THE IMPROVEMENT OF JABON WOOD DENSITY THROUGH THE FURFURYL ALCOHOL AND NANO-SiO$_2$

Pengingkatan Kerapatan Kayu Jabon Melalui Impregnasi Furfuril Alkohol dan Nano-SiO$_2$

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ABSTRACT

Jabon (*Anthocephalus cadamba* Miq.) is a fast-growing wood that is widely utilized by the society as a construction material and furniture making. This study aimed to increase the density of jabon wood through a vacuum pressure impregnation method. Furfuryl alcohol (FA) and nano-SiO$_2$ with three concentrations (0.5%, 0.75%, dan 1%) were used as impregnation additives, with control and FA without nanoparticles as comparisons. Impregnation was initiated with a vacuum (0.5 bar) for an hour, followed by pressure (2.5 bar) for 2 hours. The significant results on the physical properties of jabon wood including weight percent gain (WPG), bulking effect (BE), and density showed the success of the modification treatment through the FA and nano-SiO$_2$ impregnation process with various concentrations, which the wood density increased from 0.60 g/cm^3 to 0.94 g/cm^3. The composition of FA and 1% nano-SiO$_2$ solution was the best treatment to obtain the highest density in modified jabon wood.

Keywords: furfuryl alcohol; impregnation; jabon; nano-SiO$_2$; physical properties.

ABSTRAK

Kayu jabon (*Anthocephalus cadamba* Miq.) merupakan kayu cepat tumbuh yang banyak diminati masyarakat untuk dimanfaatkan sebagai bahan konstruksi dan pembuatan furnitur. Penelitian ini bertujuan untuk meningkatkan kerapatan kayu jabon melalui metode impregnasi vakum tekan. Furfuril alkohol (FA) dan nano-SiO$_2$ dengan tiga konsentrasi (0.5%, 0.75%, dan 1%) digunakan sebagai bahan impregnan, dengan kontrol dan perlakuan FA tanpa nanopartikel sebagai pembanding. Impregnasi dimulai dengan pemberian vakum (0.5 bar) selama 1 jam, dilanjutkan dengan tekan (2.5 bar) selama 2 jam. Hasil yang signifikan pada sifat fisis kayu jabon yang meliputi weight percent gain (WPG), bulking effect (BE), dan kerapatan menunjukkan keberhasilan perlakuan modifikasi melalui proses impregnasi FA dan nano-SiO$_2$ dengan berbagai konsentrasi, yang mana kerapatan kayu meningkat dari 0.60 g/cm^3 menjadi 0.94 g/cm^3. Komposisi larutan FA dan nano-SiO$_2$ 1% menjadi perlakuan terbaik untuk mendapatkan nilai kerapatan tertinggi pada kayu jabon termodifikasi.

Kata kunci: furfuril alkohol; impregnasi; jabon; nano-SiO$_2$; sifat fisis.

A. INTRODUCTION

Jabon wood (*Anthocephalus cadamba* Miq.) is a fast-growing wood that is familiar to the public, especially in the wood processing industry as raw material for construction and furniture (Syafitri & Vauzia 2019). This wood has abundant availability and affordable prices, but this wood also has weaknesses such as low physical and mechanical properties of wood which cause this wood to easily absorb moisture, which has an impact on low resistance to attacks by wood destroying organisms (Lima *et al.* 2022). Thus, modification treatment is needed in this study to improve the quality of wood, especially on its physical and mechanical properties and wood resistance, so as to extend the service life of wood.

Wood modification is a treatment given to wood that aims to overcome various weaknesses of fast-growing wood (Sandberg *et al.* 2017). Previously, modification of fast-growing wood through impregnation process has been reported by Augustina *et al.* (2023), namely by applying impregnant chemicals, such as phenol formaldehyde, cyclic anhydride, and organic acids, to the wood cell wall and followed by a polymerization process and resulting in several superior properties, such as low dimensional stability, hardness, and resistance to attack by wood destroying organisms. The same method was also carried out by Martha *et al.* (2021) using furfuryl alcohol and was shown to improve the mechanical properties (MOE and MOR) and durability of wood against white weathering fungi (*Coriolus versicolor*) and brown weathering fungi (*Pycnoporus sanguineus* and *Coniophora puteana*). On the other hand, the impregnation process using nanoparticles is also being developed by several researchers (Moya *et al.* 2017; Rahayu *et al.* 2022; Wahyuningtyas *et al.* 2022) to add new properties to the treated fast-growing wood, such as magnetic properties, termite resistance, fire resistance, as well as color and dimension resistance to shrinkage growth caused by weather changes, so that wood can be comprehensively utilized in various fields.

The combination of furfuryl alcohol (FA) and nano-SiO_2 as an impregnant material is very attractive for use in engineering the properties of jabon wood. The combination of these two chemicals has been applied in the study of Rahayu *et al.* (2021) and proven to significantly improve the physical properties and anatomical and chemical characteristics of ganitri wood cell walls. Prihatini *et al.* (2023) also stated the vacuum-press method as the most effective method in increasing the percentage of weight gain in jabon wood. Therefore, this study aims to increase the density of jabon wood through vacuum-press impregnation at various concentrations of FA and nano-SiO_2 mixtures.

B. METHODS

Tools and Materials

The main material in this study is 6-year-old jabon wood (*Anthocephalus cadamba* Miq.) from community forests in Bogor Regency, West Java. This wood has a diameter at breast height of 35 cm and a tree height of about 20 m. The chemicals used include furfuryl alcohol (FA), nano-SiO_2 (diameter 15 ± 5 nm), maleic anhydride, disodium tetraborate, and distilled water. The equipment used were magnetic stirrer, sonicator, oven, digital calipers, and analytical balance.

Impregnation Process

Jabon wood was cut without distinguishing the sapwood and heartwood referring to British Standard (1957) (2 cm × 2 cm × 2 cm) as many as 15 pieces with each concentration using three replicates. Furfuryl alcohol was mixed with distilled water (v/v 1:1) and made in a volume of 500 mL, referring to Rahayu *et al.* (2021). Afterwards, three concentrations of nano-SiO_2 (0.5%, 0.75%, and 1%) were added to the FA solution, stirred using a magnetic stirrer and followed by ultrasonication for 30 min (40% amplitude) until a homogeneous solution was achieved. Before impregnation, the wood was baked at 103±2 ℃ until constant to remove the moisture content, then the wood was measured and weighed. The impregnation process began by immersing the jabon wood test sample in an impregnation tube with a vacuum of 0.5 bar for 1 hour and a press of 2.5 bar for 2 hours. Samples were removed from the impregnation tube and oven at 100 ℃ for 12 hours, followed by drying in an oven at 103±2 ℃ until constant weight, then weighed and measured.

Physical Properties Evaluation of Jabon Wood

The physical properties of jabon wood tested in this study include weight percent gain (WPG), bulking effect (BE), and density. The following is the formula used in this test, following Bowyer *et al.* (2007) and Hill (2006).

$$WPG\ (\%) = \frac{W_1 - W_0}{W_0} \times 100 \qquad (1)$$

$$BE\ (\%) = \frac{V_1 - V_0}{V_1} \times 100 \qquad (2)$$

$$\text{Kerapatan (g/cm}^3) = \frac{W_1}{V_1} \qquad (3)$$

where W_0 and W_1 are the mass of jabon wood before and after treatment, while V_0 and V_1 are the volume of wood before and after treatment.

Data Analysis

A completely randomized design (CRD) was used to evaluate the effect of impregnant materials on the density of jabon wood after the impregnation process. Analysis of variance was conducted through ANOVA followed by Duncan's test with 99% accuracy using IBM SPSS 25.0.

C. RESULTS AND DISCUSSION

Research on increasing the density of jabon wood through the impregnation process using furfuryl alcohol and nano-SiO_2 produced a significant effect. The impregnation treatment caused an increase in the weight percentage of jabon wood as indicated by the weight percent gain (WPG) value which increased with the addition of nano-SiO_2 concentration. The highest WPG value was achieved by 1% FS jabon wood and the lowest was obtained in FA jabon wood, with the control wood experiencing no change in wood weight. In the control jabon wood sample, there was no increase in wood weight because no chemicals penetrated into the wood. After furfurylation, the jabon wood experienced a slight increase in wood weight. The addition of 0.5% nano-SiO_2 to the FA solution was also able to increase the wood weight, although based on statistical tests the WPG value obtained was not significant with the FA sample. Based on the WPG value, the 1% FS jabon wood sample had a significant difference compared to the other samples. Thus, the application of nano-SiO_2 1% in FA solution was able to have a significant effect on the WPG value of jabon wood. Weng *et al.* (2023) also mentioned that the addition of nano-SiO_2 to urea-formaldehyde has a positive effect on the dimensional stability and mechanical strength of poplar wood. The effect of adding nano-SiO_2 to melamine formaldehyde-furfuryl alcohol (MFFA) impregnated into ganitri wood is also able to increase wood weight, density, MOE, MOR, *hardness*, and resistance to subterranean termites and drywood termites (Rahayu *et al.* 2023). In addition, according to Wanishdilokratn & Wanishdilokratn (2024) the addition of 1% nano-SiO_2 to wood composites is the most ideal in performing nano-SiO_2 impregnation technology.

Table 1. Physical properties of jabon wood

Impregnant Material	WPG (%)	BE (%)	Density (g/cm^3)
Control	0.00±0.01[a]	6.10±0.76[a]	0.60±2.81[a]
FA	95.64±6.77[b]	5.39±0.59[a]	0.60±1.70[a]
FS 0.5%	103.74±14.14[b]	6.11±0.35[a]	0.61±2.61[a]
FS 0.75%	129.62±4.76[bc]	10.06±0.53[b]	0.65±6.70[ab]
FS 1%	193.25±24.42[c]	11.44±0.40[b]	0.94±1.03[b]

Description: FS = FA-SiO_2; WPG = weight percent gain; BE = bulking effect; [a-c] = Duncan's test results

The WPG value in the 1% FS jabon wood sample is the highest value because there is a suspected reaction between FA and nano-SiO_2 during the impregnation process called in situ polymerization. Apart from the distribution of FA and nano-SiO_2 in the cell wall and lumen of the wood, in situ polymerization also occurs when the wood is being heated at 100 ºC (Kong *et al.* 2018; Rahayu *et al.* 2021). In this preliminary study, no observations have been made regarding the distribution of FA and nano-SiO_2 microscopically under SEM (Scanning Electron Microscopy) or analyzing the chemical bonding of the impregnant solution with the constituent components of the wood cell wall through FTIR (Fourier-Transform Infrared Spectroscopy). However, previous research conducted by Rahayu *et al.* (2021) support this phenomenon. The WPG value that exceeds 100% causes the cell lumen of ganitri wood to be filled with FA and nano-SiO_2 at a nano-SiO_2 concentration of 1% and there is a bond between FA, nano-SiO_2, and wood hydroxyl groups. As is known, ganitri wood has similar anatomical characteristics to jabon wood. Fadia *et al.* (2023) also combined FA with nano-Fe_3O_4 and produced WPG values above 100% and mentioned that there was maximum penetration in the cell wall. In addition, Dong et al. (2015) also mentioned that the presence of nano-SiO_2 successfully improved the properties of jabon wood, such as physical and mechanical properties, surface hardness, anatomical characteristics, and wettability. This is due to the cross-linking between FA, nano-SiO_2 and the chemical components of wood, especially lignin. Under acidic conditions, lignin furanic resin exhibits more heat-resistant wood behavior compared to untreated wood (Liang *et al.* 2018).

The impregnant chemicals also have an impact on volume addition as indicated by the increase in bulking effect (BE) value which also increases after nano-SiO_2 is added to jabon wood. The largest BE value was obtained in the 1% FS wood sample and the smallest was obtained in the FA wood sample. In line with the increase in WPG value, this proves that the addition of nano-SiO_2 in increasing concentrations causes maximum bulking and expands the volume of the jabon wood cell wall. However, this complex chemical reaction still widely discussed by researchers whether it only causes bulking of the wood cell wall or provides a chemical modification effect on the wood cell wall polymer. As additional information, lignin in wood is also capable of covalent bonding with FA polymers so that treated wood will have wood resistance to wood destroying organisms at the molecular level (Skrede *et al.* 2019). Bulking agents that penetrate into the empty spaces in the wood will replace water in the wood cells and make the wood dimensions more stable (Martha *et al.* 2021). BE in 1% FS wood samples was not significantly different from 0.75% FS wood samples, while both were significantly different from other wood samples. The application of nano-SiO_2 concentration up to 1% also resulted in a significant increase in jabon wood density compared to the other wood samples. This significant increase proves that 1% nano-SiO_2 concentration is able to cause the wood to become denser compared to the control treatment.

The 1% FS wood sample had the highest density value, followed by the 0.75% FS wood sample. On the other hand, the FA and FS 0.5% treatments still did not have a positive impact on increasing the density value of jabon wood compared to the control sample. It is suspected that there are still some empty spaces in the wood that have not been filled by chemicals, resulting in a number of extractive substances in jabon wood vaporized by high temperature treatment after impregnation (Zhou *et al.* 2021). Fahrussiam *et al.* (2023) also explained that jabon wood contains extractive substances that are more volatile than other woods, with the level of fly substances obtained at 85.64% so that it is very volatile and causes the wood density to decrease. Therefore, in the FA and FS 0.5% samples there was no significant increase in volume and not in line with the increase in WPG value. The 1% FS wood sample experienced a significant increase in density value compared to the other treatments. The conjecture regarding this is that the porosity structure in jabon wood has been filled by FA polymers and nano-SiO_2 whose concentration increases so that the wood density increases, as stated in the research of Triquet *et al.* (2021) who impregnated birch and jatoba wood with seven different polymers. In addition, FA polymers also often form a shiny, glassy surface when heated at 70-130 ℃, which is able to resist water transport into the cell walls of jabon wood (Menager *et al.* 2019). Nano-SiO_2 also acts as an artificial mineralization material so that it is able to bind with cellulose, hemicellulose, and lignin components in modified jabon wood, causing an increase in the physical and mechanical properties of jabon wood such as surface roughness, hardness, stiffness, and resistance to attack by wood destroying organisms (Doubek *et al.* 2018). Further studies on the resistance of modified jabon wood to moisture absorption need to be carried out to determine the dimensional stability of jabon wood, including leaching rate testing which is very important to determine the activeness of polymerization. In addition, further tests on the characterization of wood materials are also needed to prove the existence of covalent bonds between chemicals and wood

D. CONCLUSION

The physical properties of jabon wood improved after being treated with modification through FA and nano-SiO_2 impregnation process with various concentrations. Mixing FA and nano-SiO_2 at 1% was the best composition in producing the highest WPG, BE, and density values in this study. FA and nano-SiO_2 solutions are thought to bind covalently with the chemical components of wood and encourage mineralization in jabon wood. In addition, further testing of dimensional stability, mechanical properties, and characterization of FA- and nano-SiO_2-modified jabon wood materials is required.

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AUTHOR'S DECLARATION

- Conflicts of Interest: None.
- We here by confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for republication,which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- No potentially identified images or data are present in the manuscript.

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