conducted on wood to develop an eco-friendly dye that may be used in furniture-making and woodworking, with no negative effects to human health. Ozen *et al.* (2014) investigated the use of an extract from pomegranate skin (*Punica granatum*) and black mulberry (*Morus nigra*) to colouring Scots Pine (*Pinus sylvestris*) and Oriental Beech (*Fagus orientalis*) woods by immersion method. The colour changes under accelerated weathering conditions were studied. The value of the total colour changes was determined using the CIELAB system and showed the best colour stability in Oriental Beech wood that was treated with 30 % pomegranate skin or black mulberry extract as well as Scots Pine wood that was treated with 25 % pomegranate skin extract or 50 % black mulberry extract. According to the results, both pomegranate skin (*Punica granatum*) and black mulberry (*Morus nigra*) can be used to colour wood materials.

Study on colorimetric properties after an impregnation treatment that followed by *in situ* polymerization was conducted on *Pinus taeda* and *Schizolobium parahybum* woods that were impregnated using methyl methacrylate, glycidyl methacrylate and methacrylic acid with benzoyl peroxide as the catalyst. The results showed that treatments with methacrylic acid resulted in the lowest changes in both chroma and lightness. L* was more influent than the specular gloss to change the vivacity of wood colors after *in situ* polymerization treatments (Mattos *et al.* 2016).

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Jabon wood (*Anthocephalus cadamba*) is one of timber species widely grown in Indonesia which is planted by both industrial forest plantation companies and by communities. There are many small business promotions to establish jabon plantations. This species is well known as a fast growing species. As a wood industry material, this species can be harvested at 5 - 10 years old. Specific gravity of jabon is 0,42 meaning it falls into low class because it is in the range of 0,19 - 0,49 (Martawijaya *et al.* 1989) Currently, in Indonesia jabon has been used for making fruit crates, toys, light construction, plywood, laminated boards, block boards, fibre board, particle board and pulp. In terms of its utilisation for furniture, this species is easy to work with during planning and drilling (Mansur and Tuheteru 2010). However, the colour of this wood is light and is not attractive for making furniture, flooring and other appearance wood products. Threfeore, a study on changing the light colour of jabon wood into dark colour which would be aligned with traditional tropical timber which is in high demand by international markets would have significant benefits to the Indonesian local communities and timber industry sector.

This study is aimed to investigate colour changes and the morphological appearance of Jabon (*Anthocephalus cadamba*) wood after impregnated using polymerised Merbau extractives (PME).

MATERIAL AND METHODS

Impregnating materials and wood samples preparation

Impregnating materials were prepared from polymerized Merbau extractives (PME) based on the polymerization process following Santoso *et al.* (2014) using a lower portion of formaldehyde (F) by 10% and activating resorcinol (F) by 5% (w/w). The mixture was mixed until homogenous, which was followed by a 1-hour conditioning period. Selected homogenous mixtures then were called as PME22 (F=5%, R=2,5%) and PME33 (F=10%, R=5%).

Wood samples were prepared from five years of age of Jabon (*Anthocephalus cadamba*) from West Java (density = 360 kg/m^3), Indonesia, that had been cut and back sawn for the experiment. All samples were dried in a kiln to reach 12% moisture content (MC) and then pretreated through impregnation using selected formulation of polymerized Merbau extractives PME22 as T1 (density = 460 kg/m^3) and PME33 as T2 (density = 460 kg/m^3). The samples with the dimension of 50 (L) by 50 (T) by 50 (R) mm were provided for colour investigation, 5 (L) by 5 (T) by 5 (R) mm for scanning electron microscopic (SEM) and 5 mg each for fourier transform infrared (FTIR) analysis. The treated samples (T1 and T2) were then compared to the untreated (UT) to determine the changes that occur after the impregnation.

Colour evaluation

The colour was measured using Konica-Minolta CR-10 Tristimulus Colour Reader equipment with a measuring area of 8 mm. All colour measurements were taken under the conditions of the standard illuminant D65 and 10° observer, as described by the *Commission Internationale de L'éclairage* (*CIEL*a*b** standard). Fifty replicates for each sample group of treatment were collected to measure the parameters of lightness (*L**), and green-red (*a**) and blue-yellow (*b**) chromatic coordinates. Chroma (*C**), hue angle (*h**) and colour variation parameters of ΔE, *ΔL**, *Δa** and *Δb** were also calculated.

To determine colour nomenclature, an online free tool from *ColorHexa.com* was used (ColorHexa 2012). ColorHexa.com is a colour software providing name and description about any colour and generating the conversion to other colour systems (such as complementary, analogous, triadic, tetradic or monochromatic colour schemes) that will be matched with acquired colour data for any designs. The *CIEL*a*b** data acquired by the Colour Reader was simply entered to the bar search with the word 'Lab' in the beginning. By clicking the search button, the ColorHexa will offer a detailed description and automatically convert it to its equivalent colour system.

Scanning electron microscopy (SEM) characterization

The samples for SEM observation were made in the form of a cube-shape where the cross-section

would be the object of observation. The cross-sections of the samples were prepared with a microtome Leica. After the surface preparation, the samples were oven-dried at 103±2°C until reaching constant weight. The images were captured with three magnifications of 50, 100 and 200 through a scanning electron microscopy model EVO 50 ex Carl Zeiss AG.

Fourier Transform Infrared Spectroscopy (FT-IR) analysis

The amount of 5 mg of untreated and treated Jabon wood powder of 120 mesh size from selected samples were directly used in the FTIR spectroscopy measurement. They were then embedded in kalium bromide (KBr) pellets and analyzed 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}.

RESULT AND DISCUSSION

Evaluation on colour changes

The results of colour changes were evaluated from macroscopic images that were captured from tangential section of treated and untreated Jabon wood (*Anthocephalus cadamba*) (Figure 1). Originally, Jabon wood visibly ranges from light to a dark cream colour (Martawijaya *et al.* 1989). In this study, the untreated samples (UT) as the control are of dark-cream colour. Impregnating treatment with selected polymerised Merbau extractives (PME) on the wood species resulted in a totally different colour in comparison with the original (untreated) colour (change from dark cream to reddish-brown colour). This colour is similar to the colour of Merbau (*Intsia sp.*) wood, as also mentioned by Martawijaya *et al.* (1989), that the colour of the heart wood of Merbau varies from greyish-brown to reddish-brown or darker. The impregnation using PME resulted in a 'new wood' that differs from the original Jabon wood.
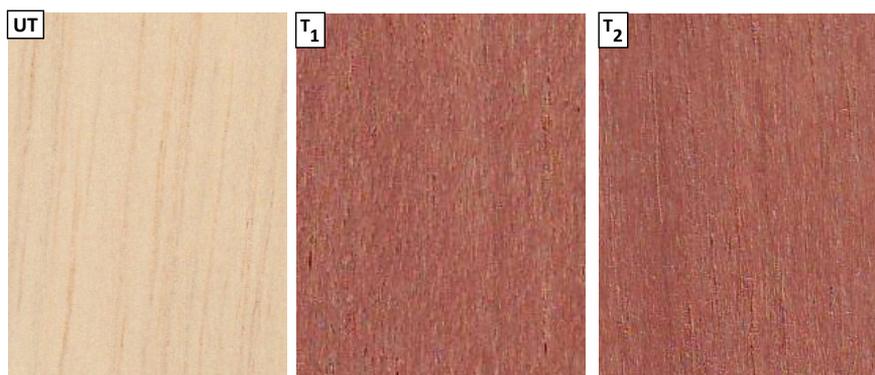

Figure 1. Visual appearance of untreated and treated wood using PME UT = Untreated samples; T1 = treated samples by PME22; T2 = treated samples by PME33.

The colour alteration occurs due to the PME infiltration into the wood structure evenly (Figure 1: T1 and T2). Moreover, deposit PME was even found in the vessels due to a chemical bonding. The morphology of the PME infiltration will be discussed later. The PMEs were made from Merbau extractives (ME) that have been polymerised with formaldehyde as a cross-linker and a little amount of resorcinol (≤ 5%) as the activator in base condition. The colour of PMEs represent the original merbau extractives. It is dark reddish-brown. Hillis (1996) mentioned the colour of water soluble material (extractives) from heartwood of Merbau as dark brown. When it infiltrated during impregnation to Jabon wood of cream colour, the colour of the treated Jabon wood (T1 and T2) was in between the colour of the untreated wood and the original colour of Merbau extractives. The proof of chemical

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bond between the impregnating material and wood component will be discussed in the next section with FTIR analysis.

Treatment with PME33 presented the highest decrement of lightness. As a result, treated Jabon wood with PME22 and PME33 look much darker than untreated samples. A decrement of L^* after *in situ* polymerization treatments was also observed by Mamiński *et al.* (2013) who treated beech wood with butyl acrylate and butyl methacrylate and Mattos *et al.* (2016) who impregnated *Pinus taeda* and *Schizolobium parahybum* woods in a vacuum/pressure system and polymerized in an oven at 90°C for 10h, using benzoyl peroxide.

Both chromatic coordinates a^* and b^* of impregnated Jabon wood using PME22 and PME33 increased after the *in situ* polymerization treatments. The increase of a^* in T1 treated wood was slightly higher than that of the T2 treated Jabon (Table 1). Higher increment also occurred for other (C^* *and* h^*) chromatic parameters of T1 in comparison to T2 treated Jabon wood. The increment of a^* from 7,14 (UT) to 17,12 (T1) and 16,57 (T2) on radial section for example, denotes a reinforcement of the reddish tones in the Jabon treated wood. Overall, an increase of both chromatic coordinates (a^* and b^*) infers a total colour change.

Table 1. Average values of *CIEL*a*b** parameters by section and impregnating material of *Anthochephalus cadamba* impregnated wood.

Section	Sample	L^*	a^*	b^*	C^*	h^*
Radial	UT	81,10 ± 1,91	7,14 ± 0,87	21,85 ± 1,95	23,10 ± 1,84	72,03 ± 1,43
	T1	41,52 ± 2,67	17,12 ± 1,40	19,16 ± 2,18	25,55 ± 2,32	47,65 ± 2,92
	T2	34,63 ± 2,37	16,57 ± 2,98	15,45 ± 2,18	21,65 ± 1,90	42,57 ± 2,66
Tangential	UT	80,92 ± 1,84	6,70 ± 0,80	19,99 ± 2,10	29,45 ± 3,08	71,83 ± 1,93
	T1	42,40 ± 3,26	19,57 ± 2,82	17,45 ± 1,80	23,36 ± 1,79	49,12 ± 4,33
	T2	32,92 ± 4,17	17,95 ± 3,58	15,68 ± 4,97	21,18 ± 1,99	40,12 ± 6,28

Remarks:
UT = Untreated; T1 = Colour investigation on impregnated samples with PME22; T2 = Colour investigation on impregnated samples with PME33.

Statisticall analysis revealed that on radial section there were significant colour changes between the group of UT T1 and T2 as determined by one-way Anova for L, a, b, C and h values, respectively with p = .000). A Tukey-HSD post hoc test revealed that colour values of untreated Jabon wood (UT) were significantly different from T1 and T2 as well as between T1 and T2 for all chromatics parameters (p = .000). The significant difference of colour changes also occurred on tangential section (p = .000).

To determine colour nomenclature based on acquired chromatocity data, there are many different types of colour systems available. Some of them are applicable to any type of substance, whereas some are specific to opaque materials or transparent materials. The use of specific colour scales or spaces varies from one industry to another depending on standards and requirements (Lovibond®, 2013). Thankfully, ColorHexa has been developed; an online data base of colour based on acquired chromatocity data with an easy and simple method. Referring to the data base, entering the values of $L^* = 80,92$; $a^* = 6,70$ and $b^* = 19,99$ for tangential surface of untreated Jabon wood (UT) the ColorHexa system defined the chromatocity as the colour of 'very soft orange' with the Hexa code of [●#e3c3a4]. Based on the nomenclature, impregnation treatment using PME22 changes Jabon wood colour from very soft orange to dark moderate red (Figure 2).
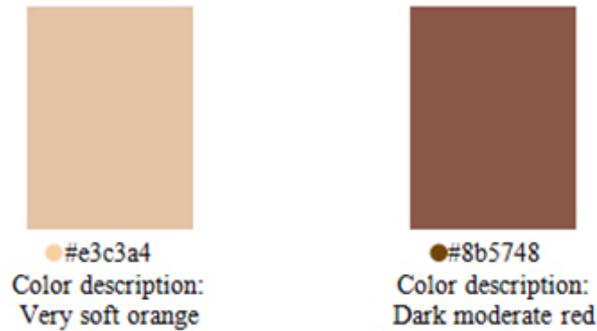
● #e3c3a4
Color description:
Very soft orange

● #8b5748
Color description:
Dark moderate red

Figure 2. Colour change due to impregnating treatment using PME22 defined by ColorHexa (2012).

Table 2 presents chromatocity to represent the colour differences amongst a paired-sample group using *Commission Internationale de l'Eclairage/*International Commission on Illumination (CIE) system. Colour differences are expressed as the delta values of ΔL^*, Δa^*, and Δb^*.

Table 2. Colour difference values using CIE parameters between treated and untreated wood of *Anthochephalus cadamba*.

Section	Pair	Colour Differences					
		ΔL^*	Δa^*	Δb^*	ΔE^*	ΔC^*	Δh^*
Radial	T1 x UT	-39,58	9,97	-2,69	41,02	2,45	-24,38
	T2 x UT	-46,46	9,43	-6,39	48,03	-3,90	-29,46
	T1 x T2	-6,88	-0,54	-3,70	8,98	-1,45	-5,08
Tangential	T1 x UT	-38,52	12,87	-2,55	40,87	-6,09	-22,71
	T2 x UT	-48,00	11,25	-4,32	49,89	-8,26	-31,71
	T1 x T2	-9,48	-1,63	-1,77	11,64	-2,18	-9,00

Remarks: UT, T1, T2, T3 and T4 refers to Table 1.

There is very high decrement of lightness parameter observed in T1/UT and T2/UT treatments, as can be seen through the results of ΔL^* (Table 2). Chroma decreases are followed by decreasing b^* but increasing a^*. Also, decreases of the hue angle were associated with the intensification of the red tones of Jabon wood due to both treatments. The significant colour differences were also statistically proven as determined by one-way Anova and Tukey-HSD post hoc test on both radial and tangential sections of Jabon wood samples. The Anova showed there were significant colour differences on the wood after impregnating treatment using polymerised merbau extractives (F > .05 and p = .000) for all chromatocity variations (ΔL^*, Δa^*, and Δb^*)and total colour changes (ΔE^*).

Figure 3 demonstrates the chromatocity variations that resulted in colour changes of Jabon wood before and after impregnation treatments on tangential section, as an example. A great change of the colour occurs after the treatment. For example, $L^*a^*b^*$ colour difference can explain T1 treatment resulting in Jabon wood being darker and redder as the red tone increased with the value of $\Delta L^* =$ -38,52; $\Delta a^* = 12,87$; $\Delta b^* = -2,55$ and total change $\Delta E^* = 40,87$. The treatment of T2 achieved a darker result than that of T1 since $\Delta L^* = -48,00$; compared to the control, although $\Delta a^* = 11,25$ and $\Delta b^* =$ -4,32 are lower and the total colour alteration of $\Delta E^* = 49,89$ is higher. The colour difference of treated wood among T1 and T2 can be seen as $\Delta L^* = -9,48$; $\Delta a^* = -1,63$; $\Delta b^* = -1,77$ and $\Delta E^* = 11,64$.
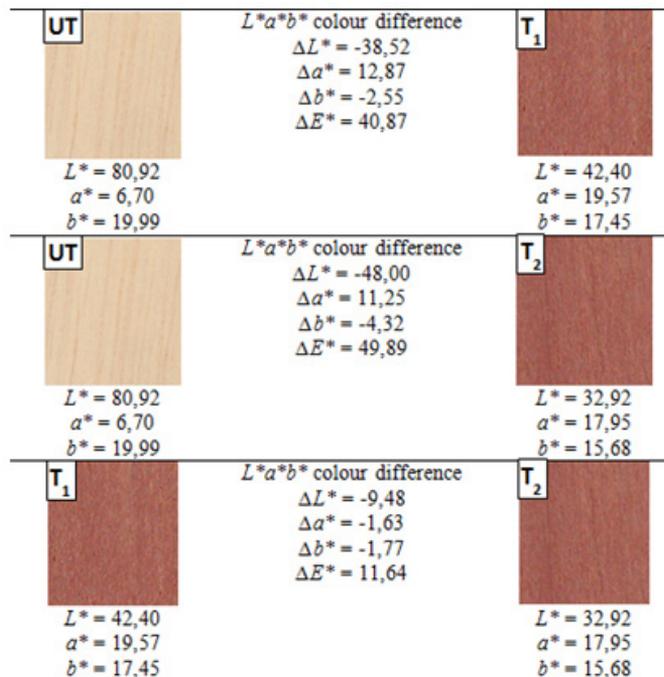
Figure 3. Identifying colour difference using $L*a*b*$ values.

The phenomenon as demonstrated in Figure 3 (decrease of $L*$ and $b*$ but increase of $a*$) typically does not occur in other treatments - normally, a decrease of $L*$, $a*$ and $b*$ is observed (Tuong and Li 2010, Cademartori *et al.* 2013, Mattos *et al.* 2015, Mattos et *al.* 2016). Through quantification of colour alteration using the delta of $L*$, $a*$, $b*$ and $E*$ values, treated Jabon wood using PME22 or T1 samples can be distinguished from that of PME33 (T2 samples) by $\Delta L* = -9,48$; $\Delta a* = -1,63$; $\Delta b* = -1,77$ and the total change of $\Delta E* = 11,64$. By these values, it can be seen that the colour difference of both treated wood samples is much lower compared to untreated samples.

Morphological appearance

The selected polymerised Merbau extractives (PME) that were used as the impregnating material can be absorbed, bonded in Jabon wood structure and not dissolved during a boiling test. As the result – from a colour point of view – the treatment caused the wood to change colour which looked like a 'new wood' (Figure 1). The PME can colour impregnate Jabon wood not only on the surface but also through the whole thickness of the wood due to the low density and high porosity of the wood. Dong *et al.* (2016) explained that with such wood properties, the impregnating material can be more easily penetrated into the cell walls. This could be due to looser structure and more open pits which contribute to the penetration to make even distribution of polymer within the wood.

The SEM results of untreated and treated Jabon wood are shown in Figure 4. Obviously, a certain amount of cured polymerised Merbau extractives (PME) precipitated on the surface of wood vessels and filled in the cell wall, as illustrated by the cross section of treated (Figure 4b and Figure 4c) wood marked with black arrows. In addition, the PME in the treated samples (T1 and T2) have not only penetrated into the cell wall, but also cured in the cell wall, and filled the pits on the vessel (Figure 4b and Figure 4c). The analysis of SEM images showed that the amount of deposited PME33 in T2 was higher than that of PME22 in the vessel. This could result in the darker colour of Jabon wood samples treated with PME33.
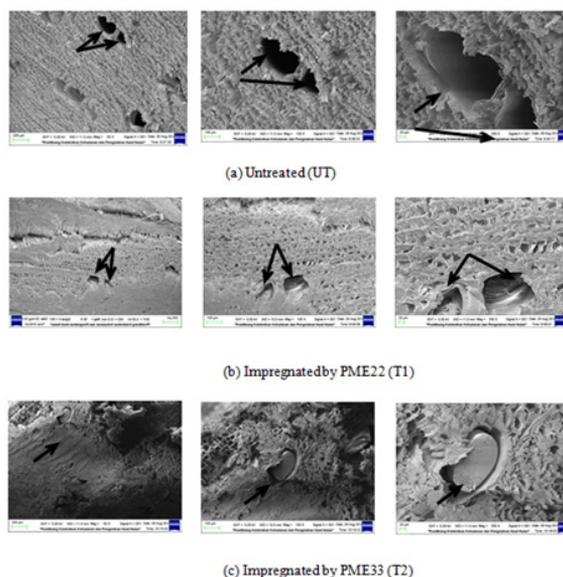
(a) Untreated (UT)

(b) Impregnated by PME22 (T1)

(c) Impregnated by PME33 (T2)

Figure 4. Morphology of the untreated and treated Jabon wood by impregnation using polymerised Merbau extractives.

Infrared spectroscopy

The reaction between wood and PME in T1 and T2 that resulted in colour changes were confirmed by FTIR spectrum analysis. Figure 5 and Table 3 present the FTIR spectra and band assignment of the peaks of UT, T1 and T2. From the FTIR spectra, it can be seen that impregnation treatment using the PME resulted in reaction between wood and the impregtnant by the presence of the peaks at 2922,16 (T1) and 2895,15 (T2); 2002,11 (T1) and 1928,82 (T2); 1327,03 (T1) and 1330,88 (T2); 1033,85 and 1041,56 for C-H and CH_3 stretching in polymerised Merbau extractives (PME), C=C asymmetric stretch, 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.
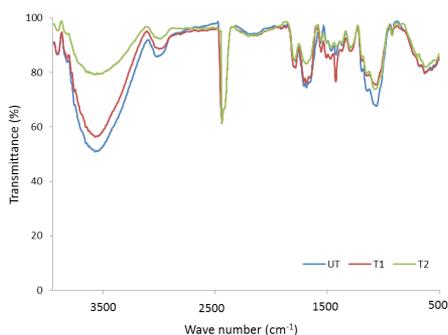

Figure 5. FTIR spectra of the untreated and treated Jabon wood by impregnation using polymerised Merbau extractives: UT = untreated; T1 = impregnated using PME22; and T2 = impregnated using PME33.

The reaction that resulted in permanent colour change can also be seen with the increase in 3448,72cm^{-1} peak intensity, which is ascribed to hydroxyl groups, significant carbonyl group (1726,29 cm^{-1}) band intensity increase as well as benzene ring (1631,78 cm^{-1}). There is no significant increment of the peak intensity in CH_2 bending in cellulose and hemicelluloses (1381,03 cm^{-1}), CH_2 wagging vibration in cellulose (1328,95 cm^{-1}), C–O stretching vibration in xylan 1253,73 cm^{-1}, C–O–C asymmetric band in cellulose and hemicelluloses (1157,29 cm^{-1}), and C_1 group frequency in cellulose

and hemicelluloses (894,97 cm^{-1}). These mean that there is no change in the wood component at all. The impregnating material – polymerised Merbau extractives – may be bonded in wood without changing the wood component. Expected crosslinking and coupling reactions between the copolymers formed from the insertion of PME22 and PME33 and the wood cell wall happened via aldehyde ring and -COOH with free OH groups, respectively. This similar mechanism occurred for epoxy in treated wood using MMA (methyl methacrylate) and GMA (glycidyl methacrylate) (Li *et al.* 2012, Zhang *et al.* 2013, Mattos *et al.* 2014, Mattos *et al.* 2015, Mattos *et al.* 2016).

Table 3. Assignments of the peaks of the FTIR spectra of the control (UT) and modified samples (T1 and T2) (Coates 2000, Silverstein *et al.* 2005, Islam *et al.* 2014, Mattos *et al.* 2015, Tuong and Li 2010).

No	Peaks			Assignments
	UT	T1	T2	
1	3448,72	3448,72	3444,87	Hydroxyl functional groups – OH stretching
2	-	2922,16	2895,15	C–H and CH3 stretching in polymerised Merbau extractives
3	-	2002,11	1928,82	C=C asymmetric stretch
4	1726,29	1726,29	1734,01	C = O stretching of carbonyl group from polymerised Merbau extractives
5	1631,78	1631,78	1633,71	Benzene ring stretching in lignin; C = C stretching of the aromatic ring in lignin
6	-	1327,03	1330,88	C–H deformation in polymers; Aromatic aldehyde
7	1381,03	1379,10	1375,25	CH$_2$ bending in cellulose and hemicellulose
8	1328,95	1327,03	1330,88	CH$_2$ wagging vibration in cellulose
9	1253,73	1157,29	1155,36	C–O stretching vibration in xylan
10	1157,29	1109,07	1114,86	C–O–C asymmetric band in cellulose and hemicellulose
11	-	1033,85	1041,56	C–O ether bond stretching vibrations in polymerised Merbau extractives reaction
12	894,97	850,61	896,90	C$_1$ group frequency in cellulose and hemicellulose

Remarks: UT, T1, T2. T3 and T4 refers to Table 1.

The peak at 1033,85 and 1041,56 cm^{-1} as the assignments of C–O ether bond stretching vibrations in polymerised Merbau extractives reaction do not exist in untreated wood samples. The peaks are related to the chemical structures of the polymers. This peak corresponds to C–H in plane deformation and symmetrical C–O stretching of cellulose – two very unreactive structures of wood in chemical or thermal treatments (Schwanninger *et al.* 2004, Islam *et al.* 2014, Mattos *et al.* 2016). It is very apparent that the impregnating treatment using polymerised Merbau extractives changed not only visually in colour but also chemically by new functional groups bonded to Jabon wood.

CONCLUSIONS

Selected polymerised Merbau extractives (PME) that were used as the impregnating material resulted in the colour of Jabon wood changed, which even looked like a 'new wood' since the liquid was absorbed and bonded in Jabon wood structure. It is apparent that the lightness (*L**) and colour coordinates (*a** and *b**) of treated Jabon wood by impregnation using both PME22 (T1) and PME33 (T2) presented a darkening colour in radial and tangential sections. The *L** values also depict that the tangential surfaces were slightly darker than those radial (*L** tangential < *L** radial). Treatment with PME33 presented the highest decrement of lightness. As a result, treated Jabon wood with PME22 and PME33 looked much darker than untreated samples. All of changes in colour were also statistically proven that the variations and differences were significantly different (F > 0,05; p = 0,000) for all

chromatocity parameters.

The SEM results of untreated and treated Jabon wood are showed apparent difference due to deposited cured polymerised Merbau extractives (PME) in wood vessels. Obviously, a certain amount of cured polymerised Merbau extractives (PME) precipitated on the surface of wood vessels and filled in the cell wall as shown on Figure 5. In addition, the PMEs not only penetrated into the cell wall, but also cured in the cell wall, and filled the pits on the vessel. The amount of deposited PME33 (T2) was be higher than that of PME22 in the vessel. As a result, in regards to the colour changes, PME33 caused Jabon wood samples to be darker. By FTIR analysis, it is apparent that the impregnating treatment using polymerised Merbau extractives changed not only visually to a new colour but also chemically by new functional groups bonded to Jabon wood.

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