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IMPROVEMENT ON SEVERAL PHYSICAL AND MECHANICAL PROPERTIES OF JATI UTAMA NUSANTARA WOOD BY THERMAL COMPRESSION TREATMENT

(*Penyempurnaan Beberapa Sifat Fisis dan Mekanis Kayu Jati Utama Nusantara Melalui Perlakuan dengan Tekanan Panas*)

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ABSTRACT

Jati Utama Nusantara (JUN) is one type of growing regime of fast grown teak (*Tectona grandis* Linn. F) derived from *Jati Plus Perhutani* (JPP). JUN trees have fewer branches and a more cylindrical-shaped trunk, as well as exhibit rapid growth compared to the teak cultivated from seed (conventional); accordingly, they can be harvested in a shorter time. Despite its fast growth, some studies showed that the wood had not met the SNI 01-0608 standard as raw material for furniture. The research aimed to improve several physical and mechanical properties of young JUN wood through thermal compression treatment. The test sample for 5-year-old JUN wood was prepared with a size of 2.5 cm (thickness/radial) by 10 cm (width/tangential) by 30 cm (length/longitudinal), then compressed using a 25 kg/cm^2-pressure for 40 minutes in three temperature treatments of 170℃, 180℃, and 190℃. Testing of wood mechanical and physical properties referred to ASTM D143. The wood crystallinity was observed using an X-Ray Diffractometer (XRD), and the wood surface was observed visually. Wood cell structure as supporting data was observed using a stereo-capable microscope (Zeiss). The results revealed that the thermal compression could improve the physical and mechanical properties of the densified JUN samples compared to the nonthermally compressed samples. Based on data simulation, the wood samples' best physical and mechanical properties occurred at approximately 185℃'s heat-press.

Keywords: Rapid growth teak, thermal compression, physical and mechanical properties, 185°C

ABSTRAK

*Jati Utama Nusantara (JUN) adalah salah satu tipe jati (*Tectona grandis* Linn. F) cepat tumbuh yang berasal dari Jati Plus Perhutani (JPP). Pohon JUN memiliki sedikit percabangan dan batang yang lebih berbentuk silinder serta menunjukkan pertumbuhan yang lebih cepat dibandingkan jati budidaya dari biji (konvensional), sehingga dapat dipanen dalam waktu singkat. Meskipun cepat tumbuh, berbagai penelitian menunjukkan kayu JUN belum memenuhi standar SNI 01-0608 sebagai bahan baku furnitur. Penelitian ini bertujuan untuk meningkatkan beberapa sifat fisis dan mekanis kayu JUN umur muda melalui perlakuan pemadatan menggunakan kempa panas. Contoh uji kayu JUN umur 5 tahun berukuran 2,5 cm (tebal/radial), 10 cm (lebar/tangensial), dan 30 cm (panjang/longitudinal) diberi tekanan sebesar 25 kg/cm^2 selama 40 menit dengan 3 perlakuan suhu, yaitu 170°C, 180°C, dan 190°C. Pengujian sifat fisis dan mekanis kayu mengacu pada standar ASTM D143. Perubahan kristalinitas kayu diamati menggunakan X-ray Diffractometer (XRD), dan permukaan kayu diamati secara visual. Sebagai penunjang, pengamatan struktur sel kayu dilakukan menggunakan mikroskop stereo (Zeiss). Hasil penelitian menunjukkan bahwa contoh uji kayu JUN yang diberi perlakuan tekan-panas dapat memperbaiki sifat fisis dan mekanisnya dibandingkan contoh uji kayu JUN tanpa perlakuan (kontrol). Berdasarkan hasil simulasi data, sifat fisis dan mekanis contoh uji terbaik diperoleh pada suhu kempa sekitar 185°C.*

Kata kunci: Jati cepat tumbuh, kempa panas, sifat fisis dan mekanis, 185°C

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I. INTRODUCTION

Teak (*Tectona grandis* Linn. F) wood from slow-grown trees is appropriate for luxury furniture, construction, decoration and veneer items. In Indonesia, the teak plantations are situated on the Java island, with a harvesting cycle of 50–80 years (Soerianegara & Lemmens, 1995). Generally, the older the tree ages, the better would be the wood properties. However, it is not desirable to wait for harvesting the wood at age 50−80 years, because of the very high demand currently. Demand for the teak wood is increasing every year, but the supply is decreasing. In 2018, the amount of teak wood production in Indonesia reached 1,304,909 m³ (BPS, 2018) but it decreased to 953,372 m³ in 2019 (BPS, 2019). There are many varieties of fast grown teak trees that have been widely cultivated for timber production. One of them is designated as Jati Unggul Nusantara, or abbreviated as JUN wood.

Jati Utama Nusantara (JUN) is a growing regime of fast grown teak derived from *Jati Plus Perhutani* (JPP). JUN trees have fewer branches and a more cylindrical-shaped trunk, as well as exhibit rapid growth compared to the teak cultivated from seed (conventional plantation teak); accordingly, they can be harvested in a shorter time (Damayanti, Ozarska, Pandit, Febrianto, & Pari, 2018). The JUN wood is intensively well-cared during its growth by adding fertilizers, which enables its trunks to grow bigger but not easily fall or collapse (Soeroso & Poedjowadi, 2008). At 5-year age, the JUN's tree can grow to 17.5 m in height, and the stem diameter reaches 20-30 cm, which is comparatively equivalent to the diameter of 30−40-year-old conventional slow-grown teak trees (Kemenhut, 2012). However, like another fast grown teak, the JUN wood also exhibits weaknesses such as dull color, rough surface, and dimensionally unstable (Basri & Wahyudi, 2013; Darmawan, Nandika, Kartikasari, Sitompul & Gardner, 2015).

Woods as raw material for furniture should meet the SNI-01-0608 standard (SNI, 1989), such as stable dimension, minimum specific gravity (0.40), and minimum strength class III to withstand heavy load and exhibits attractive appearance. A stable dimension during the wood use is needed to reduce inter-joints at the product components, which otherwise can cause loose or untied joints, cracks, or delamination in glued wood products. The fundamentals in determining wood attractiveness are wood patterns, colors and glossy surface, and smooth texture (Wiemann, 2010; Djarwanto et al., 2017).

One method to improve the inferiority of young-aged woods after harvesting is through modification technology (Rowell, 2012), among which is performed physically by heat treatment or high-temperature compression on the wood surface. Heat treatment is one of the wood modification methods for improving wood properties such as dimensional stability, water resistance, and biological durability without using harmful chemicals (Rajković & Miklečić, 2019).

The use of high temperatures to improve the quality of young teak wood has been carried out by several researchers (Garcia, Lopes, Nascimento, & Latorraca, 2014; Lopes, Garcia, & Nascimento, 2018; Adzkia, Priadi, & Karlinasari, 2019; Pasaribu & Sisilia, 2021; Martha et al., 2021). According to the research results of Adzkia et al. (2019), the best machining quality can be obtained by using a temperature of 165°C for 2 hours. However, Pasaribu and Sisilia (2021) reported that temperatures up to 170°C for 2 hours and compacted by 25% will still experience a dimension change at room temperature. Garcia et al. (2014) found that a temperature of 180°C for 7 days resulted in the best stability and the same color between the sapwood and heartwood of juvenile teak wood. Still, the wettability on both the heartwood and sapwood surfaces can only be achieved at a temperature of 200°C (Lopes et al., 2018). However, at that temperature, according to Martha et al. (2021), the impact on the mechanical properties of wood is quite severe, especially the decrease in MOR value due to the hemicellulose degradation. Relevantly, this research aimed to examine the physical and mechanical properties of 5-year-old JUN wood after being densified through the heat press (at 25 kg/cm^2-pressure for 40 minutes), combined with three levels of temperatures (170, 180, and 190 °C) to obtain the JUN wood that meets the requirements of SNI-01-0608 as furniture wood raw materials.

II. MATERIAL AND METHOD

A. Materials and Equipment

The research was conducted on the wood samples taken from 5-year-old JUN trees (at breast height), which grew at Bogor Regency, West Java Province. Both the heartwood and sapwood portions were used for the samples because the heartwood was not yet developed. The equipment used consisted of a hot-press device, dial calliper, moisture meter, digital scale, Memmert oven, solar-drying kiln, Universal Testing Machine type UH-100A (Shimadzu), X-ray diffraction (XRD-7000, Shimadzu), and stereo-capable microscope (Zeiss).

B. Research Procedures

Several JUN's wood boards which measured 100 cm (length/longitudinal/L) by 10 cm (width/tangential/T) by 2.5 cm (thickness/radial/R), were dried in the solar drying room device at 55°C maximum temperature until the moisture content reached 12%. After that, each board was further sawn into samples with a dimension of 2.5 cm (R) by 10 cm (T) by 30 cm (L) with 3 replications for each treatment and control. Before being compressed, the wood samples were preheated in the oven for 3 hours using a temperature of 180°C. Afterwards, samples were densified by heat-pressed in 25 kg/cm^2-pressure with 3 temperature treatments, i.e., 170, 180, and 190°C for 40 minutes. Furthermore, the densified and control (un-densified) samples were weighed again; their dimensions (T and R) were measured and then put in the air-temperature room (temperature about 22–30°C and humidity 76-88%) for one month. The physical (density, specific gravity (SG), thickness swelling, equilibrium moisture content (EMC), and crystallinity degree) and the mechanical properties (modulus of elasticity (MOE), modulus of rupture (MOR), compression strength parallel to fibers (C//), and hardness) of all wood samples were examined.

C. Testing

The differences in wood anatomy features were observed using a stereomicroscope, and its crystallinity was observed using the XRD. Wood physical and mechanical properties of the densified and control samples were tested referring to ASTM D143 (ASTM, 2014). From the mechanical (SG, MOR, and C//) testing results of all samples, the wood strength class could accordingly be predicted (Oey, 1990). Wood-hardness test was conducted using the Amsler machine by embedding a steel ball (11.25 mm diameter) to one-half its diameter into the specimen surface, while the qualities of the wood surface (gloss, smoothness, and color) of all samples were observed visually. After being tested, the wood samples were stored for one month under a humid condition. The number of the samples for each treatment and control were three; all were regarded as replicates.

D. Data Analysis

The data on physical and mechanical properties of the JUN samples are those which were preheated and then densified. The heat-press temperatures for densifying wood samples were 170, 180, and 190°C, as well as the control (un-densified) samples, were assessed using the analysis of variances (ANOVA), followed with the Tukey's significant difference tests. The relations between compression temperatures (T) and wood physical/mechanical strengths (Yi) were examined using regression-equation analysis in quadratic trends ($Yi = a + b\,T + c\,T^2$) and correlation coefficients (R). The estimation of such optimum temperatures was performed through the algebraic derivation technique (dY/dT) on the regression equations and the second-order derivation (dY^2/dT^2) (Steel & Torrie, 1992).

III. RESULT AND DISCUSSION

Table 1 reveals that the physical properties of the un-densified JUN samples (control) were lower than those of the densified samples. Judging from its specific gravity and strengths, then the wood sample without densification is already adequate to meet the requirements as furniture's raw material, which exhibits minimum SG (≥ 0.40) and affords strength class III. Unfortunately, its dimension is not yet stable. Yuniarti, Basri, and Abdurachman (2017) reported that the ratio of shrinkage in the tangential direction against radial direction (T/R ratio) of the 5-year-aged un-densified JUN wood was very high (about 3). Dimensional stability, presented by the T/R ratio, presents one of the wood properties that should be considered in determining the wood uses. This statement relates to the temperature and humidity fluctuation of the environment where the wood products are installed (Schönfelder, Zeidler, Borůvka, Bílek, & Lexa, 2018). The ideal T/R value of wood, according to Anish, Anoop, Vishnu, Sreejith, and Jijeesh (2015) should be a unity (one), which implies that the tangential shrinkage is equal to radial shrinkage. However, there are very few woods that could afford such equal T and R shrinkages. Research results on 87 of Indonesia's wood species reveal that only ares (*Gmelina moluccana*) wood exhibits the T/R ratio equal to one (Basri, Yuniarti, Wahyudi, & Pari, 2020). However, the wood dimension is stable if the T/R ratio is about 2 (Panshin & de Zeuw, 1980; Basri, Yuniarti, Wahyudi, Saefudin, & Damayanti, 2015).

In this research, the densified JUN samples with heat compression at 170, 180, and 190°C exhibited wood properties better than the control samples, e.g. increasing density or specific gravity, and decreasing thickness swelling (less tendency of spring back), and decreasing equilibrium moisture content in Table 1. The higher the compression temperature, the better would be the wood physical properties. This allegation was confirmed by the ANOVA and Tukey's difference test. It appears that the densified JUN samples at compression temperature approximately 185°C (Table 1) afforded the best physical properties (hence regarded as the optimum temperature). This indicates that increasing the compression temperature from 180°C to 190°C caused decreased or worsened physical properties.

This indication was supported by Tukey's test result and R-values (Table 1). The estimation of optimum compression temperatures (mostly somewhat above 180°C) for each of the wood physical properties, consecutively 185.63°C (density), 185.39°C (SG), 184.58°C (thickness swelling), and 184.88°C (EMC), or in practice roughly at 185°C. Estimating such optimum temperatures was performed using the regression equations' algebraic derivation technique (Table 1).

The heat compression caused the evaporation of free water and later bound water molecules as well as possibly low-boiling extractives. It causes an attraction between wood fibrils and microfibrils to get closer together. Then, the compressed crystallinity increased significantly (Table 1). The increase in crystallinity of the densified JUN wood until 180°C (<190°C) temperature consequently rendered wood SG and density to increase, while concurrently, wood EMC and thickness swelling decreased (Table 1). The decrease in thickness swelling and EMC of the densified wood indicates that wood capacity to attract water from the environment decreased. Such conditions indicate that the dimensions of the wood become more stable.

The use of heat-compression at 180°C on the wood surface renders the cell walls (fibers and vessels) to be flattened and become buckled, while the rays look rather crushed (Figure 1). The flattening, buckling, and crushing inside the wood structure tended to be more severe, as the temperature increased from 180 to 190°C. The flattening of the cell/fiber lumen, which starts from the surface of the wood (Darwis, Wahyudi, Dwianto, & Dwi Cahyono, 2017), could reduce the number of accessible free OH groups at the wood carbohydrate chains and prompt the wood fibers to become closer to each other even partly to intimate contact. This had a positive impact on the increase in wood density as well as SG; and adversely the decrease in EMC of the densified JUN wood (Table 1). The reduction in EMC brought about a positive impact on the dimensional stability of the densified JUN samples, which is indicated by the decrease in the wood's decreasing swelling characteristics (Table 1). In addition, the wood samples heated to high temperatures will become elastic because the lignin that melted due to heat action would further fill up the matrix space in the wood (Basri, 2011) and then harden in the cooling process. This also causes the wood hardness to increase (Table 2).

The wood fibers which become closer to each other in the densified JUN sample causes the surface of the JUN's densified wood to appear smoother. The cross-sectional anatomy structure of the 170°C's heat press densified JUN sample is not disclosed in the figure because visually no apparent distinct changes on the structure at the 170°C's densified JUN sample with the structure of the control. The densified wood at chiefly 190°C's compression temperature looks darker than the undensified wood (Figure 2). This is because the use of high compression temperatures (especially above 170°C) causes the wood lignin to melt and then migrates out to the wood surface (Shmulsky & Jones, 2019), also the hemicellulose undergoes degradation (Gasparik, Gaff, Kacik, & Sikora, 2019). Accordingly, they cause the wood color to become darker, but the wood surface looks dense and glossy (Figure 2). The glossy appearance of 180-190°C's densified JUN wood is also common in the conventional much older aged, slow-growing teak wood. Further, based on the regression equations, the optimum temperatures could be estimated 185°C (Table 1). It is presumed that increasing the temperature above 185°C induced more severe degradation to the wood holocellulose, thereby weakening the physical structures of the individual fiber.

The mechanical properties of the densified JUN samples also mostly improved at three compression temperatures (Table 2). The MOE indicates the wood stiffness or rigidity, while the MOR relates to the strength of wood in resisting the bending load. The more MOE and MOR of a wood species, the more rigid and stronger the wood would withstand the load (Oey, 1990). Mechanical properties (MOE, MOR, C//, hardness) of the densified JUN wood were aptly greater than the properties of the control wood. The higher the compression temperatures, the higher would be the wood mechanical properties. However, at the use of 190°C temperature, the values of MOE, MOR, C// and hardness have a little effect. Supported by the ANOVA and Tukey tests (Table 2), the compression temperature is considered adequate to obtain the best mechanical properties of the densified JUN wood are above 180°C (at approximately 185°C temperature). Regression equations strengthened this allegation with significant R values (Table 2), which also assisted the estimation of optimum compression temperatures as follows: 184.96°C (MOE), 184.59°C (MOR), 184.27°C (C//), and 184.25°C (hardness); or in practice roughly at 185°C. The estimation of such optimum temperatures was also performed through the algebraic derivation technique on the regression equations.

Judging from MOR and compression strength values parallel to fibers, the strength class of densified

JUN woods increased from class III to class II. However, from the SG indicator, the strength class of the 5-year-old densified JUN woods corresponded to class III. Therefore, the strength class of densified JUN woods was categorized as strength class III-II (Tables 2). Based on the value of SG, strength class, dimensional stability and wood-surface performance or wood decorative value (Figure 2), then the 5-year-old densified JUN wood at approximately 185°C temperature could meet the SNI-01-0608 (SNI, 1989) as furniture's raw material, which stipulates minimum SG at 0.40; strength class III; dimensional stability, which was indicated by maximum thickness swelling of 2%; maximum EMC of 14%; and affording decorative values.

Table 1. Average values of physical properties of densified JUN wood
Tabel 1. Nilai rata-rata sifat fisis kayu JUN yang dipadatkan

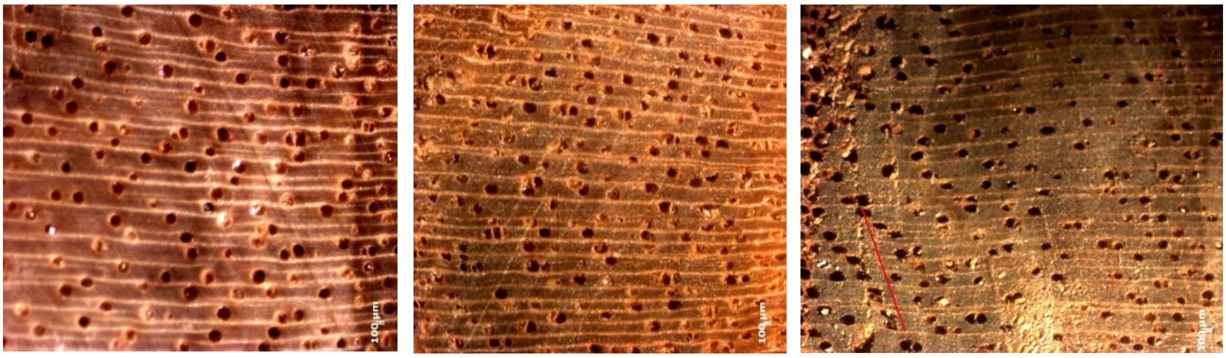
Compression temperatures (*Suhu kempa,* °C) T	Density (*Kerapatan,* g/cm^3) Y1	Specific gravity (*Berat jenis*) Y2	Thickness swelling (*Pengembangan tebal*, %) Y3	EMC (*Kadar air setimbang,* %)	Crystallinity degree (*Derajat kristalinitas,* %) Y4
170	0.59 b	0.52 b	2.10 b	12.51 b	47.41
180	0.63 a	0.56 a	2.02 b	11.54 c	60.08
190	0.63 a	0.56 a	2.00 b	11,48 c	59.02
Control	0.53 c	0.45 c	2.65 a	15.38 a	47.05
Regression equations: $Y_i = a + b\,T + c\,T^2$ (i = 1, 2, 3, and 4)					
a (intercept)	-5.1333	-5.7733	+60.172	+411.97	-
b (for T)	+0.0062	+ .6817	-0.6276	-4.3261	-
c (for T^2)	-0.000167	-0.00018	+0.0017	+0.0117	-
R	0.9293**	0.9637**	0.7092*	0.7669*	-
T-optimum, °C [1]	185.63	185,39	184.58	184.88	

Remarks (*Keterangan*): Values followed vertically with the same letters are not significantly different (*Nilai-nilai yang diikuti dengan huruf yang sama pada arah vertikal tidak berbeda nyata*); EMC=equilibrium moisture content (*Kadar air keseimbangan*); R=correlation coefficient (Koefisien *korelasi*); *=significant at 95% level (*Signifikan pada tingkat kepercayaan 95%*); **=significant at 1% level (*Signifikan pada tingkat kepercayaan 1%*); 1) Obtained from the first order algebraic derivation technique (dY/dT) of the regression equation ($Y = f[T] = a + b\,T + c\,T^2$), and then by equating to zero (0), it will get $dY/dT = b + 2c\,T = 0$; and still then by mathematic equation technique, it will get $T = -b / 2$ = T-optimum. Further through the second order derivation (dY^2/dT^2), it will get $dY^2/dT^2 = 2c$. If the value of $c < 0$, then Yi (values of wood physical properties at T-opt) will be the maximum values for practical purposes (*1) diperoleh dari teknik derivasi aljabar tingkat pertama (dY/dT) dari persamaan regresi (Y=f [T] = a + b T + c T²), dan kemudian menyamakan dengan nilai nol, akan memperoleh dY/dT = b + 2 c T = 0; masih dengan teknik persamaan matematika, akan memperoleh T= - b / 2 = T-optimum. Selanjutnya melalui derivasi tingkat kedua (dY²/dT²), akan memperoleh dY²/dT² = 2 c. jika nilai dari c < 0, kemudian Yi nilai-nilai sifat fisis kayu pada T-opt akan mendapatkan nilai maksimum untuk tujuan praktis*)

Table 2. Average values of mechanical properties of densified JUN wood
Tabel 2. Nilai rata-rata sifat mekanis kayu JUN yang dipadatkan

Compression Temperature (*Suhu Kempa*, °C) T	SG	MOE (kg/cm²) Y5	MOR (kg/cm²) Y6	C// (kg/cm²) Y7	Strength Class (Kelas kuat)	Hardness (Kekerasan) (kgf/cm²) Y8
170	0.52	85,201 b	866 b	395 b	III	356 b
180	0.56	94,454 a	951 a	439 a	III-II	411 a
190	0.56	94,415 a	947 a	435 a	III-II	406 a
Control	0.45	81,103	856 b	370 c	III	342 c
Regression equations: $Yi = a + b\,T + c\,T^2$ (i = 5, 6, 7, and 8)						
a (intercept)		-1493668	-15080	-10022		-10956
b (for T)		+17185.1	+173.81	+113.62		+123.45
c (for T^2)		-46.457	-0.4708	-0.3083		-0.335
R		0.9708**	0.9914**	0.8928**		0.9562**
T-optimum, °C [1)]		184.96	184.59	184.27		184.25

Remarks (*Keterangan*): Values followed vertically with the same letters are not significantly different (*Nilai-nilai yang diikuti dengan huruf yang sama pada arah vertikal tidak berbeda nyata*); EMC= equilibrium moisture content (kadar air keseimbangan); R= correlation coefficient (koefisien korelasi); *= significant at 95% level (*Signifikan pada tingkat kepercayaan 95%*); **= significant at 1% level (*Signifikan pada tingkat kepercayaan 1%*); 1) obtained from the first order algebraic derivation technique dY/dT of the regression equation $Y= f\,[T] = a + b\;T + c\,T^2$, and then by equating to zero (0), it will get $dY/dT = b + 2\,c\,T = 0$; and still then by mathematic equation technique, it will get $T= - b\;/\;2$ = T-optimum. Further through the second order derivation (dY^2/dT^2), it will get $dY^2/dT^2 = 2\,c$. If the value of $c < 0$, then Yi values of wood mechanical properties at T-opt will be the maximum values for practical purposes (*Diperoleh dari teknik derivasi aljabar tingkat pertama dari persamaan regresi* $Y = f\,[T] = a + b\;T + c\,T^2$, *dan kemudian menyamakan dengan nilai nol (0), akan memperoleh* $dY/dT = b + 2\,c\,T = 0$; *masih dengan teknik persamaan matematika, (akan memperoleh* $T = - b\;/\;2$ = *T-optimum. Selanjutnya melalui derivasi tingkat kedua* dY^2/dT^2, *akan memperoleh* $dY^2/dT^2 = 2\,c$. *jika nilai dari* $c < 0$, *kemudian Yi nilai-nilai sifat mekanis kayu pada T-opt akan mendapatkan nilai maksimum untuk tujuan praktis*)



Control Wood Densified Wood at 180°C Densified Wood at 190°C

Cross sectional views (*Penampang melintang*)

Remarks (*Keterangan*): The cross-sectional anatomy structure of the 170°C's heat press densified JUN sample is not disclosed in the figure, because visually no apparent distinct changes on the structure of the 170°C's densified JUN sample with the structure of the control JUN sample (*Struktur anatomi penampang melintang sampel JUN yang dikempa pada suhu 170°C tidak dikemukakan dalam gambar ini, karena secara visual tidak tampak perbedaan antara struktur sampel JUN yang dipadatkan pada suhu 170°C dengan struktur sampel JUN control*)

Figure 1. The structure of wood cells for control (un-densified) and densified JUN woods (at 100 micrometre scale)
Gambar 1. Struktur sel kayu JUN kontrol dan kayu yang dipadatkan (pada skala 100 mikrometer)

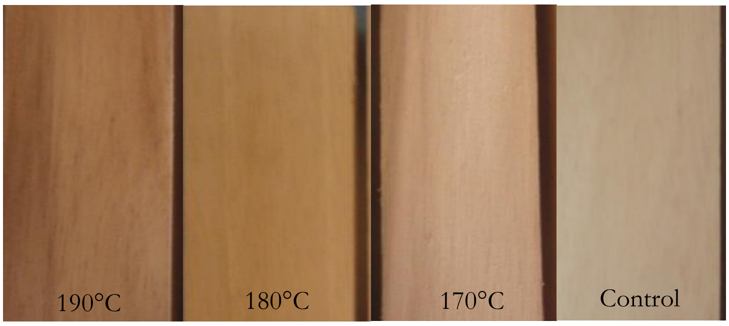


Figure 2. Surface performance of control and densified JUN wood at 170°C, 180°C, and 190°C compression temperatures

Gambar 2. Performa permukaan kayu JUN kontrol dan dipadatkan pada suhu kempa 170°C, 180°C, and 190°C

IV. CONCLUSION

Increasing the compression temperature (170, 180, and 190°C) could improve several physical and mechanical properties as well as surface qualities of the 5-years-old densified JUN wood, where all those properties were significantly better than the un-densified wood (control).

The best physical and mechanical properties (e.g., the greatest density (SG), the lowest EMC, least spring back tendency, and the greatest strengths/hardness) are achieved at the estimated optimum compression temperatures, consecutively 185.63°C (for density), 185.39°C (specific gravity), 184.58°C (thickness swelling), and 184.88°C (EMC), 184.96°C (MOE), 184.59°C (MOR), 184.2°C (compression strength), and 184.25°C (hardness); or in practice could be regarded entirely at 185°C.

Based on data simulation, the wood physical and mechanical properties at 185°C's compression temperature were judged as the most justifiable to meet the SNI-01-0608 Standard as furniture's raw material, which stipulates minimum SG at 0.40; strength class III; dimensional stability, which indicated by maximum thickness swelling 2%; maximum EMC 14%; and affording decorative values.

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AUTHOR CONTRIBUTIONS

EB and S conducted the ideas, designs and experimental designs; E.B. carried out trials and test treatments; S collected and analysed the data; E.B. wrote the manuscript; E.B. and S edited and finalized the manuscript. EB and S have equal contribution as main contributors

REFERENCES

Adzkia, U., Priadi, K., & Karlinasari, L. (2019). Evaluasi cacat pengeringan dan pemesinan pada empat jenis kayu cepat tumbuh termodifikasi panas. *Jurnal Penelitian Hasil Hutan*, *37*(3), 209–222. doi: 10.20886/jphh.2019.37.3.209-222.

Anish, M., Anoop, E., Vishnu, R., Sreejith, B., &, & Jijeesh, C. (2015). Effect of growth rate on wood quality of teak (*Tectona grandis* L.f.): A comparative study of teak grown under differing site quality conditions. *Journal of the Indian Academy of Wood Science*, *12*(1), 8. doi: 10.1007/s13196-015-0147-1.

ASTM. (2014). Standard method of testing small clear specimen of timber D143 (modification). *Annual Book of ASTM Standards*. ASTM International, West Conshohocken.

Basri, E. (2011). *Kualitas kayu waru gunung (Hibiscus macrophyllus Roxb.) pada tiga kelompok umur dan sifat densifikasinya untuk bahan mebel.* Master Tesis. Program Pasca Sarjana Fakultas Kehutanan Universitas Gadjah Mada. Yogyakarta.

Basri, E., & Wahyudi, I. (2013). Sifat dasar kayu Jati Plus Perhutani dari berbagai umur dan kaitannya dengan sifat dan kualitas pengeringan. *Jurnal Penelitian Hasil Hutan*, *31*(2), 93–102. doi: 10.20886/jphh.2013.31.2.93-102.

Basri, E., Yuniarti, K., Wahyudi, I., & Pari, R. (2020). *Teknologi pengeringan kayu*. Bogor: IPB Press. 130 pp.

Basri, E., Yuniarti, K., Wahyudi, I., Saefudin, & Damayanti, R. (2015). Effects of girdling on wood properties and drying characteristics of *Acacia mangium*. *Journal of Tropical Forest Science*, *27*(4), 498–505.

BPS (Badan Pusat Statistik). (2018). Statistik produksi kehutanan. Badan Pusat Statistik, Jakarta.

BPS (Badan Pusat Statistik). (2019). Statistik produksi kehutanan. Badan Pusat Statistik, Jakarta.

Damayanti, R., Ozarska, B., & Pandit, IKN., Febrianto, F. & Pari, G. (2018). Wood properties of 5-year-old fast grown teak. *Wood Research Journal*, *9*(2), 29–34.

Darmawan, W., Nandika, D., Kartikasari, R., Sitompul, A., & Gardner, D. (2015). Juvenile and mature wood characteristics of short and long rotation teak in Java. *IAWA Journal*, *36*(4), 429–443. doi: 10.1163/22941932-20150112.

Darwis, A., Wahyudi, I., Dwianto, W., & Dwi Cahyono, T. D. (2017). Densified wood anatomical structure and the effect of heat treatment on the recovery of set. *Journal of Indian Academy Wood Science*, *14*(1), 24–31. doi: 10.1007/ s13196-017-0184-z.

Djarwanto, Damayanti, R., Balfas, J., Basri, E., Jasni, Sulastiningsih, I.M., Andianto, Pari, G. … & Krisdianto. (2017). *Pengelompokan jenis kayu perdagangan Indonesia*. Bogor: FORDA Press.

Garcia, R. A., Lopes, J. O., Nascimento, A. M., & Latorraca, J. V. F. (2014). Color stability of weathered heat-treated teak wood. *Maderas. Ciencia y Tecnología*, *16*(4), 453–462. doi: 10.4067 /S0718-221X2014005000037.

Gasparik, M., Gaff, M., Kacik, F., & Sikora, A. (2019). Color and chemical changes in teak (*Tectona grandis* L.f.) and meranti (*Shorea* spp.) wood after thermal treatment. *BioResources*, *14*(2), 2667–2683. doi: 10.15376/biores.14.2.2667-2683.

Kemenhut (Kementerian Kehutanan). (2012). Panen perdana Jati Unggul Nusantara. Retrieved from http://ppid.menlhk.go.id/ berita/berita-foto/19/panen-perdana-jati-ungg ul-nusantara at April 16, 2012.

Lopes, J. O., Garcia, R. A., & Nascimento, A. M. (2018). Wettability of the surface of heat-treated juvenile teak wood assessed by drop shape analyzer. *Maderas. Ciencia y Tecnología, 20*(2). Version Online. doi: 10.4067/S0718-221X2018 005002801.

Martha, R., Basri, E., Setiono, L., Batubara, I., Rahayu, I. S., Gérardin, P., & Darmawan, W. D. (2021). The effect of heat treatment on the characteristics of the short rotation teak. *International Wood Products Journal.* Published Online: 27 July 2021. doi: 10.1080/20426445. 2021.1953723.

Oey, D. S. (1990). *Berat jenis dari jenis-jenis kayu Indonesia dan pengertian beratnya kayu untuk keperluan praktek*. Pengumuman Nr. 13. Pusat Penelitian dan Pengembangan Hasil Hutan, Departemen Kehutanan, Bogor.

Pasaribu, G. & Sisilia, L. (2021). Peningkatan mutu kayu jati (*Tectona grandis*) hasil penjarangan asal Kabupaten Cianjur. Retrieved from https://jurnal.untan.ac.id › article › at 21 May 2021.

Rajković, V. J., & Miklečić, J. (2019). Heat-treated wood as a substrate for coatings, weathering of heat-treated wood, and coating performance on heat-treated wood. *Advances in Materials Science and Engineering, Vol. 2019.* Article Id 8621486. doi: 10.1155/2019/8621486. 9 pages.

Rowell, R. M. (2012). *Handbook of wood chemistry and wood composites.* 2^{nd} Edition. Boca Raton, Florida, USA : Taylor and Francis Group, CRC Press. 703 p.

Schönfelder, O., Zeidler, A., Borůvka, V., Bílek, L., & Lexa, M. (2018). Shrinkage of scots pine wood as an effect of different tree growth rates, a comparison of regeneration methods. *Journal of Forest Science*, *64*(6), 271–278. doi: 10.17221/23/2018-JFS.

Shmulsky, R. & Jones, P. D. (2019). *Forest products and wood science: An introduction* (7th ed.). West Sussex (G.B.): Wiley-Blackwell. 504 p. doi: 10.1002/9781119426400.

Soerianegara, I., & Lemmens, R. H. M. J. (1995). *Plant resource of South- East Asia*, *No 5 (1) Major commercial timber*. Bogor: Prosea Foundation. pp 448-454.

Soeroso, H., & Poedjowadi, D. (2008). Usahatani jati unggul pola bagi hasil. 5 tahun panen. Unit Usaha Bagi Hasil. Koperasi Perumahan Wanabakti Nusantara. Jakarta.

Standar Nasional Indonesia (SNI). (1989). *Kayu untuk mebel, syarat sifat fisik dan mekanik.* (SNI 01-0608-1989). Badan Standardisasi Nasional, Jakarta.

Steel, R. G. D. & Torrie, J. (1992). *Principles and procedure of statistic: A biometrical approach*. New York: Mc. Graw Hill Book Company.

Panshin, AJ. & de Zeuw, C. (1980). *Textbook of wood technology*. Iowa: McGraw-Hill Book Company.

Wiemann, M. C. (2010). Characteristics and availability of commercially important woods. *In Wood Handbook. Wood as an Engineering Material.* Chap. 2. Madison, WI : U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory.

Yuniarti, K., Basri, E., & Abdurachman, A. (2017). Honeycombing and deformation of six wood species and their relationship with several physical properties *Jurnal Penelitian Hasil Hutan*, *35*(2), 115–122. doi: 10.20886/jphh.2017.35.2. 115-122.