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Elevating Timber Sustainability: Exploring Non-Chemical Wood Modification via Air Heat Treatment for Diverse Applications

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ABSTRACT

Anthocephalus cadamba wood exhibits considerable potential as a fast-growing wood species that can effectively address the issue of diminishing wood resources derived from natural forests. Nevertheless, it is important to note that wood derived from fast-growing species has substandard features compared to wood obtained from natural forests. So, it becomes imperative to enhance the quality of such wood by implementing heat treatment techniques. In addition, heat treatment of the wood is performed with a temperature in the range of 160-260°C, and the processing time is relatively short. Therefore, the purpose of this research was to evaluate the impact of air heat treatment on the dimensional stability, strength, and hardness of *Anthocephalus cadamba* wood. For 4 hours, *Anthocephalus cadamba* wood was heated to 170, 190, and 210°C. The CIE-Lab color system was used to analyze the wood's color transformation following treatment. Moisture content, density, weight changes, volume shrinkage, hardness, and compressive strength were also measured before and after treatment. Overall, color shift (E^*) was shown to be mitigated by higher treatment temperatures. The extractive ingredients in *Anthocephalus cadamba* wood discolored slightly at 170 but entirely at 190 and 210°C. Weight loss, volume shrinkage, density, and moisture content were also seen in heat-treated *Anthocephalus cadamba* wood. Polymer breakdown and water uptake by cell walls could be to blame. The dimensional stability of *Anthocephalus cadamba* wood was reduced along with its hydrophobicity. Wood's compressive strength decreases as hemicellulose is degraded during heat treatment and at higher temperatures. Reduced hardness is caused by high treatment temperatures and weight loss that weakens wood. As described, the color and dimensional stability of the heat-treated samples indicated as the effective parameters to improve in this present study. As air heat treatment temperatures rise owing to chemical compound degradation in *Anthocephalus cadamba* wood, its physical and mechanical qualities can change. In conclusion, this study showed the feasibility of heat treatment on *Anthocephalus cadamba* wood to improve the color dan dimensional stability.

1. INTRODUCTION

The main indicators of global warming include increasing average air and ocean temperatures, widespread melting of ice and snow, and rising average sea levels throughout the world [1, 2]. One of the most serious problems causing global warming is deforestation [1-3]. This tendency really needs to be avoided considering the important function of natural forests. Natural forests themselves can be an effective place to store carbon, which is also supported by their high biodiversity. Therefore, if the deforestation of natural forests is reduced, it can be a way to mitigate the global warming.

In Indonesia, recently, the plantations forests contribute to the wood supply of country and world. Plantation forests provide 85% of the wood supply in Indonesia [4-6]. It can be a hope in replacing the need for wood from natural forests. Currently, the management of plantation forests in Indonesia is one of the most important breakthroughs as a supplier of wood for industry and households in the world [7, 8]. The area of plantation forests in Indonesia until 2019 has reached around 5.1 million ha, and one of the major operations is the pulp plantation forest [6]. Currently, plantation forests develop many types of plants. Fast-growing species are plants widely developed in plantation forests [6, 9-11]. Fast-growing plant species, including sengon (*Falcataria molucana*), binuang (*Octomeles sumatrana*), acacia (*Acacia penninervis*), and jabon (*Anthocephalus cadamba*) [11-13].

Fast-growing tree species and plantations have recently been considered to be crucial components of the broader policies meant to mitigate climate change, supporting the gradual transition from an economy based on fossil fuels to one based on biofuels [14]. Therefore, the fast-growing wood species are very promising to be developed as a substitute for natural wood which is currently decreasing.

Anthocephalus cadamba is one of the native Indonesian tree species that is suitable as a basis for plantation forests. It could be caused by *Anthocephalus cadamba* wood species having the potential to be developed and meet industrial needs [15]. However, *Anthocephalus cadamba* trees are included in the category of fast-growing wood species [16]. The characteristics of fast-growing wood are usually low specific gravity and can have an impact on the dimensional stability of wood [17-20].

In order to anticipate these deficiencies, it is necessary to modify those inferior qualities of jabon wood. Wood modification is a condition in which the condition of the wood changes permanently [21-23]. Wood modification includes chemical, biological, and physical treatment to improve a material [21, 22]. There are several types of wood modification, namely chemical, surface, impregnation, and heat modification [21, 22, 24]. Wood modification is done to minimize damage to the wood without using any toxic chemicals. The heat treatment of the wood is carried out with a temperature in the range of 160-260°C, and the processing time is relatively short [25].

Heat treatment can also increase the hydrophobic properties of wood and the color of the wood can become darker [26, 27]. There are several types of heat treatment methods for wood, namely heat treatment with air (Air Heat Treatment), steam (Thermowood Treatment), and a combination of air and steam (Plato Wood Treatment), and heat treatment using oil [22].

Heat treatment can increase the dimensional stability of wood after being treated compared to wood that has not been treated [28]. Hidayat et al. [23] reported that the color change parameters of Korean pine and paulownia woods, including the lightness (L^*) decreased and total color change (ΔE^*) increased after air heat-treated at several temperatures for 2 h. *Pinus radiata* wood that has been heat treated showed significant improvements in dimensional stability and a reduction in Modulus of Rupture (MOR) [29]. Additionally, Boruvka et al. [30] observed an increase in the hardness of several surfaces of European birch wood following heat treatment at temperatures of 165 and 210°C. Suri et al. [24] reported that air heat treatment decreased the density and volume shrinkage of paulownia and Korean white pine woods.

Numerous investigations into the heat treatment of fast-growing wood have been conducted; the findings indicate that this process has an impact on modifications in the dimensional stability of a number of fast-growing woods [23, 28, 31, 32]. When Karlinasari et al. [31] applied heat treatment to the physical characteristics of sengon, jabon, and mangium woods, the wood's color changed and its hardness dropped, which had a noticeable impact. Physical characteristics, such as specific gravity and water absorption, have been shown by Priadi et al. [32] to enhance the dimensional stability of heat-treated *Neolamarckia cadamba, Falcataria moluccana*, and *Acacia mangium* woods. Rubberwood and silver oak woods were also subjected to heat treatment modification by Srivinas and Pandey [33]. They noticed that the heat treatment caused the wood to darken in color, reduced the mechanical qualities of the wood, including bending stiffness, MOR, MOE, and bending strength, and enhanced the dimensional stability of the heat-treated wood.

In order to better understand the impact of heat treatment temperatures of 170, 190, and 210°C on the mechanical and physical characteristics of *Anthocephalus cadamba* wood both before and after treatment, this study was designed to supplement earlier research.

2. MATERIALS AND METHODS

2.1 Materials

Anthocephalus cadamba wood harvested from community woods in Tanjung Bintang, South Lampung Regency, Lampung Province, Indonesia, was aged four to five years. Boards measuring 30 cm (L), 10 cm (W), and 2 cm (T) were cut using a saw. The boards were devoid of knots and had straight grain. After that, the selected boards were left to air dry at 26 ± 5°C and 60−70% relative humidity (RH) until the moisture content (MC) reached equilibrium.

2.2 Heat treatment

The heat treatment process with air was carried out in an oven (BJPX–Summer, PT. Innotech System, Jakarta, Indonesia) at various temperatures, namely 170, 190, and 210°C, for 4 h at a heating rate of 2°C/min. Upon completion of the heat treatment, the chamber was allowed to cool to room temperature naturally. The wood samples underwent heat treatment, followed by oven drying at 100 ± 5°C. They were then drained at 27.5 ± 3°C and maintained at 60 ± 5% relative humidity for a week, prior to additional testing.

2.3 Evaluation of the heat-treated wood samples

2.3.1 Color change

To calculate the change of color of the control and treated samples, the CIE $L^*a^*b^*$ system was deployed. Three components make up this system: the parameters L^* (lightness), a^* (red/green chromaticity), and b^* (yellow/blue chromaticity) were used in this instance. In order to conduct the experiment, AMT507, Amtast, China, a chromameter, was used to take three measurements at different places on the radial surface of each untreated and heat-treated specimen. It was determined using the following formula to get the total color change.

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

where, ΔL^*, Δa^*, Δb^*, and ΔE^*, respectively, indicate the shift in lightness, chromaticity of red/green and yellow/blue, and overall color. After the color evaluation, the untreated and heat-treated samples were classified to the total color change, as presented in Table 1.

Table 1. Classification of the total color change

No.	Classification Value	Description
1	$0 < \Delta E^* \leq 0.5$	Changes can be ignored
2	$0.5 < \Delta E^* \leq 1.5$	Slight color change
3	$1.5 < \Delta E^* \leq 3$	Real color change
4	$3 < \Delta E^* \leq 6$	Major color change
5	$6 < \Delta E^* \leq 12$	Color change is very large
6	$\Delta E^* > 12$	Complete color change

2.3.2 Physical characteristics evaluation

In order to calculate the percentage of weight lost heat-treated and untreated wood samples, the following formula was utilized:

$$WC\ (\%) = \frac{m_1 - m_0}{m_0} \times 100\% \quad (2)$$

where, m_0 represents the weight of samples prior to heat treatment (g), and m_1 represents the weight of samples following heat treatment (g).

Using the following equation, the volume shrinkage for both heat-treated and untreated samples was estimated:

$$VC\ (\%) = \frac{V_0 - V_1}{V_0} \times 100\% \quad (3)$$

where, V_0 represents the volume of wood samples prior to heat treatment (mm) and V_1 represents the volume of wood samples following heat treatment (mm).

The density (D) of untreated and heat-treated samples was calculated using the following equation.

$$D\ (g/cm^3) = \frac{m}{v} \quad (4)$$

where, m represents the weight of untreated and heat-treated wood samples (g), and v represents the volume of untreated and heat-treated samples (cm^3).

The moisture content of the wood samples was determined by measuring the air-dry weight and oven-dry weight before and after the heat treatment, employing the provided equation.

$$MC\ (\%) = \frac{M_1 - M_0}{M_0} \times 100\% \quad (5)$$

where, M_0 represents the first mass (g), and M_1 represents the ultimate mass (g).

2.3.3 Mechanical properties evaluation

The axial compressive strength of both untreated and heat-treated samples was determined using the following formula, which was developed in accordance with Korean Standard Association, KS F 2206 [34]:

$$P\ (N/mm^2) = \frac{F}{A} \quad (6)$$

where, F represents the maximum load (N), A represents the surface area of the compression (mm^2), and P represents the wood compressive strength (N/mm^2).

There was a comparison of the maximum hardness value between untreated and heat-treated wood with reference to KS F 2212 [35], on a sample size of 40 mm × 40 mm × 20 mm using half of a steel ball. In this test, compression on a ball that is 11.7 mm in diameter was utilized.

2.4 X-ray diffractograms analysis

Measurements were made of the crystalline characteristics of both heat-treated and untreated wood samples, including relative crystallinity index (RC) and crystallite width (CrW), using specimens that were roughly 1 mm in diameter radially, 15 mm in tangential direction, and 15 mm in longitudinal direction. An X-ray diffractometer (DMAX2100V; Rigaku, Tokyo, Japan) fitted with a Cu target ($\lambda = 0.1542$ nm) was used to measure the crystallographic characteristics. For every treatment, three samples were used to complete the measurement. The RC was calculated using Segal's equation [36, 37], as shown in the following equation.

$$RC = \frac{I_{200} - I_{am}}{I_{200}} \times 100\% \quad (7)$$

where, I_{200} is the peak intensity of the crystalline substance at 2θ (22.8°) and I_{am} refers to the amorphous substances at 2θ (18°).

The CrW was calculated using the Scherrer's equation [36, 37], as presented in the following equation.

$$CrW\ (nm) = \frac{K.\lambda}{\beta.cos\theta} \quad (8)$$

where, "K" refers to Scherrer's constant (0.9), "λ" is the wavelength of the X-ray λ = 0.1542nm, and β belongs to half-width in radians.

2.5 Data analysis

The statistical software SPSS version 24 (SPSS Inc., Chicago, IL, USA) was utilized to conduct univariate analysis of variance and Duncan's multiple range tests. These tests were employed to evaluate the presence of statistically significant variations in the mean values of moisture content, density, weight loss, volume shrinkage, hardness, and compressive strength, relative crystallinity, and crystallite width across different treatment temperatures.

3. RESULTS AND DISCUSSION

3.1 Color change

Color is one of the physical properties of wood that can be seen with an eye the changes and differences after being given AHT treatment. The color change that occurs is presented in Figure 1. The wood before heat treatment is bright (yellowish white) and turns darker as the temperature is increased. The main effect of heat treatment is increased darkening of wood when the treatment temperature exceeds about 200℃, accompanied by degradation of lignin due to heat treatment [38, 39].

Figure 1. The appearance of untreated and heat-treated *Anthocephalus cadamba* wood at various temperatures

The CIE-Lab* system produces color measurements, namely changes in brightness (L^*), red/green chromaticity (a^*), and yellow/blue chromaticity (b^*) values after heat treatment. L* has a value range of 0 to 100, where the smaller the value obtained, the darker the color obtained. The most obvious change after heat treatment is a decrease in the L^* value or a darker wood color [38, 40].

Anthocephalus cadamba wood boards experience a decrease in L^* values (Figure 2). Wood samples treated with AHT at 210°C for 4 hours showed a darker color change than samples at 170°C and 190°C. This supports Hill [22] that wood color changes are affected by temperature and treatment time.

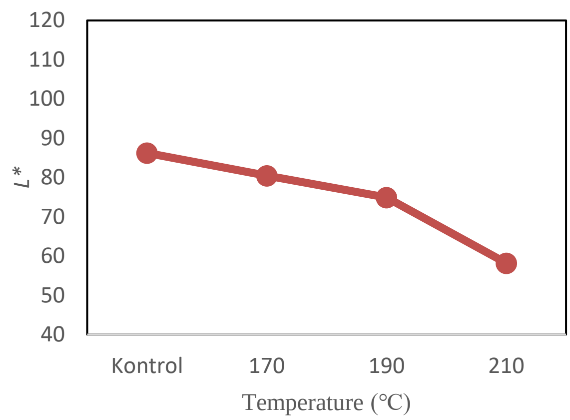

Figure 2. Change in lightness (L^*) of utreated and heat-treated *Anthocephalus cadamba* wood

Sivrikaya et al. [38] stated that the longer the heat treatment is carried out on the wood, the lower the L^* value in the wood, which means the darker the color of the wood. Based on research by Sandoval-Tores et al. [41], the decrease in L^* is caused by a decrease in hemicellulose, especially pentosan, where the extractive substance is present in each wood species to form a certain color in the form of two chromatic parameters, namely a^* and b^*.

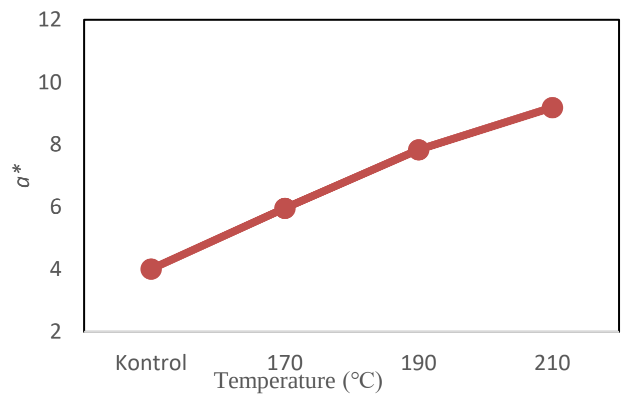

Figure 3. Change in red/green chromaticity (a^*) of untreated and heat-treated *Anthocephalus cadamba* wood

As shown in Figure 3, changes in red/green chromatization (a^*) in *Anthocephalus cadamba* wood experienced an increase compared to before being treated with AHT. There was an increase in the value of a^* sequentially in line with increasing temperature in the treatment. The results of research on *Anthocephalus cadamba* wood on a^* values showed positive results. Positive values lead to the color change produced after the AHT process, which tends to be more reddish and negative values lead to a more greenish color change.

Changes in chromatization of yellow/blue (b^*) in *Anthocephalus cadamba* wood after being treated with water heat treatment increased at 190°C and decreased at 210°C (Figure 4). The results of research on jabon wood on b^* values showed positive results. Positive values lead to a color change that results after being given AHT treatment which tends to be more yellowish and negative values lead to a more bluish color change.

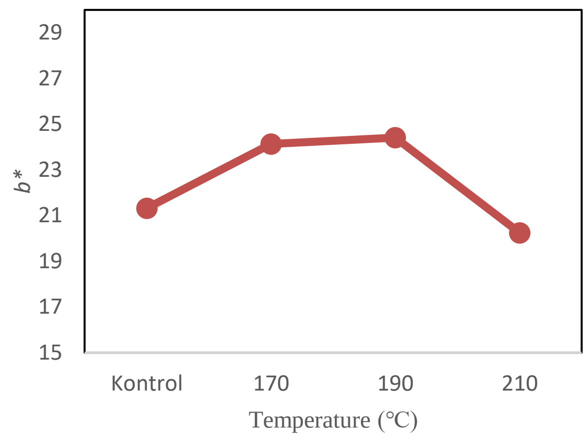

Figure 4. Change in yellow/blue chromaticity (b^*) of untreated and heat-treated *Anthocephalus cadamba* wood

Total discoloration (ΔE^*) of *Anthocephalus cadamba* wood after being treated with water heat treatment (Table 1). The ΔE^* value obtained at 170°C yields $6 < \Delta E^* \leq 12$, while for ΔE^* at 190°C and 210°C for 4 h the result is that the value of $\Delta E^* > 12$ means the color changes completely. At 170°C, a slight change in color occurs because only extractive substances in the wood are degraded during heat treatment [42]. There was an increase in color change at 190°C and 210°C. Changes in the value of ΔE^* aligned with increasing treatment temperature (Table 2).

Table 2. Overall color change (ΔE^*) of *Anthocephalus cadamba* wood after heat treatment

Wood Species	Temp. (°C)	Color Change Parameter			
		L^*	a^*	b^*	ΔE^*
Anthocephalus cadamba	170	80.48 (1.51)	5.96 (0.58)	24.13 (0.77)	6.35 (0.68)
	190	74.96 (1.52)	7.83 (0.72)	24.41 (0.93)	16.70 (1.60)
	210	58.23 (3.36)	9.19 (0.59)	20.25 (1.91)	28.90 (4.93)

*The standard deviation is indicated by the values in parenthesis.

Hidayat et al. [43] reported that the increase in temperature that occurs when the temperature is >170°C is the time when the total color change occurs. The total color discoloration (ΔE^*) increases with increasing temperature with higher degrees [38-40]. According to Sandoval-Torres [41], color is a component of visual perception and one of the key elements influencing consumers' decisions about wood products. Changes that can be seen visually or visually are in the form of darkening of the color of *Anthocephalus cadamba* wood after being treated with water heat treatment when compared to the color of *Anthocephalus cadamba* wood which was not given heat treatment [23].

3.2 Weight loss and volume shrinkage

Weight changes that occur according to Sundqvist et al. [44]

namely when hemicellulose indicated a major shift in its components of the chemical when treated at >170℃ for 4 hours, which resulted in a significant reduction in wood weight. Changes in weight will also have an impact on the specific gravity of the wood itself [45]. According to Poncsak et al. [46] reported that there was a loss of weight at high treatment temperatures (170 - 230℃).

As the treatment's temperature was raised, the weight change that took place in *Anthocephalus cadamba* wood decreased (Figure 5). Following consecutive AHT treatments, weight loss was the outcome. The last step of the heat treatment process, which involves the dehydration and breakdown of cell wall polymers into hemicellulose, cellulose, and lignin, is when the weight loss begins [47]. The weight loss that occurred in wood after heat treatment, as reported by Dubey et al. [28], was indicative of a change in the chemical makeup of the wood, namely a 70% reduction in hemicellulose content. Hidayat et al. [43] and Mburu et al. [48] stated that the hemicellulose degradation that takes place during the heat treatment procedure is the cause of the decrease in wood weight.

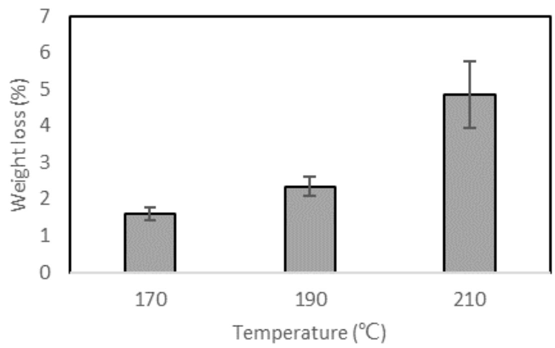

Figure 5. Weight loss of heat-treated *Anthocephalus cadamba* wood

The volume of wood that is given heat treatment will experience shrinkage, especially AHT heat treatment [24]. According to Uribe and Ayala [49], as treatment temperature increased, so did the volume shrinkage of thermally processed teak, pink poul, and chanul woods.

Volume shrinkage in *Anthocephalus cadamba* wood after being treated with AHT (Figure 6). The results obtained were that the most significant shrinkage occurred at 210℃. As to Hidayat et al. [50], following heat treatment at 210℃, each species' volume shrinkage often leads to a greater variation.

3.3 Density

In this work, the density values were measured under air dry conditions, also known as equilibrium moisture content (EMC), and oven dry. The *Anthocephalus cadamba* wood's density value decreased after heat treatment (Figure 7). At 190℃, the density value dropped, and at 210℃, it grew once again. The volume shrinkage that occurred during the AHT heat treatment was the cause of the density drop. Lee et al. [25] clarified that during heat treatment, a rise in temperature might impact the density of the wood by causing hemicellulose and extractive compounds to degrade. Polymer depolymerization in wood may be the cause of the density drop at higher temperatures [26].

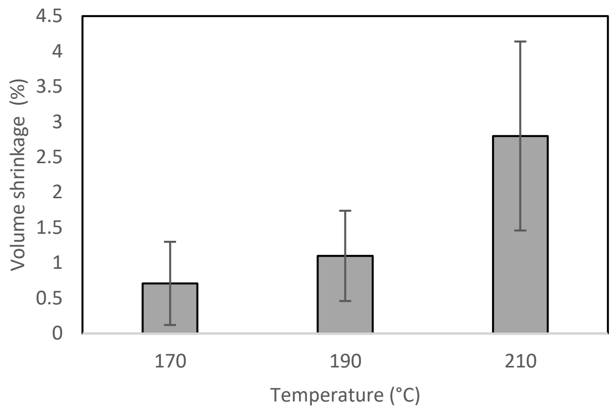

Figure 6. Volume shrinkage of heat-treated *Anthocephalus cadamba* wood

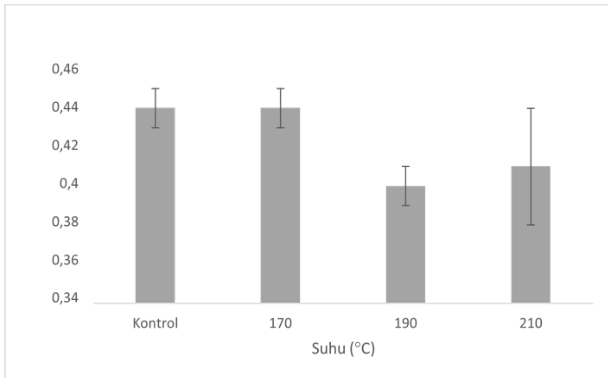

Figure 7. Density changes of control and heat-treated *Anthocephalus cadamba* wood

In addition, the reduction in wood density subsequent to heat treatment may also affect the material's strength and structural soundness [24]. Lower density can result in reduced load-bearing capacity even if it may also increase dimensional stability and decay resistance [25, 28, 43, 50]. So, when thinking about heat-treated wood for a certain application, it's important to weigh the advantages of lower density against any possible strength trade-offs. It is a fascinating field of study within the field of materials science and engineering as researchers and engineers constantly investigate and perfect heat treatment procedures to maximize the benefits of reduced wood density while guaranteeing the wood's acceptability for a variety of end purposes.

3.4 Moisture content

The moisture content of wood can be impacted by AHT heat treatment, according to several research. In comparison to the untreated sample, the AHT heat treatment can yield a higher reaction [50]. As the treatment temperature rose, the moisture content decreased, according to the study's findings (Figure 8). Boonstra et al. [51] clarified that the drop in moisture content in wood was brought about by less water being absorbed by the cell walls as a result of heat treatment, which altered the chemical composition of the wood by reducing the amount of hydroxyl groups. Heat-treated wood will degrade hemicellulose and have lower moisture content in the cell walls [26, 52].

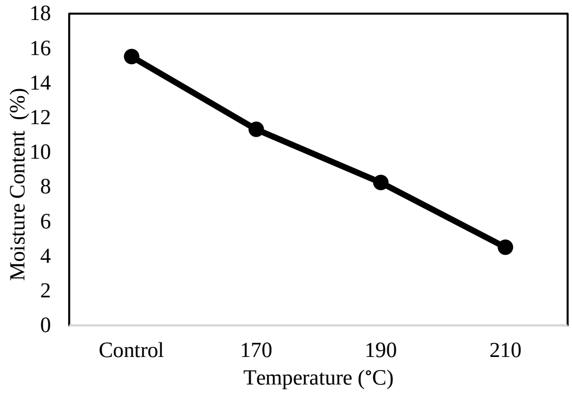

Figure 8. Moisture content of heat-treated *Anthocephalus cadamba* wood

A wood that has not been heated or treated as control has a moisture content of 15% EMC. After AHT treatment at 170℃, the moisture content of the wood decreased. In the meantime, when the treatment temperature rose, the amount of wood treated with AHT at 190℃ and 210℃ dramatically dropped. According to Hidayat et al. [26], low moisture content and the release of extractive chemicals are caused by higher heat treatment temperatures. At > 170℃, heat treatment evaporates extractive chemicals and changes the moisture content of the wood, among other things [26].

3.5 Dimensional stability

The heat treatment temperature of *Anthocephalus cadamba* wood resulted in an increase in its dimensional stability. According to Esteves and Pereira [21], heat treatment is a technique used to modify wood in order to improve the material's durability and dimensional stability. Wood's dimensional stability refers to its capacity to tolerate dimensional alterations brought about by variations in the water content [28]. Wood's dimensional stability is a crucial factor to take into account, particularly in areas with high humidity. When compared to untreated wood, wood that has undergone heat treatment helps stabilize its dimensions [46].

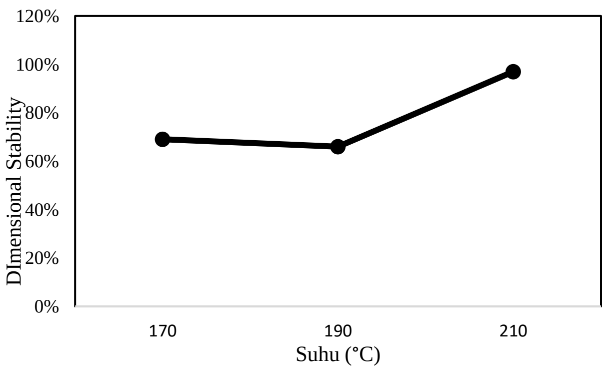

Figure 9. Dimensional stability of heat-treated *Anthocephalus cadamba* wood

Due to the inner cell wall contains OH (hydroxyl) groups and other oxygen that draws water vapor through hydrogen bonds, the dimensions of the wood will alter in tandem with changes in the water content in the cell wall [28]. According to studies conducted, dimensional stability following AHT heat treatment differs from water content and water absorption (Figure 9).

3.6 Mechanical properties

3.6.1 Compressive strength

Tankut et al. [53] stated that heat treatment of wood can have an impact on its mechanical qualities, but that impact can be reduced by varying the treatment or temperature. Figure 10 illustrates the impact of research findings, which show that compressive strength decreased as the temperature rose. The breakdown of hemicellulose, which is less heat stable than cellulose and lignin, is the primary cause of the strength loss. The cellulose chains' crystallization may increase or decrease depending on the heat treatment. Compressive strength increases are influenced by the density and crystallinity of the wood after heat treatment [54]. According to Esteves et al. [55], wood with a weight loss of about 3% and a fall in strength characteristics of less than 30% is acceptable. The study's findings suggest that heat treatment at temperatures between 170 and 210℃ may result in a reduction in compressive strength due to temperature fluctuations.

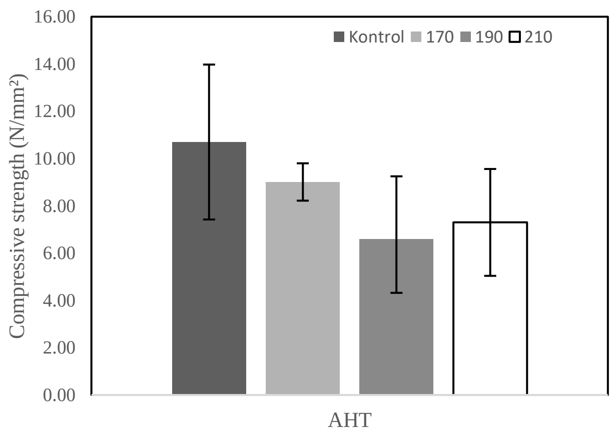

Figure 10. Compressive strength of untreated and heat-treated *Anthocephalus cadamba* wood

3.6.2 Hardness

Heat treatment is commonly employed on species with low value in order to enable their employment in more demanding conditions. The aforementioned factor has an impact on the characteristics of wood, particularly its hardness. Hardness is a crucial attribute of wood that holds significant relevance in the context of household appliances [56]. In this study, the hardness of heat-treated *Anthocephalus cadamba* wood decreased as the treatment temperature increased (Figure 11). The hardness of wood exhibits a reduction when exposed to more intense treatment methods involving elevated temperatures or extended curing durations [24, 45]. Similarly, Shi et al. [57] asserted that variations in hardness are contingent upon factors such as species, orientation, and treatment method. The reduction can be ascribed to the decrease in mass within the cellular wall [45].

Based on research that has been carried out to determine the hardness level of *Anthocephalus cadamba* wood after being given heat treatment (Figure 11), the result is a slight increase and then a decrease in the level of hardness as the temperature used increased. The hardness level of wood treated with a temperature of 170℃, there was a slight increase in the hardness level, and again decreased the hardness level at 190℃ and again decreased at 210℃. This is in line with the results obtained by Esteves et al. [56] regarding the hardness of processed wood which explains that the increase in hardness that occurs at the start of the heat treatment may be due to an increase in cross-linking in lignin. More so than the effect of lignin crosslinking, the higher temperature treatment causes a drop in hardness because of the huge weight loss that weakens the wood [24]. The first step in weight loss is the breakdown of hemicellulose, which is known to have a major impact on the characteristics of wood. Hemicellulose loss is particularly noticeable when wood is treated at higher temperatures.

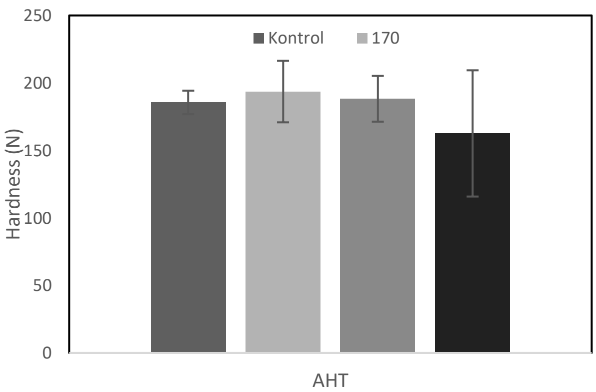

Figure 11. Hardness of untreated and heat-treated *Anthocephalus cadamba* wood

3.7 Crystalline properties

As seen in Table 3, the heat-treated woods' relative crystallinity of *Anthocephalus cadamba* wood was marginally greater than that of the untreated woods. One could argue that heat treatment led to an increase in relative crystallinity. Paulownia wood's relative crystallinity was found to increase under heat treatment, according to Kim et al. [58]. Additionally, Yun et al. [59] noted that as temperature rose, *Eucalyptus urophylla* and *E. camaldulensis'* relative crystallinity increased. According to Tang et al. [60], the breakdown of hemicelluloses and the realignment of cellulose are likely the causes of the rise in crystallinity.

Table 3. Crystalline properties of untreated and heat-treated *Anthocephalus cadamba* wood

Wood Species	Temperature (℃)	Relative Crystallinity (%)	Crystallite Width (nm)
Anthocephalus cadamba	Control	58.4 (1.7)	2.58 (0.12)
	170	59.3 (2.5)	2.73 (0.14)
	190	61.2 (2.0)	2.86 (0.13)
	210	68.7 (1.5)	3.11 (0.16)

Table 3 also shows that the heat-treated woods displayed a somewhat wider crystallite than the untreated one. It appears that following oil-heat treatment, the crystallite diameter may rise. Additionally, Kubojima et al. [61] noted that the heat-treated Sitka spruce appeared to have a longer crystallite. The same tendency was noted by Andersson et al. [62], who reported that the breakdown of the amorphous portion of wood after heat treatment caused changes in the porosity of the cell wall, which in turn caused an increase in the size of cellulose crystallites.

4. CONCLUSIONS

As the temperature used increases, it causes a total discoloration of the wood, high weight and volume shrinkage, decreases in density and moisture content as the treatment temperature increases due to the degradation of the chemical compounds present in the wood due to heat treatment, water absorption at 190℃ experienced the highest water absorption and increased dimensional stability after being given AHT treatment. The higher the temperature given, the lower the compressive strength and hardness of the wood. This occurs due to the degradation of hemicellulose which can increase the crystallinity of wood. The decrease that occurs due to heat treatment with high temperatures on wood increases at the beginning due to an increase in cross-links in lignin and due to a decrease in the weight of wood in large quantities. Therefore, based on several changes that occur in several parameters, especially in the color of the wood after heat treatment, it shows that this type of fast-growing wood is very promising to be developed as a substitute for natural wood, which is currently decreasing in quantity.

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