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Effect of impregnation methods and bioresin concentration on physical and mechanical properties of soft-inner part of oil palm trunk

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Abstract. Bioresin from derived of pine (*Pinus merkusii*) was used to increase the strength of the soft-inner part of oil palm trunk (S-OPT). This purpose of this study was to evaluate the effect of impregnation methods (soaking 1 day, 3 days, and vacuum 600 mmHg for 1 hour) and bioresin concentration (0%, 5%, 10%, 15%, and 20%) on the physical and mechanical properties of S-OPT. Bioresin was dissolved with ethanol. The result showed that weight gain from bioresin into S-OPT was 0.85 % - 39.4%. The bioresin impregnation with several concentration significantly improved the physical and mechanical properties of S-OPT up to (1) 5.7-57.14% in density; (2) 29.94%-145.18% in compressive strength; (3) 114.78%-345.66% in modulus of elasticity (MOE); and (4) 43.01%-111.79% in the in modulus of rupture (MOR). The best performance of S-OPT when bioresin impregnated 20% bioresin using vacuum method as shown higher the physical and mechanical properties.

1. Introduction

The oil palm plantations are a promising company in Indonesia, as seen from the large area and production that increased sharply. The plantation area was originally 0.13 million ha in 1970 with production reached 0.22 million tons. Then the area of this plantation grew rapidly. In 2016 the area of oil palm plantations had reached more than 11.26 million ha, with production reached 31.07 million tons [1].

Oil palm plantations were a very large area, so when replanted will be produced a lot of waste, such as oil palm trunk (OPT). The morphology of trunk was a cylindrical shape and big trunk diameter, so it can be used as raw material for wood industry, and it was a very promising alternative. When replanted, the plantation can produce 50.1 m^3/ha sawn timber from the outer part of OPT [2]. While the inner part of OPT becomes waste owing to weaknesses of OPT, such as a variation of density, low durability, low mechanical properties, high moisture content, high shrinkage-swelling, and low machining Properties [3, 4]. Hartono et al. [5] reported that density variation was 0.23-0.74 g/cm^3 while the other research was 0.14-0.60 g/cm^3 [4]. The OPT had a high moisture content of 345%-500%, which causes shrinkage-swelling [3]. The mechanical properties of OPT were two times lower than teak and rubber wood which usually used as furniture [6]

The efforts to increase properties of OPT, such as increase durability had to be done by using the impregnation of 28% ammonia solution [7] or preservative material of Basilit-CFK and Impralit-BI [8]. While the effort to increase the physical and mechanical properties were done by using impregnation of phenol formaldehyde [9]. The impregnation of phenol formaldehyde (PF) resin into wood and wood has been reported to improve the dimensional stability of wood [10], physical and mechanical properties [9, 11] and increased the resistance against termites attack and fungal decay [12, 13].

Quality Improvement of OPT by using impregnation or impregnation with artificial chemicals and formaldehyde-based materials causes many problems. The problem was formaldehyde emissions and was not environmental friendly. Therefore, it is necessary to modify the wood without using formaldehyde-based resin or toxic chemicals. One of the efforts made to improve the physical and mechanical properties of OPT was by compression and using environmental friendly bioresins to improve dimensional stability and durability. Erwinsyah [4] reported that impregnation with bioresin from *Pinus merkusii* was able to increase the physical, mechanical and chemical properties of OPT. Based on the above, it is necessary to conduct densification research combined with the use of bioresin to produce good quality of OPT regarding of physical and mechanical properties.

2. Material and Methods

2.1. Materials

OPT approximately 23 years in age was collected from Bukit Sentang experimental area of Indonesian Oil Palm Research Institute at Langkat district, north sumatera province, Indonesia. Sample was preparing from the soft-inner part of OPT (S-OPT) with dimensions of 150 mm × 50 mm × 20 mm in length, width, and thickness, respectively. To get the initial density, samples were dried at 102±3 ^{0}C until reached a constant weight. The initial density of S-OPT was 0.23 g/cm^3.

Bioresin which is derived from pine *Pinus merkusii* was used to improve the quality of S-OPT. Bioresin was purchased from a wood material shop.

2.2. Methods

2.2.1. Bioresin impregnation and densification. Before Bioresin impregnation, a group of samples were soaked bioresin for one day, soaked for three days, and vacuum at 600 mmHg for 1 hour. Bioresin solution was prepared in various concentrations (0, 5, 10, 15 and 20%) which has been dissolved in ethanol. The sample was put in a box and soaked in bioresin with a variable impregnation. Then it was dried at 60 ^{0}C for 3 days to get the dry condition, so that weight gain can be calculated in the S-OPT. Then, samples was hot-pressed to a compression ratio of 50% for 15 minutes. After compression in a hot press, sample was conditioning for 2 weeks. The final size of sample was 150 mm (length) × 50 mm (width) × 10 mm (thickness).

2.2.2. Physical properties evaluation. The samples after bioresin impregnation and compressed with dimensions of 20 mm × 20 mm × 10 mm was determined by measuring their air-dry weight and volume. Weight gain percentage (WG%) was determined by measuring samples weight before impregnationo (Wo) and weight after PF resin impregnation (Wi), and then calculated using the equation:

$$\text{WG (\%)} = \frac{\text{Wi}-\text{Wo}}{\text{Wo}} \text{ x } 100\% \tag{1}$$

The air-dry density of samples with dimensions of 20 mm × 20 mm × 10 mm was determined in by measuring their air-dry weight (M) and volume (V). The air-dry density was calculated using the equation:

$$\text{D (g/cm}^3) = \frac{\text{M}}{\text{V}} \tag{2}$$

Moisture content (MC) was calculated by measuring air-dry weight (W0) and oven-dry weight (W1). The sample for MC was 2 cm x 2 cm x 1 cm. Moisture meter was calculated using the equation:

$$\text{MC (\%)} = \frac{\text{W0} - \text{W1}}{\text{W1}} \text{ x } 100\% \qquad (3)$$

Thickness swelling (TS) was a sample with dimensions of 20 mm × 20 mm × 10 mm was determined in by measuring their initial thick (T0) and thick after soaking in water (T1). The sample soaked for 1 hour and 24 hours. Thickness swelling was calculated using the equation:

$$\text{TS (\%)} = \frac{\text{T1} - \text{T0}}{\text{T1}} \text{ x } 100\% \qquad (4)$$

2.2.3. Mechanical properties evaluation. The mechanical properties in this research were the modulus of elasticity (MOE), Modulus of rupture (MOR), and compressive strength tests. The mechanical properties were conducted using Universal Testing Machine. Size sample for MOE and MOR test were 150 mm (length) × 10 mm (width) × 10 mm (thickness), while the size dimensions for compressive strength (CS) test were 40 mm × 10 mm × 10 mm. The MOR, MOE, and compressive strength (R) were calculated using the equation:

$$\text{MOR (kg/cm}^2\text{)} = \frac{3\text{PL}}{2\text{bh}^2} \qquad (5)$$

$$\text{MOE (kg/cm}^2\text{)} = \frac{\text{P}_\text{p}\text{L}^3}{4\text{Y}_\text{p}bh^3} \qquad (6)$$

$$\text{CS (kg/cm}^2\text{)} = \frac{\text{P}}{\text{bh}} \qquad (7)$$

where P is the maximum load (kg), P_p is the load at the proportional limit (kg), h is the hight sample, b is the width sample (cm), L is the length span (cm), and Y_p is the deflection (mm).

3. Results and Discussion

3.1. Physical properties

The physical properties in this research were weight gain (WG), density, moisture content (MC) and thickness swelling (TS). The physical properties was shown in Table 1. The results showed that the WG value and density increased with the concentration used. The other hand, the higher concentrations will result in lower MC and TS, both with 1-hour immersion and 24-hour immersion. While the best method for the physical properties of wood is the 1-hour vacuum method, followed by soaking for 3 hours, and the lowest is soaking for 1 hour.

Table 1. Relationship between bioresin concentration and impregnation methods on physical properties

Methods	Concentration (%)	WG (%)	Density (g/cm^3)	MC (%)	TS (%) 1 hour	TS (%) 24 hours
Soaking 1 hour	0	0.00	0.35	10.29	35.80	58.39
	5	0.88	0.36	8.30	31.79	50.48
	10	9.01	0.45	7.76	25.90	41.84
	15	16,6	0,48	6.08	19.64	37.41
	20	23.55	0.49	6.52	17.93	32.69
Soaking 3 hour	0	0.00	0.35	10.37	36.45	55.44
	5	0.86	0.37	7.58	37.17	51.03
	10	11.8	0.44	6.84	25.14	43.66
	15	20.61	0.49	6.64	21.53	36.89
	20	25.79	0.51	6.11	14.57	32.53

Vacuum for	0	0.00	0.35	9.88	36.45	56.43
1 hour	5	7.40	0.41	9.14	41.17	50.29
	10	20.18	0.49	7.52	25.14	34.19
	15	33.1	0.52	7.83	21.53	33.97
	20	39.4	0.55	6.74	14.57	29.41

Notes: MC = moisture content, WG= weight gain, TS = thickness swelling

In general, the anatomical structure of oil palm trunk (OPT) is composed of vascular bundles and parenchyma. The outer part of OPT is dominated by vascular bundles, while the soft-inner part of oil palm trunk (S-OPT) is dominated by parenchyma cell. The S-OPT has a very low density. The S-OPT is dominated by parenchyma cell and a little of the vascular bundle density [4, 14].

Based on the function, vascular bundles serve as the supporting structure and the transport system, while the parenchyma is the food storage elements so that it has poor characteristics for the use of S-OPT as an industrial raw material. Efforts to improve the characteristics of S-OPT are carried out by combining bioresin into S-OPT by several methods and compressing. In this study, the initial density of oil palm stem was 0.23 g/cm^3. The combination of bioresin with various concentrations and compression further increases the value of physical properties of wood.

Based on Table 1 show that increasing bioresing enter to S-OPT, the bioresin will fill the cavities in the structure of S-OPT, so the density of the S-OPT will be higher. This can be seen from the increasing WG value (Figure 1).

Figure 1 shows that Bioresin impregnation methods of S-OPT with several concentration resulted in the highest WG and density. The increasing the WG value, will make higher the density. In this study, increasing density with 1-hour immersion, 3-hours immersion and 1-hour vacuum was 56-113%, 61-122%, and 78-139%, respectively. When compared with the PF impregnation into S-OPT, the increase in the S-OPT value is 94-176% [15].

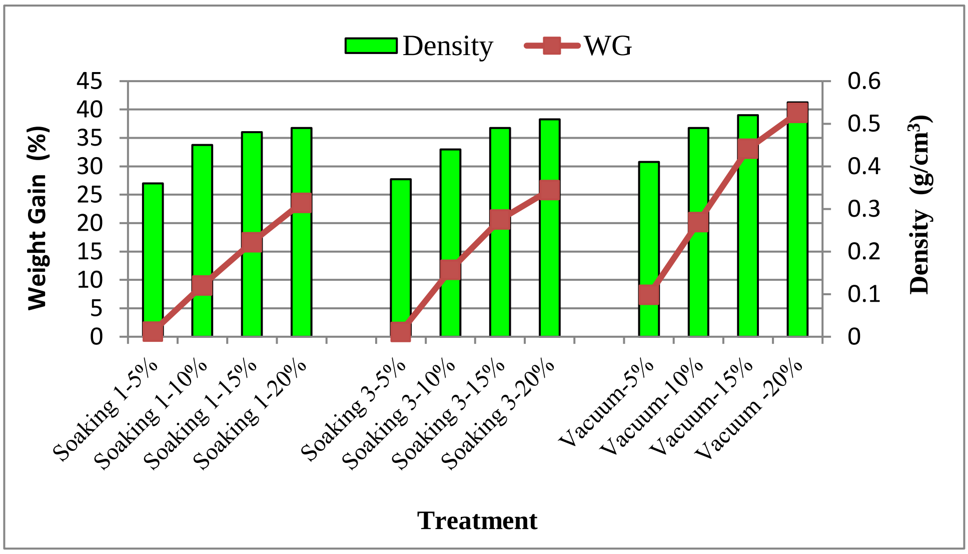

Figure 1. The relationship between WG value and Density

Based on Table 1 show that bioresin impregnation methods of S-OPT with several concentration resulted the lowest TS and MC. The TS values indicated that the treatment resulted better dimensional stability. The relationship between bioresin impregnation as indicated by WG value with thickness swelling value was shown in Figure 2.

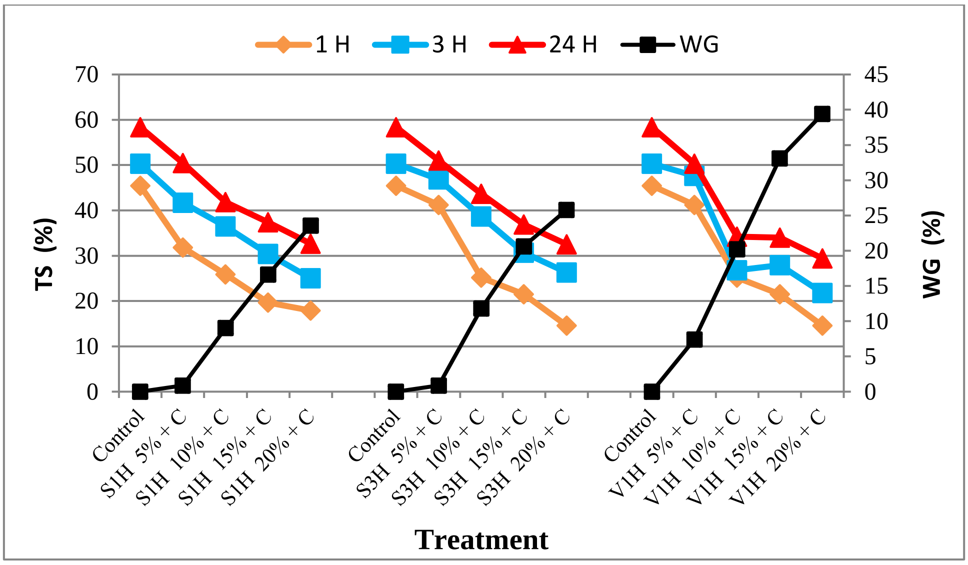

Figure 2. The relationship between WG value and Thickness swelling

Figure 2 shows TS value increased with increasing soaking time of the sample in water. Soaking for 24 hours was the highest of TS value, followed with soaking time for 3 hours dan the lowest was soaking time for 1 hour. In additional, the WG value increased with the higher concentration, while TS value decreased with the higher concentration. The higher WG value caused lower TS value.

The TS values that occur, especially after soaking for 24 hours was very high. Bioresin that enters to S-OPT only fills in cavities or binds physically. The bioresin has not entered the wood cell wall and chemically bound. So, if sample soaking in water, bioresin will be released.

Some study of resin impregnation, such as phenol formaldehyde resin was reported that impregnation resin to wood structure achieves dimensional stability into bamboo strips [16], beech wood [17], oil palm trunk [15]. Also resin impregnation can decreased hygroscopic properties of wood [18].

3.2. Mechanical properties

The mechanical properties in this study were the modulus of elasticity (MOE), modulus of rupture (MOR) and compression strength (CS). The mechanical properties, such as MOE, MOR and CS values were 7296 kg/cm^2 - 15139 kg/cm^2; 86.98 kg/cm^2 - 128.81 kg/cm^2 and 44.87 kg/cm^2 - 84.66 kg/cm^2, respectively. The mechanical properties shown are shown in Table 2.

Table 2. The effect of bioresin concentration and impregnation methods on mechanical properties of S-OPT

Methods	Concentration (%)	MOE (kg/cm^2)	MOR (kg/cm^2)	CS (kg/cm^2)
Control		3397	60,82	34,53
Soaking 1 hour	5	7573	86,98	44,87
	10	10021	106,61	62,04
	15	11970	106,77	64,99
	20	12094	119,91	66,49
Soaking for 3 hour	5	7296	88,83	48
	10	11846	120,47	69,42
	15	12028	119,61	70,55
	20	13985	127,71	66,71

Vacuum for 1 hour	5	7508	91,3	50,07
	10	11896	118,89	66,01
	15	12289	123,87	65,51
	20	15139	128,81	84,66

Notes: MOE= Modulus of Elasticity, MOR = Modulus of Rupture, CS= Compression Strenght.

The mechanical properties of the untreated wood (control) from showed significantly different values. The increasing of MOE, MOR and CS value were 29.94% -145.18%; 114.78%-345.66%; and 43.01%-111.79%, respectively.

Based on Table 2 it can be seen that the mechanical properties increased with the bioresin concentration used. From the method used, the highest mechanical properties are the 1-hour vacuum method, followed by soaking 3-hours and soaking 1-hour. It is attributed that the applied technique has a positive influence to improve the mechanical properties of the palm oil trunk

Increased value of mechanical properties related to WG of S.OPT. This indicates that bioresin which enters to structure wood will be increased the MOE, MOR and CS properties. Bioresin enters the vessel and ground parenchyma of oil palm trunk. The relationship between MOE and WG is presented in Figure 2 and the relationship between MOR, CS, and WG is presented in Figure 3 and Figure 4.

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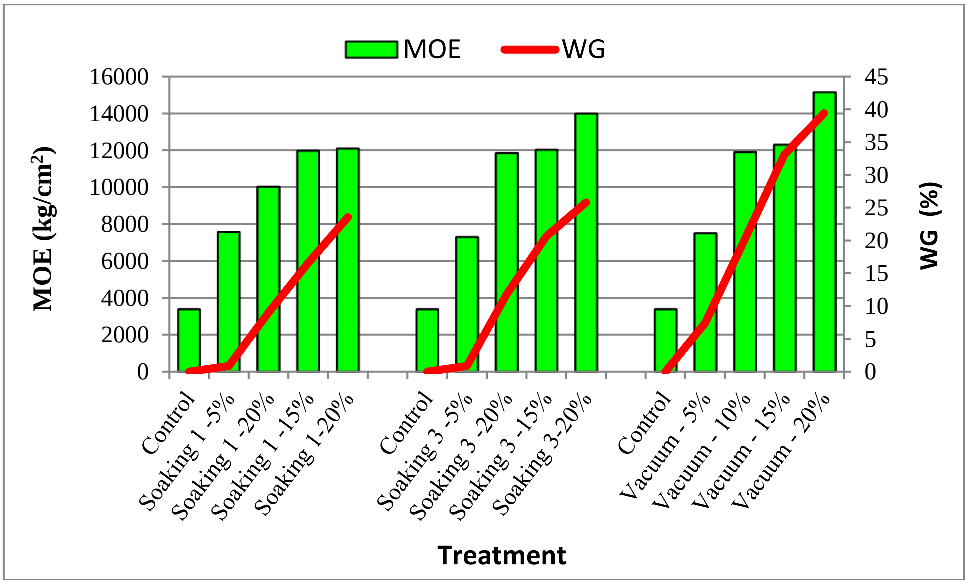

Figure 3. The relationship between MOE value and WG

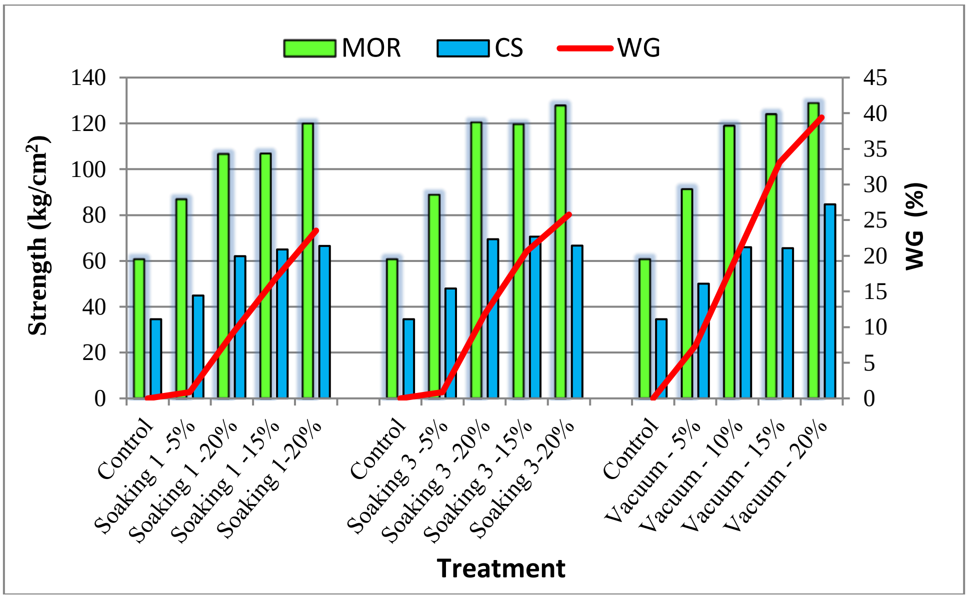

Figure 4. The relationship between MOR, CS value and WG

Based on Fig 3 and 4, it can be seen that mechanical properties, such as MOR, MOE, Compression strength increased with increasing of bioresin concentration, with several methods for bioresin impregnation. This is because the amount of bioresin that enters the wood and it is marked by the increasing weight gain of a sample of oil palm trunk.

Erwinsyah [4] reported that bioresin from pine was applied to improve the physical and mechanical of oil palm trunk. Bioresin which was derived from pine resin was used as filler and binding agent. Also, the bioresin impregnated results from the machinery properties tests including cross-cutting, planning, shaving and moulding and boring result in a higher performances in comparison to the untreated wood of oil palm trunk.

The other research using bioresin from Acetic Anhydride to increase composite fibers [19] and bioresin from cashew nut shell liquid by ozonolysis process [20]. The results showed that the treatment increased the mechanical properties, such as stiffness and shear strength of the bond. The decay resistance was successfully increased by impregnation bioresin.

4. Conclusion

The bioresin impregnation derived from pine *Pinus* merkusii with several concentration significantly improved the physical and mechanical properties of S-OPT. The physical and mechanical properties increased with the bioresin concentration used. From the method used, the highest mechanical properties are the 1-hour vacuum method, followed by soaking-3 hours and soaking-1 hour. The best treatment was bioresin of 20% using vaccum methods.

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Reference

[1] Ministry of Agriculture 2017 Center of Agricultural Data and Information, Republic of Indonesian Ministry of Agriculture (Indonesia, Jakarta).

[2] Febrianto F and Bakar E S 2004 *Kajian Potensi, Sifat-sifat Dasar dan Kemungkinan Pemanfaatan Kayu Karet dan Biomassa Sawit di Kabupaten Banyuasin* (Indonesia: Lembaga Manajemen Agribisnis dan Agroindustri. Institut Pertanian Bogor. Bogor).

[3] Bakar E S 2003 *Forum Komunikasi Teknologi dan Industri Kayu* **2** 1-8.
[4] Erwinsyah 2008 Improvment of Oil Palm Wood Properties Using Bioresin, Dissertation of graduated school of Universität Dresden.
[5] Hartono R, Wahyudi I, Febrianto F dan Dwianto W 2011 *J. Ilmu dan Teknologi Kayu Tropis* **9**(1) 73-83.
[6] Ratanawilai T, Chumthong T dan Kirdkong S 2006 *J. Oil Palm Research (Special Issue-April 2006)* 114-121
[7] Wong A H H, Koh M P and Shapiei M J 1990 *Holz als Rob-und Werkstoff Springer-Verlag.* **48**
[8] Bakar ES, Massijaya Y, Tobing TL and Ma'mur A 1999 *J. Forest Prod. Technol* **XII**(2): 13–20.
[9] Hartono R, Wahyudi I, Febrianto F, Dwianto W, Hidayat W, Jang J H, Lee S H, Park S H and Kim N H 2016 *J. Korean Wood Sci. Technol.* **44**(2) 172-183.
[10] Furuno T, Imamura Y and Kajita H 2004 *Wood Science and Technology* **37**(5) 349-361.
[11] Shams M I and Yano H 2009 *J. Tropical Forest Science* **21**(2) 175-180.
[12] Nabil F L, Zaidon A, Anwar U K M, Bakar E S, Lee S H and Paridah M T 2016 *Sains Malaysiana* **45**(2) 255-262.
[13] Bakar E S, Tahir P M, Sahri M H, Mohd Noor M S dan Zulkifli F F 2013 *Pertanika J. Trop. Agric. Sci.* **36**(S) 93-100.
[14] Rahayu I S 2001 *Sifat Dasar Vascular Bundle dan Parenchyma Batang Kelapa sawit (Elaeis guineensis Jacq.) Dalam Kaitannya dengan Sifat Fisis, Mekanis serta Keawetan* Thesis Program Pascasarjana, Institut Pertanian Bogor
[15] Hartono R, Hidayat W, Wahyudi I, Febrianto F, Dwianto W, Jang JbH dan Kim NbH 2016 *J. Korean Wood Sci. Technol* **44**(6) 842-851.
[16] Anwar U M K, Paridah M T, Hamdan H, Sapuan S M and Bakar E S 2009 *Industrial Crops and Products* **29**(1) 214–219.
[17] Franke T, Mund A, Lenz C, Herold N and Pfriem A 2018 *Pro Ligno* **13** 373-378.
[18] Hill C 2006 *Wood Modification: Chemical, Thermal and Other Processes* (England: John Wiley and Sons)
[19] Loong M L and Cree D 2018 *J.of Polymers and the Environment* **26**(1) 224–234.
[20] Ashaduzzaman M 2014 Physico-Mechanical And Decay Resistance Properties Of Bio-Resin Modified Wood, Dissertation of graduated school of Bangor University, Gwynedd, United Kingdom.