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Effects of Temperature during Oil Heat Treatment on the Quality Improvement of Mindi (*Melia azedarach*) and Sengon (*Falcataria moluccana*) Woods

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ABSTRACT

Fast growing wood species has high availability potential in quantity, but has low quality in its application, so it requires modification treatment to improve the wood quality. Oil heat treatment (OHT) is a wood modification method using vegetable oil as the heating medium. The objective of this research was to investigate the influence of temperature during OHT on the mindi (Melia adezarach) and sengon (Falcataria moluccana) woods. The physico-mechanical properties such as the color changes (ΔL, Δa*, Δb*, and ΔE), water content, material density, water absorption, mass changes, and compressive strength, were observed. OHT was conducted for 2 h at the treatment temperatures of 180 °C, 200 °C, 220 °C, and 240 °C. The results showed that the increase of temperature indicated an increase of the ΔL*, Δa*, Δb*, and ΔE values at a higher treatment temperature. The increase of temperature exhibited an increase of material density and a decrease of water content, water absorption, and mass changes of wood. The compressive strength of woods slightly increased at 180 °C but decreased as at more elevated temperature. Consequently, OHT of mindi and sengon at 180 °C is recommended to improve color and physical properties of wood and prevent a decrease in compressive strength.*

1. INTRODUCTION

Log production worldwide has consistently increased from 2009 to 2018, from 1.55 billion m^3 to 2.05 billion m^3 (FAO, 2019). A similar trend was also observed on the log production in Indonesia, showing an increase from 33.41 million m^3 in 2013 to 48.74 million m^3 in 2018 (KLHK, 2018). This making Indonesia as one of the largest round wood producers in the world (FAO, 2019). The increase in wood production shows that interest in using wood is also increasing. Wood species in Indonesia that significantly increased in production are primarily fast-growing trees, like mindi (*Melia azedarach*), mangium (*Acacia mangium*), and sengon (*Falcataria moluccana*) (Febrianto *et al*., 2010; Haryanto *et al*., 2021; Rafly *et*

al., 2022). Fast-growing wood species have the advantages of short growth rotation and short time for harvesting, but they have several disadvantages in terms of wood quality, such as lower density and shorter fiber than slow-growing wood species (Aisyah *et al*., 2021; Suri *et al*., 2021a; Yunita *et al*., 2022). Therefore, efforts to improve fast-growing wood quality through modification are urgently needed.

Wood modification is a practice of increasing wood characteristics to produce new and desirable material properties (Hidayat & Febrianto, 2018; Hidayat *et al*., 2020; Hill, 2006). Heat treatment of wood is considered simpler and more environmentally friendly than other wood modification techniques because it does not use dangerous chemicals in the process (Hidayat *et al*., 2016; Jamsa & Viitaniemi, 2001). Based on the media, process stages, and heat transfer equipment used, heat treatment of wood has several types of methods, namely Plato Wood, Thermo Wood, Le Bois Perdure, Retification, and Oil Heat Treatment (OHT) (Hidayat *et al*., 2015; Sandberg & Kutnar, 2016; Suri *et al*., 2022).

Oil heat treatment (OHT) can improve inferior wood properties due to the combined effects of oil and heat (Ma'ruf *et al*., 2021). OHT uses vegetable oil as a heat transfer medium so that the heat spreads over the wood more evenly and can prevent oxygen from entering during the treatment process to prevent the wood from burning (Suri *et al*., 2021b; Jamsa & Viitaniemi, 2001). OHT is also relatively inexpensive and simple compared to other wood modification technologies, such as surface and chemical modification (Tang *et al*., 2019).

Several studies on the effect of OHT on improving wood properties have been reported by previous researchers (Bazyar, 2012; Dubey *et al*., 2011; Suri *et al*., 2021a; Suri *et al*., 2022; Wang & Cooper, 2005). Oil absorption contributes to increased dimensional stability, hydrophobicity, and resistance to mold and fungi (Dubey *et al*., 2011; Wang & Cooper, 2005). Bazyar (2012) reported an increase in the weight percentage of *Populus tremula* wood after OHT at 190°C to 220°C for 4, 5, and 6 hours. Suri *et al*. (2021a) reported the effect of OHT on the anatomical properties of gmelina and mindi wood, where OHT had a thickening effect on the fiber cell walls in both wood species. Suri *et al*. (2021b) reported significant differences in yield in color and weight changes in royal paulownia and Korean white pine woods after the modification by hot air and hot oil. Suri *et al*. (2022) also reported that OHT in royal paulownia and Korean white pine caused an increase of wood density, a lower volume shrinkage and weight loss in wood abrasion, and an increase in compressive strength and hardness.

Studies on OHT using various fast-growing wood species are still limited. OHT studies on fast-growing tropical wood species have been reported for *Acacia mangium* (Razak *et al*., 2011) and *Hevea brasiliensis* (Umar *et al*., 2016). However, the study of OHT using mindi (*Melia azedarach*) and sengon (*Falcataria moluccana*) woods has not been widely reported. Therefore, this study was conducted to add new scientific information regarding the effect of OHT on the wood properties and to determine the optimal OHT temperature to improve the quality of mindi and sengon woods.

2. RESEARCH METHOD

2.1. Materials

The important materials used in this study were two fast-growing wood species, namely mindi (*Melia azedarach*) and sengon (*Falcataria moluccana*), and palm oil. The equipment used in this study included an oil bath, oven drier, band saw, circular saw, sanding machine, caliper, screw micrometer, digital balance, thermometer, digital camera, color meter (chromameter), and Universal Testing Machine (Testometric).

2.2. Methods

Mindi and sengon logs of 6-year-old were obtained from community forests. The logs were cut into boards with dimension of 20 mm (thickness) × 90 mm (width) × 300 mm (length). The boards were then dried gradually and stored at room temperature (25ºC) until they reached equilibrium moisture content. Next, the boards were selected, and only boards with regular fiber and free from defects were chosen for samples. The board samples were prepared using metal supports, and the upper pile was maintained using metal supports to keep the board from lifting during the OHT process (**Figure 1**). The oil was then put into a designated OHT furnace as heating medium. The OHT process carried out as follows: (1) the temperature of the oil medium increased from 25–30 °C to the target temperature with an increase in temperature of 4°C/min, (2) the target temperature of 180 °C, 200 °C, 220 °C, or 240 °C was maintained for 2 h, (3) the temperature cooled-down until reached room temperature, (4) the boards were then conditioned by storing it at room temperature for approximately 2 weeks before tested.

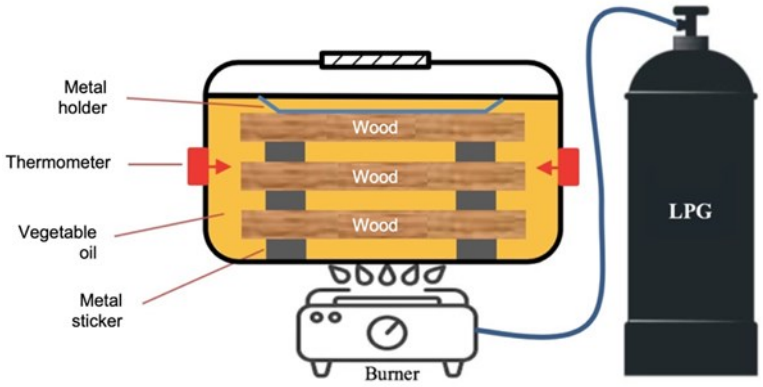

Figure 1. Scheme of the oil heat treatment furnace

2.3. Wood Properties Evaluation

2.3.1. Color change

Measurement of color change was investigated at three points on each sampled wood surface before and after OHT using the Colorimeter AMT507 (Amtast Inc., USA). The color measurement consisted of three color parameters: the *L** parameter indicates the lightness level of the wood, the *a** parameter describes the green-red color chromatization, a negative number indicates a green color (-*a**) and a positive number indicates a red color (+*a**). The *b** parameter describes the blue-yellow color chromatization, where a negative number indicates a blue color (-*b**) and a positive number indicates a yellow color (+*b**). Discoloration was measured on wood before and after OHT on a sample measuring 30 cm × 10 cm × 2 cm by calculating the total color change with the following calculations.

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

$$\Delta L^* = L^*_f - L^*_i \quad (2)$$

$$\Delta a^* = a^*_f - a^*_i \quad (3)$$

$$\Delta b^* = b^*_f - b^*_i \quad (4)$$

where ΔE^* is the overall color change, ΔL^* is the change in wood lightness, Δa^* is the change in red-green chromatization, Δb^* is the change in yellow-blue chromatization of yellow, and subscript *f* and *i* is for final and initial, respectively.

2.3.2. Water content

Wood water content was calculated for the mass of wood with OHT and control wood in the condition before being baked (air dry mass) and after being baked (oven dry mass) with a temperature of 100 ± 2°C for 24 hours on a sample size of 4 cm x 2 cm x 2 cm with the equation:

$$MC = \frac{M_1 - M_o}{M_o} \quad (5)$$

where MC is water content (%, db), M_1 is initial mass (g), and M_o is final mass (g).

2.3.3. Water absorption

Water absorption is the ability of wood to absorb maximum water with immersion time of 14 days using the equation:

$$WA = \frac{M_w - M_o}{M_o} \quad (6)$$

where WA is water absorption (%), M_w is mass after immersed in water (g), and M_o is initial oven-dry mass (g).

2.3.3. Mass Change

The change in wood mass was measured before and after OHT in the oven dry state to determine the change in mass that occurred in the wood using the equation:

$$DM = \frac{M_{OHT} - M_o}{M_o} \quad (7)$$

where ΔM is mass change (%), M_o is oven-dry mass of sample before OHT (g), and M_{OHT} is oven-dry mass of sample after OHT (g).

2.3.4. Density

The density of wood sample before and after OHT was determined by measuring the wood mass and volume in the oven-dry condition and calculated using equation (8):

$$D = \frac{M}{V} \quad (8)$$

where *D* is density (g/cm^3), *M* is oven-dry mass (g), and *V* is oven-dry volume (cm^3).

2.3.5. Compressive Strength

The compressive strength of OHT and control woods was compared to determine the effect of OHT on the compressive strength of wood with the equation (9):

$$P = \frac{F}{A} \quad (9)$$

where *P* is compressive strength (N/mm^2), *F* is maximum load (N), and *A* is surface area (mm^2).

2.3.6. Data Analysis

Data analysis used a non-parametric statistical model of completely randomized design with 2 factors (2 × 4). The first factor was wood species (sengon and mindi), and the second factor was the treatment temperatures (180 °C to 240 °C, incremental 20 °). Anova was used to analyze the impact of factors on observed parameters, and the Duncan's Multiple Range Test (DMRT) was run at 95% confidence interval to compare the levels of the factors influencing the response.

3.RESULTS AND DISCUSSION

3.1. Color Change

The color of wood after OHT has various differences for each species (**Figure 2**). The difference in color was measured using the values of Δ*L*, Δa*, Δb**, and the total change in wood color using the values of Δ*E** (**Table 1**). The effect of OHT temperature on both species of wood causes the *L** value of wood after OHT to be smaller, therefore the wood is darker than the wood before OHT. The decreased *L** value is due to the process of releasing wood volatile compounds by heat which produces carbon residue causing more wood volatile compounds to be released at higher temperatures (Salim, 2016).

Statistical results show that temperature has a significant effect on the Δ*L** value. The results of Duncan's Multiple Range Test (DMRT) for each type of wood showed that mindi wood showed no significant difference at temperature 180°C and 200°C, and

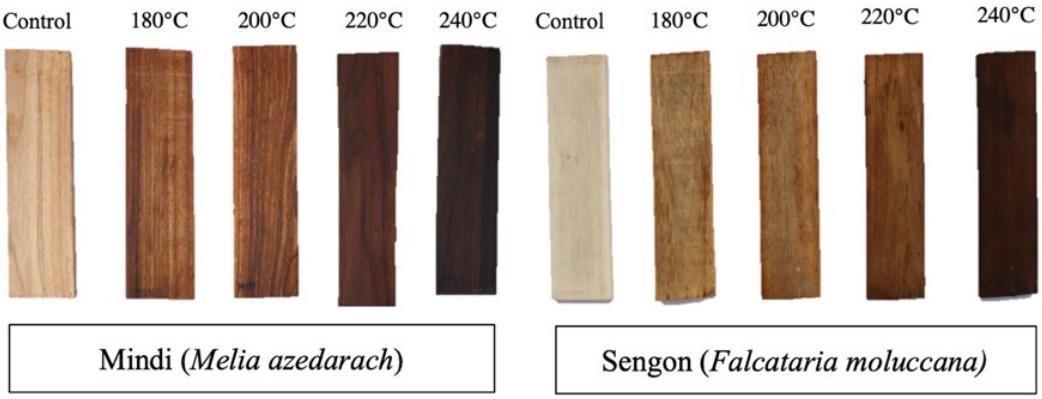

Figure 2. The appearance of wood samples before and after OHT at different temperatures

Table 1. Change in wood color after OHT

Species	Temp.	△*L**		△*a**		△*b**		△*E*	
Mindi	180 °C	23,80^{a}	(0,61)	-1,17^{a}	(0,42)	3,18^{a}	(0,21)	24,56^{a}	(1,26)
	200 °C	24,97^{a}	(3,87)	-0,93^{a}	(0,14)	5,15^{b}	(0,31)	25,42^{a}	(1,24)
	220 °C	33,92^{b}	(0,73)	1,73^{b}	(0,38)	10,87^{c}	(0,47)	34,96^{b}	(1,78)
	240 °C	34,28^{b}	(2,24)	6,52^{c}	(0,21)	15,03^{d}	(0,74)	37,68^{b}	(0,33)
Sengon	180 °C	21,70^{a}	(0,96)	-4,12^{a}	(0,37)	-5,13^{a}	(0,99)	22,67^{a}	(1,26)
	200 °C	28,10^{b}	(1,09)	-6,35^{b}	(0,47)	-5,17^{a}	(0,38)	29,27^{b}	(1,13)
	220 °C	35,43^{c}	(1,86)	-4,32^{a}	(1,06)	-2,90^{b}	(1,32)	37,62^{c}	(1,87)
	240 °C	44,08^{d}	(0,26)	-1,63^{a}	(1,39)	5,75^{c}	(1,41)	46,30^{d}	(2,06)

Notes: Different superscript letters in the results indicate a significantly different level of 5% in each column or type of wood. Numbers in parenthesis are standard deviation.

Then showed a significant difference at higher temperatures. Whereas in sengon wood the value of Δ*L** was significantly different at each OHT temperature. This shows that the Δ*L** value of sengon wood changes more easily with changes in temperature than mindi. The effect of temperature on the Δ*L** values of both types of wood tends to increase with increasing OHT temperature. Suri *et al*. (2021b) also reported that oil heat treatment tends to change the color of *Pinus koreansis* and *Paulownia tomentosa* wood to become darker compared to water heat treatment.

The effect of temperature on the Δ*a** and Δ*b** values of mindi and sengon wood tends to increase with increasing OHT temperature. There are differences in changes in the values of Δ*a** and Δ*b** for the two types of wood due to differences in chemical composition (lignin, hemicellulose, and cellulose) present in the two types of wood. Sengon and mindi wood have different chemical compositions such as lignin and cellulose (Martawijaya *et al*., 1989). Srinivas & Pandey (2012) reported color changes in *a** and *b** values for *Hevea brasiliensis* and *Grevillea robusta* wood species. They explained that the changes in the *a** and *b** values of wood during heat treatment were due to the decomposition of hemicellulose so that the proportion of lignin became higher, but the changes in the *a** and *b** values of each wood were different due to differences in chemical content.

Statistical results showed that temperature has a significant effect on the values of Δ*a** and Δ*b**. DMRT results of the Δ*a** value of each type of wood showed that mindi wood only had a temperature of 180 °C and 200 °C which was not significantly different, while sengon wood had a temperature of only 200 °C which was significantly different from the other temperatures. DMRT results of the Δ*b** value of each type of wood showed that mindi wood was significantly different at each treatment temperature, while for sengon the values were only 180 °C and 200 °C which were not significantly different. This shows the difference in the reaction values of Δ*a** and Δ*b** of mindi and sengon wood due to differences in chemical reactions. The increase in Δ*a** and Δ*b** values is in line with the research by Razak *et al*. (2011) on hybrid Acacia wood which showed an increase in Δ*a** values up to 220 °C and Δ*b** values up to 200 °C in the OHT process for 2 hours.

The effect of temperature on the Δ*E* value of both types of wood tends to increase with increasing OHT temperature. The same result was also described by Dubey *et al*. (2011), that *Pinus radiata* wood with OHT treatment showed the Δ*E* value increased with increasing temperature. Statistical results show that temperature has a significant effect on the ΔE value. DMRT results for each type of wood showed that in mindi wood there was no significant increase in temperature up to 200 °C and significantly different at higher temperatures, whereas in sengon wood the ΔE value was significantly different at each OHT temperature. This shows that the Δ*E* value or total color change in sengon wood is higher and more easily changed than mindi. The color of the wood changes during heat treatment because hemicellulose degrades at a temperature of 190–245 ºC resulting in a higher proportion of lignin clasons and there are carbon residues which cause the color of the wood to become darker (González-Peña & Hale 2009; Hidayat *et al*., 2017a).

3.2. Physical Properties

The physical properties of wood include density, moisture content, water absorption, and changes in wood mass. The effect of temperature on density resulted in an increase in wood density up to 240 ℃ for mindi wood and 220 ℃ for sengon wood compared to the control, but the effect was reduced at higher temperatures (**Table 2**).

Table 2. Density, water content, and water absorption capacity of wood after OHT

Species	Temperature (°C)	Density (g/cm³)	Water content (%)	Water Absorption (%)
Mindi	Control	0.50 [a] (0,01)	11,80 [a] (2,13)	48,04 [a] (2,86)
	180	0.70 [b] (0,12)	5,32 [b] (1,48)	37,98 [b] (1,98)
	200	0.61 [b] (0.04)	4,90 [b] (1,55)	36,20 [b] (0,79)
	220	0.60 [ab] (0,04)	4,61 [b] (1,52)	34,23 [b] (2,44)
	240	0.53 [a] (0.04)	4,37 [b] (1,24)	33,88 [b] (2,66)
Sengon	Control	0.27 [a] (0,01)	8,65 [a] (0,68)	69,61 [a] (4,65)
	180	0.35 [b] (0,06)	6,80 [b] (0,63)	62,46 [b] (1,08)
	200	0.31 [ab] (0,04)	6,46 [b] (0,57)	59,82 [b] (1,90)
	220	0.29 [a] (0,04)	4,32 [c] (0,66)	58,57 [b] (5,26)
	240	0.26 [a] (0,01)	2,93 [c] (0,99)	56,57 [b] (5,76)

Notes: Different superscript letters in the results indicate a significantly different level of 5% in each parameter within a wood species. Numbers in parenthesis are standard deviation.

Research Azis *et al*. (2020) showed a similar thing in *Aleurites moluccanus* wood where up to an OHT temperature of 160 °C there was an increase in density from the control but a decrease in density at higher temperatures. Statistical results show that temperature has a significant effect on wood density. DMRT results for each type of wood showed that mindi wood at 180 °C and 200 °C was significantly different from the control and 240 °C but not significantly different from 220 °C, while sengon wood at 180 °C was significantly different from the other temperatures except 200 °C. This shows that the most optimal density for both types of wood is at 180 °C to 200 °C.

Mindi and sengon woods experience an increase in density caused by the ingress of oil into the wood to the cell walls resulting in an increase in the mass of the wood, especially during the longer OHT period (Hidayat & Febrianto, 2018). Suri *et al*. (2022) also reported that OHT heat modified *Paulownia tomentosa* and Korean white pine wood showed the highest density value at 180 °C and then decreased slightly at 200 °C and 220 °C. The decrease in the density of OHT-produced wood at temperatures of more than 180 °C is related to the evaporation of extractive substances and the degradation of the chemical compositions contained in the wood such as holocellulose (hemicellulose and cellulose) due to high temperatures (Hidayat et al., 2017b; Razak *et al*., 2012). The density of the two control wood species was in accordance with the standard measurements of Martawijaya *et al*. (1989) and PKKI (1961) as well as increasing wood density changed the strength class of sengon wood from class V to class IV and mindi from class III to class II.

Changes in water content occurred in both woods after OHT which reduced the wood moisture content to be lower than the control. The effect of higher OHT temperature on sengon wood causes a decrease in wood moisture content, but not significantly. Statistical results show that temperature has a significant effect on wood moisture content. DMRT results showed that the OHT yield of mindi wood was not significantly different at each temperature but significantly different from the control, while the temperature of sengon wood which was not significantly different was 180 °C and 200 °C as well as 220 °C and 240 °C. This shows that OHT heat modification greatly affects the decrease in wood moisture content. Wang & Cooper (2005) reported that *Picea glauca* wood had a lower moisture content at an OHT treatment temperature of

220 °C compared to 200 °C and controls. Both types of wood experience a decrease in water content due to the ingress of oil into the wood until the cell walls replace water that evaporates at temperatures of more than 100 °C (Esteves & Pereira, 2009). When drying OHT wood from air dry to oven dry, the temperature used does not cause the oil to evaporate so the moisture content of the wood will be lower (Bazyar, 2012).

Both wood species have less water absorption after OHT. The effect of OHT temperature on both types of wood has the same decrease, that is, the higher the OHT temperature, the lower the water absorption capacity of wood, although not significantly. Statistical results show that temperature has a significant effect on the water absorption capacity of wood. DMRT results showed that the two types of OHT wood were not significantly different at each temperature, but significantly different from the control. This shows that OHT greatly affects the decrease in wood water absorption compared to the control. Dubey *et al*. (2016) also reported that in pine wood (*Pinus radiata*) there was a reduction in wood water absorption as the OHT temperature increased to 210 °C. Jamsa & Viitaniemi (2001) explained that the decrease in wood water absorption after OHT was caused by chemical reactions occurred during heat modification that decrease the number of hydroxyl groups which lead to an increase the hydrophobicity of cell wall.

Mindi and sengon woods showed an increase in maximum mass at 180ºC and then decreased with increasing treatment temperature (**Figure 3**). Statistical results show that temperature has a significant effect on changes in wood mass. DMRT results showed that the two types of OHT wood were not significantly different at each temperature, but significantly different from the control. This shows that OHT greatly affects the decrease in wood water absorption compared to the control. Bazyar (2012) reported in his research that OHT-treated *Papulus trimula* wood increased in mass and the higher the OHT temperature the lower the mass change up to 220 °C. Bal (2015) also reported that in *Fagus orientalis* wood there was an increase in maximum mass at 190 °C and then decreased at higher temperatures. There was an increase in mass due to oil entering the wood (Octavia *et al*., 2011) and a decrease in wood mass due to the degradation of wood hemicellulose at high temperatures during heat treatment (Yang *et al*., 2007).

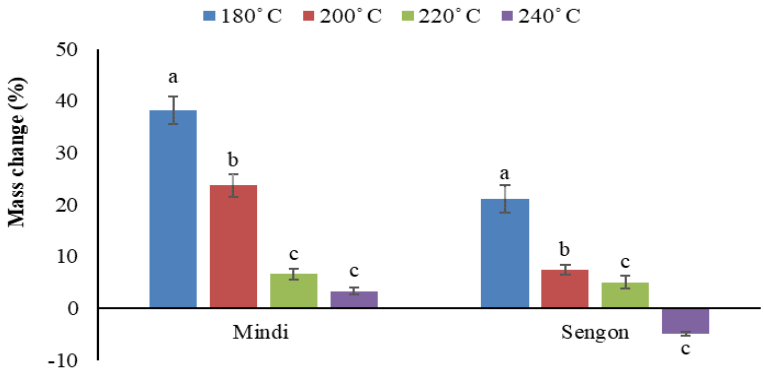

Figure 3. Changes in wood mass after OHT (Different letters show significant differences between treatment temperatures within a wood species at 5% confidence level).

3.4. Compressive Strength

Both types of wood show an increase and decrease in compressive strength of wood at certain temperatures (**Figure 4**). The treatment temperature at OHT affected the increase in compressive strength of the two woods up to 180 °C and then decreased at

a higher temperature which could even be smaller than the control even though all temperatures were not significantly different for sengon wood.

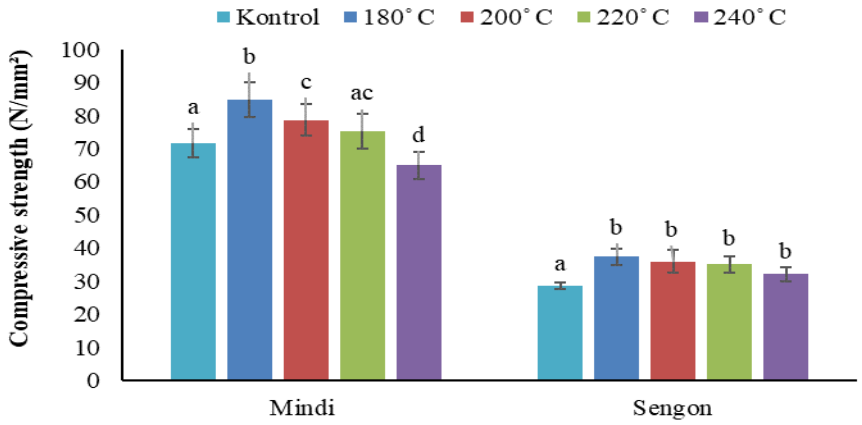

Figure 4. Compressive strength of OHT-produced wood (Different letters show significant differences between treatment temperatures within a wood species at 5% confidence level).

Statistical results show that temperature has a significant effect on compressive strength. DMRT results showed that mindi wood at each OHT temperature was significantly different except 220 °C which was not significantly different from the control and 200 °C, while sengon wood was not significantly different at each temperature but significantly different from the control. This shows the compressive strength of mindi wood. OHT results are most optimal at 180 °C and sengon 180 °C to 240 °C because each temperature used is not significantly different. This is in accordance with the research of Suri *et al*. (2022) for *Paulownia tomentosa* and *Pinus koraiensis* wood there was an increase in maximum compressive strength at 180°C but the increase in compressive strength decreased at higher temperatures and Tomak et al. (2011) revealed that the compressive strength was less on the treated *Pinus sylvestris* wood than the control, while *Fagus oriantalis* wood increased at an OHT temperature of 160 °C for 30 minutes. The mechanical properties of wood can have a positive correlation with wood density (Pasaribu, 2007), in which in this study the compressive strength of wood according to density increased at certain OHT temperatures and then decreased at higher temperatures. There is an increase in compressive strength because at a temperature of 180 °C or more there is an increase in the size and distribution area of microporosity due to the detaching and loss of various wood components (Hietala *et al*., 2002) and a decrease in the compressive strength of wood due to an increase and decrease in wood density at certain temperatures due to its degradation. wood chemical components such as cellulose, hemicellulose, and lignin due to high heat.

4. CONCLUSION

Oil heat treatment on mindi and sengon wood gives different results on the color, physical properties, and compressive strength of the wood because it is influenced by temperature and wood type. OHT resulted in an increase in the values of ΔL*, Δa*, Δb*, and ΔE in sengon and mindi wood as the OHT temperature increased. Moisture content, water absorption capacity, and changes in mass of sengon and mindi wood decreased with increasing OHT temperature. OHT had an effect on increasing the compressive strength of sengon and mindi wood at a treatment temperature of 180 °C,

but the compressive strength decreased as the treatment temperature increased. The most optimal OHT temperature for compressive strength and density for mindi wood is 180 °C because it has the largest value, while the most optimal OHT temperature for moisture content, water absorption and mass change is 240 °C because it has the smallest value.

REFERENCES

Aisyah, S., Haryadi, J., Maulana, M. I., Marwanto, Prasetia, D., Hidayat, W., Lubis, M. A. R., Kim, N. H., & Febrianto, F. (2021). Effects of Strands Pre-treatment and Adhesive Type on the Properties of Oriented Strand Board Made from Gmelina (*Gmelina arborea*) Wood. *Jurnal Sylva Lestari*, *9*(3), 475–487. DOI: 10.23960/jsl.v9i3.532

Azis, A., Yunianti, A. D., & Agussalim, A. (2020). Changes in the density, specific gravity and dimensional stability of candlenut wood (*Aleurites moluccanus* (L.) Willd.) from several variation temperatures with oil-heat treatment. *IOP Conference Series: Materials Science and Engineering*, *935*(1), 012031. DOI: 10.1088/1757-899X/935/1/012031

Bal, B. C. (2015). Physical properties of beech wood thermally modified in hot oil and in hot air at various temperatures. *Maderas. Ciencia Y Tecnología*, *17*(4), 789–798. DOI: 10.4067/S0718-221X2015005000068

Bazyar, B. (2012). Decay resistance and physical properties of oil heat treated aspen wood. *BioResources*, *7*(1), 696–702.

Dubey, M. K., Pang, S., & Walker, J. (2011). Effect of oil heating age on colour and dimensional stability of heat treated Pinus radiata. *European Journal of Wood and Wood Products*, *69*(2), 255–262. DOI: 10.1007/s00107-010-0431-0

Dubey, M. K., Pang, S., Chauhan, S., & Walker, J. (2016). Dimensional stability, fungal resistance and mechanical properties of radiata pine after combined thermo-mechanical compression and oil heat-treatment. *Holzforschung*, *70*(8), 793–800. DOI: 10.1515/hf-2015-0174

Esteves, B. M., & Pereira, H. M. (2009). Wood modification by heat treatment: A review. *BioResources*, *4*(1), 370–404. DOI: 10.15376/biores.4.1.esteves

Febrianto, F., Hidayat, W., Samosir, T. P., Lin, H. C., & Soong, H. D. (2010). Effect of Strand Combination on Dimensional Stability and Mechanical Properties of Oriented Strand Board made from Tropical Fast Growing Tree Species. *Journal of Biological Sciences, 10*(3): 267–272.

Food and Agriculture Organisation (FAO). (2019). Global Forest Products 2018. In *Forest Products and Statistics Team Forestry Policy and Resources Division FAO Forestry Department*. FAO Forestry Department.

González-Peña, M. M., & Hale, M. D. C. (2009). Colour in thermally modified wood of beech, Norway spruce and Scots pine. Part 1: Colour evolution and colour changes. *Holzforschung*, *63*(4), 385–393. DOI: 10.1515/HF.2009.078

Haryanto, A., Hidayat, W., Hasanudin, U., Iryani, D. A., Kim, S., Lee, S., and Yoo, J. (2021). Valorization of Indonesian Wood Wastes through Pyrolysis: A Review. *Energies, 14*(5), 1407. DOI: 10.3390/en14051407

Hidayat, W., & Febrianto, F. (2018). *Teknologi Modifikasi Kayu Ramah Lingkungan: Modifikasi Panas dan Pengaruhnya terhadap Sifat-sifat Kayu*. Pusaka Media.

Hidayat, W., Jang, J. H., Park, S. H., Qi, Y., Febrianto, F., Lee, S. H., and Kim, N. H. (2015). Effect of Temperature and Clamping during Heat Treatment on Physical and Mechanical Properties of Okan (*Cylicodiscus gabunensis* [Taub.] Harms) Wood. *BioResources, 10*(4), 6961–6974. DOI: 10.15376/biores.10.4.6961-6974

Hidayat, W., Maruf, S. D., Abdillah, M., Prayoga, S., Zevan, R., Prihastono, G. B. A., Hardianto, A. H., & Ridjayanti, S. M. (2020). *Perlakuan Minyak Panas (Hot Oil Treatment) pada Kayu*. Pusaka Media.

Hidayat, W., Qi, Y., Jang, J. H., Park, B. H., Banuwa, I. S., Febrianto, F., & Kim, N. H. (2017a). Color Change and Consumer Preferences towards Color of Heat-Treated Korean White Pine and Royal Paulownia Woods. *Journal of the Korean Wood Science and Technology*, *45*(2), 213–222. DOI: 10.5658/WOOD.2017.45.2.213

Hidayat, W., Qi, Y., Jang, J. H., Febrianto, F., & Kim, N. H. (2017b). Effect of mechanical restraint on the properties of heat-treated *Pinus koraiensis* and *Paulownia tomentosa* woods. *BioResources*, *12*(4), 7539–7551. DOI: 10.15376/biores.12.4.7539-7551

Hidayat, W., Qi, Y., Jang, J. H., Febrianto, F., Lee, S. H., and Kim, N. H. (2016). Effect of Treatment Duration and Clamping on the Properties of Heat-Treated Okan Wood. *BioResources, 11*(4), 10070–10086. DOI: 10.15376/biores.11.4.10070-10086

Hietala, S., Maunu, S. L., Sundholm, F., Jamsa, S., & Viitaniemi, P. (2002). Structure of thermally modified wood studied by liquid state NMR measurements. *Holzforschung*, *56*(5), 522–528. DOI: 10.1515/HF.2002.080

Hill, C. A. S. (2006). *Wood Modification: Chemical, Thermal and Other Processes*. Wiley. DOI: 10.1002/0470021748

Jamsa, S., & Viitaniemi, P. (2001). Review on heat treatments of wood : Heat treatment of wood - better durability without chemicals. *Proceedings of Special Seminar Held in Antibes*, *41*(3), 66. DOI: 10.1007/BF02608498

KLHK (Kementerian Lingkungan Hidup dan Kehutanan). (2018). *Statistik lingkungan hidup dan kehutanan tahun 2018*. Pusat Data dan Informasi Kementerian Lingkungan Hidup dan Kehutanan (KLHK).

Ma'ruf, S. D., Bakri, S., Febryano, I. G., Setiawan, A., Haryanto, A., Suri, I. F., Kim, N. H., & Hidayat, W. (2021). Effects of Eco-frendly Hot Oil Treatment on the Wood Properties of Gmelina Aborea and Cocos Nucifera. *Proceedings of the International Conference on Sustainable Biomass (ICSB 2019)*, 190–194. DOI: 10.2991/aer.k.210603.033

Martawijaya, A., Kartasujana, I., Kodir, K., & Prawiro, S. A. (1989). Atlas Kayu Jilid II. In *Atlas Kayu Jilid II*. Departemen Kehutanan Badan Penelitian dan Pengembangan Kehutanan.

Octavia, Z., Anne-marie, B. L., & Beldean, E. (2011). Improvements in stability of the oil treated wood. *Recent Researches in Energy, Environment and Landscape Architecture*, 146–150.

Pasaribu, G. (2007). Physical and Mechanical Properties of Four Endemic Wood Species from North Sumatra. *Jurnal Penelitian Hasil Hutan*, *54*(1), 15–27.

PKKI (Peraturan Konstruksi Kayu Indonesia). (1961). *Peraturan Konstruksi kayu Indonesia NI-5*. Departemen Pekerjaan Umum, Direktorat Jenderal Cipta Karya, Direktorat Penyelidikan Masalah Bangunan.

Rafly, N. M., Riniarti, M., Hidayat, W., Prasetia, H., Wijaya, B. A., Niswati, A., Hasanudin, U., & Banuwa, I. S. (2022). Pengaruh Pemberian Biochar Tandan Kosong Kelapa Sawit terhadap Pertumbuhan Sengon (Falcataria moluccana). *Journal of Tropical Upland Resources*, *4*(1), 1–10. DOI: 10.23960/jtur.vol4no1.2022.124

Razak, W., Izyan, K., Roziela Hanim, A., Othman, S., Aminuddin, M., & Affendy, H. (2011). Effects of hot oil treatment on colour and chemical changes in 15-year-old Acacia hybrid. *Journal of Tropical Forest Science*, *23*(1), 42–50.

Razak, W., Khalid, I., Tabet, T. A., Mohamed, A., Sulaiman, O., Salim, R. M., & Ayob, F. W. (2012). Effectiveness of hot oil treatment on cultivated 15 year-old Acacia hybrid against Coriolus versicolors, Gloeophyllum trabeum and Pycnoporus sanguineus. *Sains Malaysiana*, *41*(2), 163–169.

Salim, R. (2016). Karakteristik dan Mutu Arang Kayu Jati (*Tectona grandis*) dengan Sistem Pengarangan Campuran pada Metode Tungku Drum. *Jurnal Riset Industri Hasil Hutan*, *8*(2), 53–64. DOI: 10.24111/jrihh.v8i2.2113

Sandberg, D., & Kutnar, A. (2016). Thermally modified timber: Recent developments in Europe and North America. *Wood and Fiber Science*, *48*, 28–39.

Srinivas, K., & Pandey, K. K. (2012). Effect of heat treatment on color changes, dimensional stability, and mechanical properties of wood. *Journal of Wood Chemistry and Technology*, *32*(4), 304–316. DOI: 10.1080/02773813.2012.674170

Suri, I. F., Purusatama, B. D., Lee, S. H., Kim, N. H., Hidayat, W., Ma'ruf, S. D., & Febrianto, F. (2021a). Characteristic Features of the Oil-Heat Treated Woods from Tropical Fast Growing Wood Species. *Wood Research, 66*(3), 365–378. DOI: 10.37763/wr.1336-4561/66.3.365378

Suri, I. F., Kim, J. H., Purusatama, B. D., Yang, G. U., Prasetia, D., Lee, S. H., Hidayat, W., Febrianto, F., Park, B. H., & Kim, N. H. (2021b). Comparison of the Color and Weight Change in *Paulownia tomentosa* and *Pinus koraiensis* Wood Heat -treated in Hot Oil and Hot Air. *BioResources, 16*(3), 5574–5585. DOI: 10.15376/biores.16.3.5574-5585

Suri, I. F., Purusatama, B. D., Kim, J. H., Yang, G. U., Prasetia, D., Kwon, G. J., Hidayat, W., Lee, S. H., Febrianto, F., & Kim, N. H. (2022). Comparison of physical and mechanical properties of Paulownia tomentosa and Pinus koraiensis wood heat-treated in oil and air. *European Journal of Wood and Wood Products*, *80*(6), 1389 –1399. DOI: 10.1007/s00107-022-01840-4

Tang, T., Chen, X., Zhang, B., Liu, X., & Fei, B. (2019). Research on the Physico-Mechanical Properties of Moso Bamboo with Thermal Treatment in Tung Oil and Its Influencing Factors. *Materials*, *12*(4), 599. DOI: 10.3390/ma12040599

Tomak, E. D., Viitanen, H., Yildiz, U. C., & Hughes, M. (2011). The combined effects of boron and oil heat treatment on the properties of beech and Scots pine wood. Part 2 : Water absorption, compression strength, color changes, and decay

resistance. *Journal of Materials Science, **46***(3), 608-615. DOI: 10.1007/s10853-010-4860-2

Umar, I., Zaidon, A., Lee, S. H., & Halis, R. (2016). Oil-heat treatment of rubberwood for optimum changes in chemical constituents and decay resistance. *Journal of Tropical Forest Science*, *28*(1), 88–96.

Wang, J. Y., & Cooper, P. A. (2005). Effect of oil type, temperature and time on moisture properties of hot oil-treated wood. *Holz Als Roh - Und Werkstoff*, *63*(6), 417–422. DOI: 10.1007/s00107-005-0033-4

Yang, H., Yan, R., Chen, H., Lee, D. H., & Zheng, C. (2007). Characteristics of hemicellulose, cellulose and lignin pyrolysis. *Fuel*, *86*(12-13), 1781–1788. DOI: 10.1016/j.fuel.2006.12.013

Yunita, E., Riniarti, M., Hidayat, W., Niswati, A., Prasetia, H., Hasanudin, U., and Banuwa, I. S. (2022). Pengaruh Penambahan Enkapsul Biochar Tandan Kosong Kelapa Sawit terhadap Perkembangan Akar Sengon (*Falcataria moluccana*). *Gorontalo Journal of Forestry Research, 5*(1), 1–10. DOI: 10.32662/gjfr.v5i1.1787