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ORIGINAL RESEARCH

Coconut oil effect on the hygroscopic properties of Simalambuo wood *(Lophopetalum spp.)*

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Abstract. Simalambuo tree (*Lophopetalum spp*.) is endemic to Southeast Asia. The plant grows in natural forests in Nias, an island in North Sumatra. The purpose of this study was to modify simalambuo wood by using thermal treatment in coconut oil at ambient conditions. Thermal treatment is an environmentally friendly method requiring non-harmful materials to improve simalambuo wood. Simalambuo wood was treated with coconut oil at 130-210^{o}C for 6 hours. Coconut oil absorption to simalambuo wood reached 174%. Leaching test (AWPA E-06 standard) showed that the wood samples after treatment did not absorb water easily. Coconut oil retention time varied according to different treatment temperature and cooling temperature. Coconut oil heat treatment affected water absorption and increased the dimensional stability of simalambuo wood. The longest water immersion time test, at 192 hours, reduced water absorption from 162% to 16% and improved dimensional stability from 8.4% to 4.2%.

Keywords: Heat modification, simalambuo wood, water absorption, oil absorption, coconut oil heat treatment, dimensional stability.

INTRODUCTION

The simalambuo tree is endemic to Southeast Asia. The plant thrives and is abundantly found in the natural forests in Nias, an island in North Sumatra, Indonesia, occupying around 143.221.80 ha of space. The locals also plant a lot of these trees. According to Lubis et al (2017) Simalambuo trees come from the same genus as *Lophopetalum javanicum* and *Lophopetalum beccarianum Pierre*, which have high economic value and become the main source of timber throughout the island. However, the basic characteristics of simalambuo wood have not been fully explored.

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The trees are fast-growing, where the trunks of medium to large trees will have up to 1 meter diameter and up to 35 meters height. The trees have bright and vibrant colors. Their appearances resemble *Evodia latifolia DC* and *Albizia Chinensis* trees. Preliminary studies showed that the wood of simalambuo has a density between 0.30-0.69 g/cm^3. The locals recognize this wood to easily absorb water.

Water absorption plays a major role in the mechanical strength of wood. When wood absorbs water, its volume expands. On the other hand, when the wood releases water, the volume decreases. This is known as the shrinkage of wood, which causes the wood to bend or break on its own. There has not been much research on the modification of simalambuo wood to reduce water absorption and increase its dimensional stability.

There are many modification methods available allowing water absorption reduction and dimensional stability increase in woods. One of them is thermal modification. This modification is advantageous because the steps are simple and harmless to the environment without the requirement of chemicals [1][2][3]. The basic principle is to use heat to break down the hydroxyl groups in wood and reduce its hydrophilic properties. Among the main components that make up the structure of wood, the hydroxyl groups in hemicellulose, cellulose and lignin are the most accessible to water. The content of hydroxyl groups in hemicellulose is higher than in cellulose, and lignin has the least hydroxyl groups [4]. Hemicellulose is known to react first when wood is exposed to heat [5][6][7]. Pure hemicellulose reacts at 90ºC. Then, exothermic reactions begin to occur at 200ºC – leading to the carbonization process when the polymers start to degrade [8][9]. Water absorption in wood will decrease with the destruction of the OH groups in the hemicellulose, hence increase in the dimensional stability of wood. The degradation of hemicellulose increases the crystallinity of wood, and accompanied by the degradation or reorientation of amorphous cellulose contents [5][10][11]. A proportional increase in the crystallinity of cellulose is also understood to reduce the hygroscopicity of the wood as water will be less accessible in the crystal areas.

In addition, thermal modification is able to facilitate oil impregnation. The provision of ambient oil in wood is intended to better control oxidation. Oil is a good heating medium that easily and evenly transfers heat into wood (Lee at al., 2018). The oil also contributes to the final character of wood products. The higher the oil absorbed, the better the quality of wood becomes. Oil absorption is determined by various things such as the type of oil itself, temperature, type of wood and method of execution.

Modification of simalambuo wood by using coconut oil heat treatment aims to increase dimensional stability and reduce water absorption. Simalambuo wood and coconut oil are abundant in Nias – thus supporting the use of local materials. The approach to increase the uptake of coconut oil in simalambuo wood was carried out by immersing the treated samples at various temperatures as soon as possible in oil at room temperature. It aims to take advantage of the larger temperature difference between the treatment and cooling steps to enable oil extraction within a short duration. The coconut oil uptake and how it was retained in the wood pores at different temperature treatments were compared, and the wood-water interaction of each sample was evaluated.

METHODOLOGY

Data analysis

Statistical analysis was performed using one-way ANOVA (analysis of variance).

Ingredient

Simalambuo wood as the sample in this study was obtained from Nias (LU 1°23'27.661", E 97°9'47,206"). The first four meters from the base of the trunk were cut to 20 mm (W) × 20 mm (R) × 20 mm (H) following the China National Standard GBT 1934.1-2009 for water absorption and dimensional stability tests of wood.

To avoid cracking, the samples were dried at 60, 70, 80, 90ºC for 3 hours each, followed by drying at 102ºC for 6 hours in order to reach constant weight. The dimensions of the wood were measured longitudinally (1_o), tangentially (t_o), and radially (r_o). The initial volume (V_o) and weight (m_o) were calculated and the density of wood was 0.4367 g/cm^3.

There were seven pieces of wood samples prepared for different temperature in the thermal treatment. All samples were free from visible damage, knots, fungal infections, stains, and mildew.

Commercial coconut oil used in the thermal modification was purchased from the local market.

Heat treatment and oil impregnation

First, the wood sample was placed in a 500 mL glass bowl and immersed completely in coconut oil (3 cm below the oil). Then the bowl, without any cover, was placed in a proportional-integral-derivative (PID) controlled oven adjusted to 130ºC for 6 hours. In order to prolong oil absorption, the sample was immediately immersed into a new batch of coconut oil at room temperature (24ºC) for 30 minutes. After that, the sample was removed from the oil and each side of the wood surface was covered with tissue paper for 10 minutes. The sample dimensions (l1, r1, t1) and weight (m1) were measured, and the wood sample was stored in a desiccator. This sample was labelled as S130.

The same steps were repeated for different treatment temperature, such as at 150ºC, 170ºC, 190ºC and 210ºC. These different samples were labeled as S150, S170, S190, and S210 respectively.

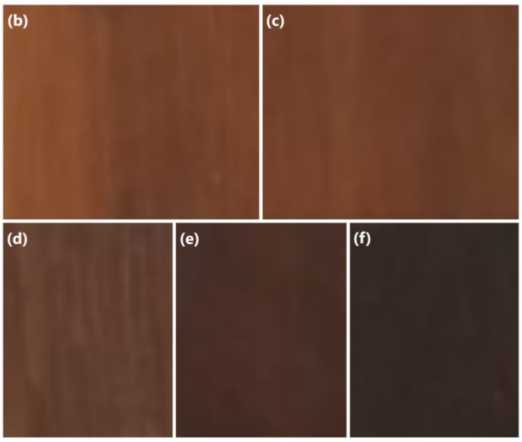

Figure 1. Samples were heated at different temperature 130°C (b), 150°C (c), 170°C (d), 190°C (e) and 210°C (f).

Weight and volume change

Oil penetration was measured from the increase in the weight of the wood sample (weight percentage increase, WPG). Calculation was based on the difference in mass; before (m_o) and after (m_1) treatment (Equation 1). The change in volume, known as the bulking coefficient (BC), is measured from the difference in volume before (V_o) and after (V_1) treatment (Equation 2). The weight and volume changes in each sample were measured.

$$WPG = \frac{m_1 - m_0}{m_0} x100(\%) \quad (1)$$

$$BC = \frac{v_1 - v_0}{v_0} x100(\%) \quad (2)$$

Coconut oil wash test

The leaching test was carried out following the AWPA E-06 standard. First, the sample was immersed in water 5 cm below the surface of the water for 192 hours, where every 6, 24, 48, 96, 144, and 192 hours, the water was replaced with a new batch. Next, the samples were dried at 60, 70, 80, 90ºC for 3 hours each temperature, followed by final drying at 102ºC for 6 hours to achieve constant weight. The final weight was measured. Coconut oil retention after leaching test was measured from the difference in weight after treatment (m_1) and after leaching test (m_2). The oil retention in this study shows how much oil was left in the sample after the leaching test (Equation 3). The oil retention of each sample was measured.

$$Retention = \frac{m_1 - m_2}{m_1} x100(\%) \quad (3)$$

Water absorption and swelling

Wood samples water absorption and expansion parameters were measured following the Chinese National Standard GBT 1934.1-2009. First, the sample was immersed in distilled water at room temperature, where the weight and dimensions were measured every 24, 48, 96, 144, and 192 hours (m_1). Water absorption (WA) was calculated by comparing the difference in weight between each measurement interval (m_1) and after treatment (m1) (Equation 4). Volumetric swelling (S) was calculated from the difference in volume between each measurement interval (vi) and after treatment (v1) (Equation 5). Water absorption and swelling were measured for all samples, including untreated wood sample. WA and S values obtained in percentage for all samples were averaged and presented together with standard deviation.

$$WA = \frac{m_i - m_1}{m_1} x100(\%) \quad (4)$$

$$S = \frac{v_i - v_1}{v_1} x100(\%) \quad (5)$$

Instrumental characterization

Morphological changes of wood samples treated with coconut oil were observed using SEM TM3000 (Hitachi) under vacuum with an acceleration of 15kV and a magnification of 2000x.

RESULTS AND DISCUSSION

Weight and volume change

The amount of oil absorbed was indicated by the increase in the weight of the wood sample after treatment. Table 1 shows the changes in the weight and volume after coconut oil heat treatment at different temperature. WPG increased more than twice the initial weight at all treatment temperature. The great increase in weight was thought to be the result of sample immersion into a batch of fresh oil at room temperature right after the heat treatment – causing coconut oil to be impregnated into the wood sample. This finding was similar to the impregnation of soybean oil into ponderosa pine wood reported by Awoyemi, et al (2009) and impregnation of tung oil into radiata pine wood carried out by Ahmad et al. (2017). According to Dubey, et al. al (2012), the cooling step reduced the pore pressure of the wood and created a vacuum-like condition that absorbed oil deep into the wood pores. Dubey, et al. al (2012) used radiata pine wood and allowed the wood samples and linseed oil to cool from 210ºC to 55ºC. This procedure was similar to the study conducted by Awoyemi, et al. (2009), where cooling at 135°C showed higher soybean oil absorption than cooling at 180°C from 220°C heat treatment.

Table 1. Changes in weight and volume, and retention of coconut oil.

Sample	WPG (%)	BC (%)
S130	174.84 (19.7)	5.49 (0.26)
S150	147.95 (5.23)	4.46 (0.35)
S170	124.00 (6.31)	-1.24 (2.09)
S190	125.65 (12.48)	-1.91 (1.03)
S210	143.66 (26.96)	-0.63 (0.38)

Higher oil absorption was expected with higher difference of temperatures between treatment and cooling. However, it was interesting that WPG would not go higher with higher temperature treatment. The highest WPG was observed at S130, then WPG decreased significantly (p=0.00) at S150 and S170 samples. But, it rose again in S190 and S210 samples. This finding was most likely influenced by the changes in the volume of wood due to the treatment. The volumes of S130 and S150 increased after coconut oil heat treatment, a different phenomenon from the heat treatment of the air environment where the volume decreased and was more severe at high temperature treatment.

This phenomenon was different from heat treatment under ambient conditions with air or water. Generally the sample volume is smaller before treatment, [15][16][17][18][2][19]. The increase in the volume of S130 and S150 might be due to the expansion of cell wall in the temperature range between heat treatment and cooling treatment. The cell wall was not significantly damaged. As a result, the pore volume increased and allowed for higher oil absorption. This explains the higher WPG at S130 and S150 than in other samples with higher temperature. At higher temperature, more polysaccharides were broken down (Figure 2) and the volume shrinkage became more pronounced. In the S170-S210 range, greater temperature difference occurred and increased oil absorption – allowing higher oil uptake. The significant temperature difference caused a greater vacuum effect to absorb more oil into the pores, resulting in higher WPG.

Coconut oil retention

High retention value of coconut oil impregnation in the wood samples greatly affected the ability to repel water from wood, [12]. The presence of oil in wood has been reported to improve the mechanical properties of wood [20] and allow greater resistance to termites [21][22]. This is because the cell walls become thicker, because the oil is trapped longer in the wood cells so a higher amount of oil has been absorbed.

Figure 3 shows that coconut oil in the wood, twice the sample weight, could retain in the samples even after 192 hours of water immersion. Oil retention (Figure 3), if observed, followed the WPG value with a smaller gap with increasing temperature – meaning the leaching effect diminishes. This confirmed that oil absorption has penetrated deeper into the forest with a larger vacuum effect generated by the higher difference between the treatment and cooling temperature.

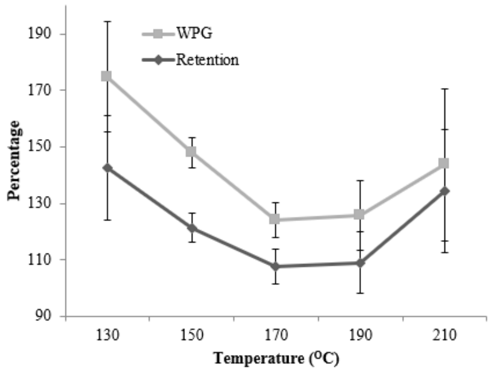

Figure 3. Relationship between WPG and coconut oil retention after leaching.

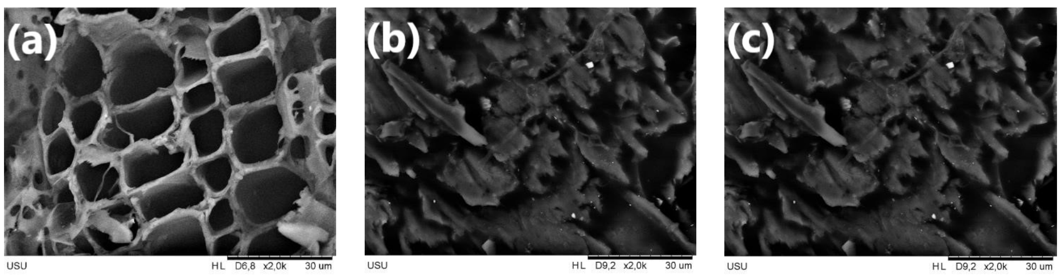

Figure 2. Transverse SEM image of (a) untreated sample, (b) 130°C and (c) 210°C.

Another thing that could reduce the effect of leaching is the shrinking of the wood pores after exposure to cold, causing coconut oil to be tightly trapped in the pores. The increase in WPG in samples S190 and S210 together with volume shrinkage could be understood by this phenomenon.

Water absorption and volumetric swelling

Figure 4 shows water absorption by simalambuo wood treated with heat and coconut oil. Without the treatment, the wood samples absorbed 52% of water after 6 hours and 162% after 192 hours of immersion in water. This data shows how easily simalambuo wood attracts water, as local residents with experience using simalambuo have claimed. Coconut oil heat treatment in iimalambuo wood reduced water absorption drastically. Sample S130 only absorbs 3% water in the first 6 hours of immersion and 16% after 192 hours. Temperature treatment significantly affected water absorption (p=0.00). Lower water absorption was observed with the increase in temperature. The decrease in WA was more pronounced at 130 - 190ºC temperature range. However, at 210ºC the decrease in WA was no longer drastic (p=0.48).

The effect of coconut oil heat treatment on the swelling of simalambuo wood is presented in Figure 3. Untreated simalambuo wood swelled 7.2% in the first 6 hours and 8.4% after 192 hours. However, after coconut oil heat treatment at 130ºC, the swelling became 1.6% in the first 6 hours and 4.2% at 192 hours. Swelling attenuation was observed to be better with the increase in treatment temperature. Looking at the trend, the expansion of the untreated simalambuo wood in the first 6 hours took place much faster than the treated samples. The saturated expansion of the treated samples occurred more rapidly at higher temperature treatment as shown by the slope in the graph (Figure 4).

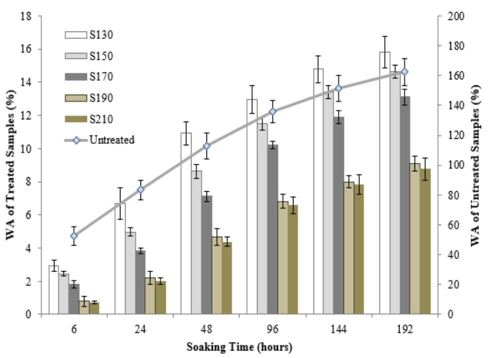

Figure 4. Water absorption capacity of simalambuo wood treated with coconut oil.

In general, the decrease in WA was strongly correlated with the increase in WPG (Figure 5). However, sample S130 had the highest WPG but absorbed the most water. On the contrary, lower WPG values in S150 with higher temperature treatment absorbed less water. It seems that the volume shrinks oil intensively in blocking the wood pores and provides very little free space for water.

In the case of swelling, the increase in dimensional stability by coconut oil occurs indirectly. Coconut oil was most likely unable to bind to cell walls. The presence of oil has prevented access of hydroxyl from water – which directly affected the dimensional stability of the wood. In addition, the decrease in hemicellulose content due to heat exposure to wood has reduced the hydroxyl functional groups and therefore decreased the total water bound to the cell wall [5][6][7]. Another possibility is that the hydrophobic nature of the oil inhibits the diffusion of water into the wood and provides better effects on WA and swelling.

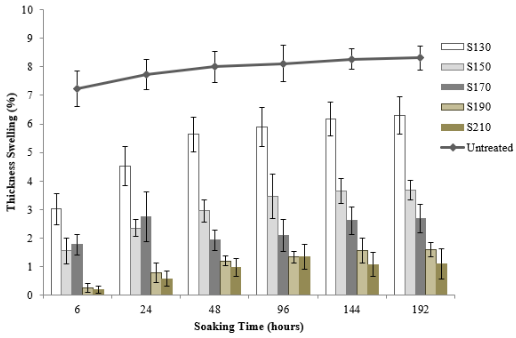

Figure 5. Dimensional stability of simalambuo wood treated with coconut oil.

CONCLUSION

There was a high uptake of oil in Simalambuo wood, double the sample weight. The oil held well in the wood sample after washing. Coconut oil heat treatment affected the water absorption ability and increased dimensional stability.

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