Characteristics of impregnated wood by nano silica from betung bamboo leaves

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Abstract, Sengon (Falcataria moluccana Miq.) as a fast-growing wood species that has low quality. Therefore, wood modification is needed to improve its wood qualities. The objective of this study was to analyse the effect of monoethylene glycol (MEG) and nano silica of betung bamboo leaves impregnation treatment on physical, mechanical properties and durability of sengon wood. 5-years-old Sengon wood from community forest, MEG and nano silica (average size = 436.16 nm) from betung bamboo leaves were used. The impregnation solutions were consisted of water treated (untreated), MEG, MEGSilika 0.5% and MEGSilika 1%. Impregnation process with 0.5 bar (60 minutes) vacuum and 2.5 bar (120 minutes) pressure. Physical properties (density and colour alteration), mechanical properties (Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and hardness) and durability against subterranean (Coptotermes curvignathus) attack. The results showed that the weight percent gain (WPG) and density of treated Sengon wood were increased as the nano silica concentration increased. While colour alteration (ΔΕ) of treated samples were declining. Mechanical properties (MOE, MOR and hardness) were also improved. Durability based on laboratory tested against subterranean attack resulted that the percentage of termite mortality from the treated samples increased, while the percentage of weight loss decreased.

1. Introduction
Based on a report from the Ministry of Environment and Forestry (KLHK), the supply of raw materials for the timber industry from natural forests is decreasing. In 2015, the supply was 8.3 million m³, while in 2018 it was 5.7 million m³, meanwhile the supply of raw materials from plantation forests and community forests has increased from 37.3 million m³ in 2015 to 46.6 million m³ in 2018. In particular, the supply of raw materials from community forests increased by 4.8 million m³ in 2015 to 6.2 million m³ in 2018 [1]. Thus, there is a gap between need and demand, thus making community plantation forests and community forests a solution for the supply of raw materials. Wood produced from community forests is generally a fast-growing species.

Sengon (Falcataria moluccana) is a fast-growing wood species that has several drawbacks, namely low specific gravity, strength, durability, density and dimensional stability. Sengon wood has a wood specific gravity of 0.24–0.49 with an average of 0.33, wood density 0.3–0.5 g/cm³, hardness 112–122
kg/cm² and is classified in Durability Class IV-V and Strength Class IV-V as well as termite resistance class III [2]. Timber originating from community forests has low wood quality because it is cut at a young age so that it contains a high proportion of juvenile wood. Based on the research results of [3], concluded that 5, 6 and 7 years old sengon wood contains 100% juvenile wood. Therefore, we need a technology that can improve the quality of fast-growing wood.

According to [4] some basic properties of wood in the form of durability, dimensional stability and wood hardness can be improved by wood modification. Several wood modification treatments include chemical modification, thermal modification, surface modification and impregnation methods. The impregnation process is carried out by introducing chemicals into the wood so that the polymer enters the wood structure with the aim of increasing the durability of the wood against destructive organisms and increasing the service life of the wood [5]. Many studies on impregnation of fast-growing Indonesian sengon species have been carried out, such as using styrene [6]; [7] and methyl metacrylate (MMA) [8]; [9]; [10] but very little information about impregnation using Monoethylene Glycol (MEG).

Research on impregnation using a mixture of MEG and nano-SiO₂ has been carried out by several researchers showing that MEG and nano-SiO₂ solutions have been shown to be able to increase the dimensional stability and density of sengon wood [11]; [12], the resistance of sengon wood to drywood termites and subterranean termites [13] and the rotting fungus S. commune [14]. Nano-SiO₂ has also been used as a polymer to increase dimensional stability and density in poplar wood [15]. This is presumably because the nano-sized material produces an even distribution and penetration in the wood, as well as its low viscosity [16]. The use of nano-sized materials has several drawbacks, including aspects of LCA (Life Cycle Assessment) and the absence of a comprehensive study related to AMDAL (Environmental Impact Analysis), which raises concerns, especially its impact on humans and the environment.

Bamboo leaves are considered as waste that cannot be reused and are considered waste by the community, but there are many compounds that can be used, one of which is silica. The results of research [17] who analyzed bamboo from roots to leaves resulted a silica content of 0.3% in roots to 9.95% in leaves. Thus, bamboo betung leaves have the potential to be used as an alternative raw material for the manufacture of nano silica. Silica plays a role in building plant structures so that they do not fall easily and are more upright [18].

[19] conducted a study using bamboo leaves to produce nano silica. The particle size of the nano silica produced was 472.67 nm. The results of the size of nano silica can be categorized as nanoparticles which are particles with a size below 1 micron [20]; [21]. The study concluded that MEG and nano silica impregnation treatment could increase the dimensional stability and density of sengon and jabon wood. Based on the things mentioned above, in this study an impregnation solution in the form of a mixture of MEG and nano silica derived from bamboo betung leaves was used to improve the physical, mechanical and durability of fast-growing wood.

Therefore, in this study the effects of impregnation of a mixture of MEG and nano silica derived from bamboo betung leaves was used to improve the physical, mechanical and durability of sengon wood were investigated to improve the properties for further utilization of the fast-growing wood species.

2. Methods

2.1. Material and Tools

The material used in this study was 5-years old sengon wood (Falcataria mollucana) which has a branch-free height of about 9-10 meters with a diameter of 30 cm and subterranean termites (Coptotermes curvignathus). The impregnant solution used consisted of distilled water, Monoethylene Glycol and nano silica from bamboo leaves (436.16 nm).

2.2. Wood Test Sample Preparation

The wood size were vary based on standards with 4 repetitions of each treatment. The size of the wood test samples, as shown in Table 1.
2.3. Preparation of Nano Silica Bamboo Betung Leaves
The betung bamboo leaves originated from the area around Bogor. Betung bamboo leaves were dried under the sun until reached air dry which were then burned without fuel to form charcoal. Then the bamboo leaves charcoal were burned at a temperature of 700 °C for 6 hours using a furnace. The ash obtained was then refluxed in 100 mL of 3 N NaOH for 3 hours. The solution was filtered with filter paper and the residue was washed using distilled water until the pH was neutral and oven-dried for 103±2 °C. The ash obtained was then dissolved in PEG-6000 in a ratio of 1:5. The next stage is the manufacture of nanosilica by ultrasonication method for 2 hours. The results of the process were re-furnaciated for 3 hours at a temperature of 700 °C to obtain nano silica. The resulting nano silica was measured using PSA test analysis. The size of nano silica particles from bamboo leaves produced is 436.16 nm.

2.4. Preparation of impregnation solution
The process of mixing nano silica using a Cole Parmer brand sonicator, with an amplitude of 40% for 2 hours. The sonication method can be used to accelerate the dissolution of a material by breaking down the intermolecular using ultrasonication with a high frequency such as 20 kHz to 56 kHz.

Table 2. Composition of a mixture of MEG and nano silica solutions in various treatments

| Treatment                  | MEG (mL) | Water (mL) | Nano Silica (gram) |
|----------------------------|----------|------------|--------------------|
| Untreated (water treated)  | 0        | 1000       | 0                  |
| MEG                        | 1000     | 0          | 0                  |
| MEGSilica 0.5%             | 1000     | 0          | 5                  |
| MEGSilica 1%               | 1000     | 0          | 10                 |

2.5. Impregnation Process
The impregnation process with MEG and nano silica solution was carried out in several stages (Figure 1). The stages of this process were adapted from [11] impregnated sengon wood using MEG and nano-SiO₂.

- Drying of the test sample in an oven at 103 ± 2°C until reached constant weight.
- The impregnation solution was put into the impregnation tube. Then the test sample were immersed in the impregnation solution and put inside the impregnation tube.
- Polymerization: The samples were wrapped in aluminum foil and stored at room temperature for 12 hours.
- The impregnation tube was vacuumed with a pressure of 0.5 bar for 60 minutes and continued with a pressure of 2.5 bar for 120 minutes.
- Drying: The test sample was dried in an oven at 103± 2°C until reached constant weight.

Figure 1. Impregnation process using MEG solution and nano silica

2.6. Physical Properties Testing
2.6.1. Weight Percent Gain (WPG) and density. Measurement of physical properties using parameters Weight Percent Gain (WPG) and density. WPG and density tests can be calculated by the following formula:

\[
WPG (\%) = \frac{W_2 - W_1}{W_1} \times 100
\]

\[
\rho (g/cm^3) = \frac{W_{\text{sample}}}{V_{\text{sample}}}
\]

Information:
- \(W_1\) = Oven dry weight of sample before impregnation (g)
- \(W_2\) = Oven dry weight of sample after impregnation (g)
- \(W_{\text{sample}}\) = Weight after impregnation treatment (g)
- \(V_{\text{sample}}\) = Volume after impregnation treatment (cm³)

2.6.2. Color Testing. The test sample for color testing uses a size (2 x 5 x 6) cm. Each test sample image is measured 3 times (3 points) which have been marked to find the values of L, a and b. Then a comparison of the difference in wood color was carried out using Adobe Photoshop CS 4 software. Using the CIELab method, the \(L^*\) value was used to express the brightness parameter with a scale of 0 (black) – 100 (white). The \(a^*\) value is used to represent the red to green color parameters. A value of +a (0 to +80) for red and a value of –a (0 to -80) for green. While the value of \(b^*\) represents the parameters for the colors blue to yellow. Values +b (0 to +70) for yellow and –b (0 to -70) for blue [23].

![CIELab color space](image)

**Figure 2.** CIELab color space [26]

The color change (\(\Delta E\)) is calculated from the formula:

\[
\Delta E = \sqrt{\left(\Delta L\right)^2 + \left(\Delta a\right)^2 + \left(\Delta b\right)^2}
\]

Information:
- \(\Delta E\) = Color change
- \(\Delta L\) = Difference in brightness (L test sample after treatment – L test sample before treatment)
- \(\Delta a\) = Difference in red or green (a test sample after treatment – a test sample before treatment)
- \(\Delta b\) = Difference in yellow or blue (b test sample after treatment – b test sample before impregnation treatment)

Delta E (\(\Delta E\)) is a quantity to determine changes in color brightness that can be seen with the naked eye. The amount of color change in the wood can be determined using the guidelines in Table 3.

**Table 3.** The effect of the difference in the value of \(\Delta E\)**
2.7. Mechanical Properties Testing

2.7.1. Modulus of Elasticity (MOE) dan Modulus of Rupture (MOR). The test sample used is 2.5 cm x 2.5 cm x 41 cm. MOE and MOR testing refers to [24] (Secondary Method) using the Chung Yen Universal Testing Machine with the One Point Loading method. MOE testing is carried out by loading up to the point of elasticity. While the MOR test is carried out simultaneously with the MOE test, but is carried out until the test sample is damaged/broken. MOE and MOR values can be calculated using the formula:

\[ \text{MOE (kg/cm}^2) = \frac{\Delta P L^3}{\Delta Y b h^3} \]
\[ \text{MOR (kg/cm}^2) = \frac{3 \ P_{\text{max}} L}{2 b h^2} \]

Information:
- MOE = Modulus of Elasticity (kg/cm²)
- MOR = Modulus of Rupture (kg/cm²)
- P_{\text{max}} = Maximum load (kg)
- L = Span distance (cm)
- b = Width of test sample (cm)
- h = Test sample thickness (cm)

2.7.2. Hardness. Surface hardness testing using the Universal Testing Machine (UTM) according to [24]. The test is carried out by inserting a steel ball with a diameter of 1 cm with a cross-sectional area of 1 cm² into the wood. The ball is pressed down to a depth of 0.5 cm. The value of wood hardness is measured by the formula.

\[ H \left(\frac{\text{kg}}{\text{cm}^2}\right) = \frac{P_{\text{max}}}{A} \]

Information:
- H = hardness value (kg/cm²)
- P max = maximum load (kg)
- A = cross-sectional area (cm²)

2.8. Wood Durability

2.8.1. Resistance to Subterranean Termite Attack. Subterranean termite testing was carried out based on the Japanese Industrial Standard [25]. The test sample was dried in an oven at 60 ± 2 °C for 48 hours until the weight was constant (W1). Each test sample was put into an acrylic tube (8 cm in diameter, 6 cm in height) whose bottom was made of 1 cm thick dental cement. The position of the test sample lies in the middle of the bottom of the tube with a base in the form of a plastic net size 2 x 2 cm. Then 150 worker castes and 15 subterranean warrior castes were put into each acrylic tube. The top of the acrylic tube was covered with aluminum foil and placed in a container with a damp tissue and then stored in a dark room (T 28 °C, RH 77%) and stored for 21 days. During the test, try to keep the tissue moist by...
dripping ± 10 ml of water every day. Dead termites are removed. After 21 days, all the test samples were cleaned and baked for 48 hours at 60 ± 2 °C and then weighed (W2). The weight loss of the test sample is calculated by the formula:

\[ P = \frac{(W1 - W2)}{W1} \times 100\% \]

Information:
- \( P \) = Percentage of weight loss (%)
- \( W1 \) = Weight of test sample before feeding (g)
- \( W2 \) = Weight of the test sample after being fed (g)

The termite mortality can be calculated by the formula:

\[ Mortality = \frac{D}{150} \times 100\% \]

Information:
- \( D \) = Number of dead termites (tails)
- 150 = Number of working caste termites at the start of feeding (tails)

![Figure 3. Subterranean termite testing [25]](image)

| Class | Durability      | Weight loss (%) |
|-------|-----------------|-----------------|
| I     | Very durable    | < 3.52          |
| II    | Durable         | 3.52 – 7.40     |
| III   | Medium          | 7.50 – 10.80    |
| IV    | Not durable     | 10.90 – 18.90   |
| V     | Very not durable| >18.90          |

Source: [28]

2.9. Data Analysis
The experimental design used was a completely randomized design (CRD) with 1 factor, namely the variation factor of the concentration of the impregnation solution with 4 levels, namely untreated (water treated), MEG, MEGSilica 0.5% and MEGSilica 1%. The test was carried out using the IBM SPSS Statistics (Statistical Package for service solutions) version 22.0 calculation program and continued with Duncan's test at a 95% confidence interval.
The equation model used by [29] is as follows:

\[ Y_{ij} = \mu + \tau_i + \epsilon_{ij} \]

Information:
- \( i = 1, 2, \ldots, t \) and \( j = 1, 2, \ldots, r \)
- \( Y_{ij} \) = response or observation value from the treatment of the i-th concentration of the solution and the j-repetition
- \( \mu \) = general average
- \( \tau_i \) = effect of the i-th treatment
- \( \epsilon_{ij} \) = the effect of experimental error from the treatment of the i-th concentration of the solution and the j-th replication

3. Result and Discussion

3.1. Physical Properties of Wood
3.1.1. Weight Percent Gain (WPG). The resulting WPG value is shown in Figure 4. The test results show an increase in the WPG value for each treatment. The WPG values for MEG, MEGSilica 0.5% and MEGSilica 1% treatments were 22.98%, 34.3% and 46.84%, respectively. The results of the analysis of variance showed that MEG and nano silica had a significant effect on the WPG value. Meanwhile, Duncan's test results showed that untreated, MEG, MEGSilica 0.5% and MEGSilica 1% had values that were significantly different from one another.

![Figure 4. WPG values in various MEG and nano silica impregnation treatments on sengon wood.](image)

The increase in WPG value is thought to be due to the addition of a mixture of MEG and nano silica which can replace free water and bound water in the cavity and cell walls of the wood so that impregnants in the form of MEG and nano silica can enter the wood. According to [30] that impregnation using a polymer causes penetration of the polymer into the cell wall and bonds can occur with the components that make up the wood cell wall. Based on [19] through SEM analysis, it was explained that the cause of the increase in WPG value in impregnated sengon wood was due to the addition of nano silica which could increase the distribution of MEGSilica solution.
3.1.2. Density. Wood density is the ratio between weight and volume of wood. The test results on the resulting density value showed an increase in each treatment (Figure 5). The density values in untreated, MEG, MEGSilica 0.5% and MEGSilica 1% were 0.28 g/cm$^3$, 0.39 g/cm$^3$, 0.41 g/cm$^3$ and 0.44 g/cm$^3$, respectively. Based on the results obtained, the addition of the mixed concentration of MEG nano silica can increase the density value of each treatment.

![Figure 5. Density values in various MEG and nano silica impregnation treatments on sengon wood.](image)

The results of the analysis of diversity showed that MEG and nano silica had a significant effect on the density value. Based on the results of Duncan's test, it showed that MEG treatment was not significantly different from 0.5% MEG silica treatment, but MEG and 0.5% MEG silica treatments were significantly different from 1% silica MEG treatment and significantly different from the untreated.

![Figure 6. The relationship between density values and WPG results from nano silica impregnation of bamboo betung leaves](image)

The increase in the density value in each treatment was due to the penetration and expansion of the cell wall, the development occurred because the polymer had entered and was able to fill the space in the cell wall. The tendency to increase the density value along with the increase in the resulting WPG value. The WPG value increases, the resulting density value also increases (Figure 6). This is in accordance with what was stated by [31], that the higher the wood density value, the more wood substances in the cell wall, which means the thicker the cell wall. The polymer content in wood is also influenced by the concentration of the impregnated material, polymerization method, the anatomical structure of the wood and the use of additives [10]. In addition, a vacuum system is used in the impregnation process. will remove excess air and water in the cell wall that can inhibit the entry of the impregnant solution.
3.1.3. Color change. Each untreated and treated wood had different color characteristics, this is shown in Figure 7. There was a change in the values of L, a and b of sengon wood, after the impregnation treatment using MEG and nano silica solutions. After being given treatment, the value of the color change parameter (L, a, b) decreased, which means there was a change in the color of the wood.

![Figure 7](image)

*Figure 7.* The value of L*a*b* (before) and the value of L# a# b# (after) the MEG and nano silica impregnation treatment on sengon wood.

The color test results in Figure 7 show a decrease in the brightness value (L) after the impregnation treatment. Treatment with MEGSilica 0.5% and MEGSilica 1% on the graph showed an increase in the brightness value (L) of sengon wood. While the treatment using MEG decreased the value of wood brightness. This is presumably due to the addition of nano silica contained in the wood which can increase the brightness value of the wood. Yellowish value (a*) increased at MEGSilica 0.5% and decreased a value at MEGSilica 1%. The same thing also happened to the value (b*) where at MEGSilica 1%, the a and b values obtained did not show a change in color (Figure 8). According to [30], color changes can occur due to the addition of the degree of crystallinity, degree of polymerization and OH content.

![Figure 8](image)

*Figure 8.* Color of untreated sengon wood (a), MEG (b), MEGSilica 0.5% (c), MEGSilica 1% (d).

Figure 9 shows the highest color change value occurred in the treatment with MEG concentration (14.2) followed by MEGSilica 0.5% (10.95) and untreated (7.53) treatment. The color change produced in the untreated treatment, MEG and MEGSilica 0.5% reached a value of 6. This indicates that the treatment caused a large color change. While the treatment with MEGSilica 1% concentration was classified as a moderate change, which was 5.28. The results of the analysis of variance showed that MEG and nano silica had a significant effect on the value of wood discoloration. Duncan's test results showed that the treatment with 1% MEG silica concentration was not significantly different from the untreated but significantly different from the MEG and 0.5% MEG silica treatment. MEG and MEGSilica 0.5% were not significantly different.
Figure 9. Value of color change of various MEG and nano silica impregnation treatments on sengon wood.

The impregnation process is expected to cause changes in the composition or chemical structure of the treated wood due to the formation of new compounds in the impregnated wood. The color change in the wood became darker in the MEG treatment due to the reaction between MEG and the components that make up the wood cell wall. The color change of wood after MEG and nano silica treatment resulted in a lighter color change when compared to MEG treatment. This is due to the presence of nano silica contained in the mixture of MEG and nano silica. This is in line with the research of [15] which stated that the color change in wood with furfuryl alcohol treatment showed a darker wood color change, but the color became lighter after the addition of SiO$_2$ caused by conjugation or the formation of certain molecules in the nano-SiO$_2$ network in PFA (Polymer Furfuryl Alcohol).

3.2. Mechanical Properties of Wood
3.2.1. MOE (Modulus of Elasticity). Modulus of Elasticity (MOE) is an indication of wood stiffness, namely the ability of wood to withstand changes in shape. According to [31] modulus of elasticity is the stiffness property of a material or material to withstand changes in shape or bending that occur due to loading up to the proportion limit.

Figure 10. MOE values of various MEG and nano silica impregnation treatments on sengon wood.
The MOE value in MEG impregnated wood and nano silica from bamboo betung leaves (Figure 10) increased in untreated, MEG, MEGSilica 0.5% and MEGSilica 1%. The results of the analysis of variance showed that the MEG and nano silica treatments had a significant effect on the MOE value. Duncan's test results showed that the MOE value in MEGSilica 1% was significantly different from the untreated, MEG and MEGSilica 0.5%, while the MOE value in the MEG treatment was not significantly different from the MEGSilica 0.5% treatment but significantly different from the MOE value of the untreated.

The increase in the MOE value obtained is thought to be due to the addition of a mixture of MEG and nano silica solutions that enter the sengon wood. This indicates that the addition of nano silica with various concentrations can affect the morphology of sengon wood. This is supported by [30] who suggests that when the cell wall is filled with a polymer, the polymer will bond to the hydroxyl cellulose so that it occupies the space normally occupied by water molecules. It is suspected that impregnated silica nanoparticles crystallize in the wood, thereby increasing the strength of the wood.

Based on [19] on SEM analysis, it shows that MEGSilica impregnation treatment causes MEG and nano silica to enter the pits and some pits are covered by MEGSilica and even cover almost all vessel walls on sengon. Figure 11a shows the pits on the walls of the sengon wooden vessel partially covered by MEG. The pits that were originally empty after being treated with impregnation using MEG and nano silica became filled and almost covered by nano silica (Figure 11b). Furthermore, Figure 11c shows a better morphological change that MEG and nano silica can enter the pits, stick to and even partially cover the walls of the sengon wood vessel. The incoming nano silica fills the vessel providing a bulking effect on sengon wood. This causes the weight of sengon wood to increase so that the WPG value increases. The presence of nano silica covering the pits is also able to prevent the entry of water into the pits on the vessel wall.

![Figure 11](image)  
Figure 11. Morphology of MEG wood (a), MEGSilica 0.5% (b), MEGSilica 1% of sengon at 1000x magnification.

The trend of increasing the MOE value is accompanied by an increase in the WPG value and the resulting density value (Figure 12). The higher the WPG value produced, the resulting density value increases so that the MOE value obtained increases. The addition of MEG and nano silica caused more and more nano silica enter the wood and fill the lumen and cell wall of the wood with the help of MEG. This is supported by [13] which showed that impregnation treatment using MEG and nano-SiO$_2$ was able to increase the MOE and MOR values in wood. This indicates that the addition of nano silica with various concentrations of 0.5% MEGSilica and 1% MEGSilica can affect the morphology of sengon wood so as to increase the WPG value and density which in turn can increase the MOE value.
3.2.2. MOR (Modulus of Rupture). Modulus of Rupture (MOR) is the ability of a material to withstand loads up to the maximum limit. The stiffer the wood, the more difficult it is to change its shape, and vice versa. The MOR value is closely related to the MOE value of the wood and also the density. The higher the density of a wood, the higher the MOR value. Modification of wood with impregnation technology using a mixture of MEG and nano silica solutions causes an increase in the MOR value in the sengon wood test sample. The resulting MOR values are presented in Figure 13.

Figure 12. Relationship of MOE value with WPG value (a) and density (b) on sengon wood impregnated with nano silica

Figure 13. MOR values of various MEG and nano silica impregnation treatments on sengon wood.

Figure 13 shows the increase in MOR values in untreated, MEG, MEGSilica 0.5% and MEGSilica 1%. The MOR values increased along with the addition of a mixture of MEG and nano silica solutions. The results of the analysis of variance showed that MEG and nano silica had a significant effect on the MOR value. Based on the results of Duncan's test that the MOR values of sengon wood in the MEG treatment was not significantly different from the treatment among untreated, 0.5% MEGSilica, while the 1% MEGSilica treatment was significantly different from the 0.5% MEGSilica treatment and significantly different from untreated.

The increasing MOR values were caused by the addition of MEG and nano silica (Figure 14). This trend was in line with the increase in the WPG value and the density obtained. The increase in the WPG value indicates an increase in the density value which causes an increase in the resulting MOR value. Based on research [12] the addition of MEG and nano-SiO₂ can cause polymer penetration into the wood cell wall, because the polymer is able to fill the pits on the cell wall. This is also supported by [32] who
suggested that the addition of nano-SiO₂ concentrations could increase the MOR value of wood due to compression of the wood pores which in turn could increase the stiffness of the wood.

![Graph showing relationship between MOR and WPG or density](image)

**Figure 14.** Relationship of MOR with WPG (a) and density (b) of sengon wood.

3.2.3. **Hardness.** Wood hardness is influenced by several factors, namely density, elasticity, wood fiber size, bonding power between wood fibers and the composition of wood fibers [33] Impregnation technology using a mixture of MEG and nano silica solutions causes an increase in the hardness value of the sengon wood test sample. Hardness values are presented in Figure 15.

![Hardness values of various MEG and nano silica impregnation treatments on sengon wood](image)

**Figure 15.** Hardness values of various MEG and nano silica impregnation treatments on sengon wood.

The hardness value showed an increase in each treatment (Figure 15). The highest hardness value was 1% MEGSilica. Based on the results of the analysis of variance shows that the MEG and nano silica treatments have a significant effect on the hardness value. Duncan's test results showed that the hardness values were significantly different among MEG, 0.5% MEGSilica and 1% MEGSilica treatment against the untreated on sengon wood.

The hardness values tend to increase along with the addition of the WPG value (Figure 16). The higher the WPG value obtained, the higher the hardness value produced, presumably due to the addition of MEG and nano silica. This is supported by [19] which suggests that the addition of MEG and nano silica can cause nano silica to enter the wood and fill the lumen and cell walls of the wood with the help of MEG as a medium, so that the wood strength increase due to the presence of crystallized nano silica in the wood. This is also in line with [13] which concluded that the impregnation treatment using MEG and nano-SiO₂ was able to increase the hardness value of wood.
3.3. Wood Durability

3.3.1. Subterranean Termite C. curvignathus Testing. Wood durability is the resistance of a type of wood to biological organisms that destroy wood such as insects, fungi and marine animals. In order to express its durability, the durability of wood is expressed in the durable class. In Indonesia, there are five classes of durable, namely Class I (very durable) to Class V (very not durable) [34].

3.3.2. Weight loss. Figure 17 shows the weight loss value of untreated was higher than the MEG, 0.5% MEGSilica and 1% MEGSilica treatments. For comparison, the weight loss value of untreated pine sample was 17.54%. Pine wood was considered as termite’s favourite food and also as an indicator of the suitability environmental conditions during the test. If the test environment conditions are suitable then the wood will be eaten by termites during the test. [35] these environmental conditions include humidity and temperature.

The results of the analysis of variance showed that the MEG and nano silica treatments had a significant effect on the percentage value of weight loss of the subterranean termite test samples. Duncan's test showed that the untreated samples with other concentration treatments were significantly different. MEG silica concentration of 1% was significantly different from other treatments, while the treatment with MEG concentration and 0.5% MEG silica was not significantly different.
For comparison, the untreated pine wood had the percentage of weight loss value of 17.54%. According to research [36] stated that the weight loss of untreated test samples was at least 15%. Meanwhile, the weight loss value for MEG, 0.5% MEGSilica and 1% MEGSilica treatments decreased. The higher the WPG value, the lower the percentage of weight loss (Figure 18). It was due to the addition of a mixture of MEG and nano silica solutions into the wood. This is supported by the research of [37] which showed that the addition of nano-SiO$_2$ particles could increase resistance to wood destroying organisms with a low percentage of weight loss. The increase in the value of wood hardness also affects the percentage of weight loss because the harder the wood, the harder it is for termites to consume it, in other words, the harder the wood, the harder it is to be damaged by termites [38].

3.3.3. Termite Mortality. Termite mortality can be used as a criterion for the toxicity of a material to the termite [39]. This is because mortality is the termite mortality rate observed in the testing process. Based on the results showed that the percentage of mortality had increased. The highest mortality value of the test samples occurred in the 1% MEGSilica treatment of 89.17%. For comparison, untreated pine wood has a mortality percentage value of 24.33%.

![Figure 18. The relationship between the weight loss value of C. Curvignathus and the WPG value.](image)

![Figure 19. Percentage of average mortality in the test samples after three weeks of feeding the subterranean termite C. curvignathus.](image)
The results of variance showed that MEG and nano silica treatments had a significant effect on the mortality values of subterranean termites. Based on Duncan's test, each treatment was significantly different from the untreated, MEG, MEGSilica 0.5% and MEGSilica 1%.

The value of termite mortality in wood treated with MEGSilica was higher than untreated. The higher the mortality value, the more resistant the wood is to *C. curvignathus* subterranean termites. The resulting increase in mortality value is thought to be due to the addition of a mixture of MEG and nano silica mixed concentrations in each treatment. MEG and nano silica can increase the toxicity which causes the termites have difficulty in eating the wood test sample. Termites do not like toxic materials [40].

![Figure 20. Correlation between subterranean termites (*C. Curvignathus*) mortality and WPG value.](image)

The trend of increasing subterranean termite mortality is in line with the increase in WPG value (Figure 20). The higher the WPG value, the higher the percentage of termite mortality. This is supported by research by [41] which shows that the addition of silica nanoparticles can increase the toxicity of plants against insect attacks. High toxicity can terminate termites. Based on research by [42] nano-SiO$_2$ particles are toxic particles other than ZnO, TiO$_2$ and Al$_2$O$_3$. In addition, according to [43], the preservation treatment is said to be effective if the termite mortality is more than 70%. Test samples with concentrations of MEG, 0.5% MEGSilica and 1% MEGSilica obtained a mortality percentage value above 70%. In other words, wood preservation using a mixture of MEG and nano silica solutions can be said to be effective.

### 3.4. General Discussion

Modification of wood by impregnation method with MEG and nano silica showed an increase in each parameter of physical and mechanical properties and wood durability. Based on [13], impregnation using monoethylene glycol and nano-SiO$_2$ was able to increase the mechanical properties and durability of impregnated sengon wood. MEGSiO$_2$ 0.5% treatment was the most optimum concentration. These results are not in line with the results of the study. This is due to the different size of nanoparticles between nano silica from bamboo betung leaves (436.16 nm) and nano-SiO$_2$ (diameter 15 ± 5 nm). The size of nanoparticles can affect the entry of nanoparticles into pits and vessel walls on sengon wood. Nano silica can enter the wood and spread in the lumen and cell walls of the wood with the help of MEG. This is also supported by [19] through SEM analysis showing morphological changes that the addition of a mixture of MEG and nano silica can enter pits, stick to, and even cover the walls of sengon wood vessels.

Based on the results in Table 5, it shows that MEGSilica 1% impregnation treatment is the most optimum value. Sengon wood impregnated with 1% MEGSilica treatment showed an increase in the wood strength class from strength class IV - V to strength class III-IV and durable class IV - V to durable class III-IV.
Table 5. Results of physical, mechanical and durability properties of various treatments

| Testing                      | Untreated | MEG | MEGSilika 0.5% | MEGSilika 1% |
|------------------------------|-----------|-----|----------------|--------------|
| WPG (%)                      | 0 (a)     | 22.98(b) | 34.3(c) | 46.84(d) |
| Density (g/cm³)              | 0.28(a)   | 0.39(b) | 0.41(b) | 0.44(c) |
| Color change                 | 7.53(ab) | 14.2(c) | 10.95(bc) | 5.28(a) |
| MOE (MPa)                    | 3978.15(a) | 4575.28(b) | 4780.24(b) | 5546.68(c) |
| MOR (MPa)                    | 33.79(a) | 36.96(ab) | 40.18(b) | 44.56(c) |
| Hardness (Kg/cm²)            | 106.48(a) | 115.86(b) | 126.16(c) | 135.91(d) |
| Weight loss percentage (%)   | 16.35(c) | 11.79(b) | 10.97(b) | 6.71(a) |
| Mortality percentage (%)     | 25.50(a) | 73.83(b) | 77.5(c) | 89.17(d) |

4. Conclusion
Modification of wood by impregnation method by MEG and nano silica had a significant effect on the WPG value, density, wood color change, MOE, MOR, hardness, percentage of weight loss and percentage of mortality of subterranean termites C. curvignathus on sengon wood. The increase in WPG, density, MOE, MOR and hardness values indicated that MEG and nano silica were able to fill all wood pits, thereby improving wood quality. Overall MEGSilica 1% treatment was the most optimum treatment for sengon wood in improving the physical, mechanical and wood durability.

5. References
[1] [KLHK] Ministry of Environment and Forestry 2019 Statistics of the Ministry of Environment and Forestry in 2019

[2] Martawijaya A, Kartasujiana I, Mandang YI, Prawira SA and Kadir K 2005 Indonesian Wood Atlas Volume II (Bogor: Forestry Research and Development Agency, Ministry of Forestry)

[3] Rahayu I, Darmawan W, Nugroho N, Nandika D and Marchal R 2014 Demarcation point between juvenile and mature wood in sengon (Falcatoria moluccana) and jabon (Antocephalus cadamba). J. Trop. For. Sci. 26(3) 331-339

[4] Homan WJ and Jorissen AJM 2004 Wood modification developments Heron 49(4): impregnation with furfuryl alcohol and nano SiO₂ BioResources 9(4) 6028-6040

[5] Kikata Y 2000 Text for Wood based Material Application Technology Course (Nagoya: Nagoya International Training Centre JICA)

[6] Darma IGKT, HadiYS and Atmojo AT 2002 Resistance of wood-plastic polystyrene composites against brown rot fungus (Tyromycus palustris) attack J. Man. Hut. Trop. 8(1) 31-38

[7] Jasni, Hadjib N, Barly, HadiYS and Afidudin Y 2004 The resistance of wood polymer composite to the dry wood termite (cryptotermes cycocycephalus Light) and the subterranean termite (coptotermes curvignathus Holmgreen) infestation J. For. Res. 1(1) 50-59

[8] Wardani L, Risnasari I, Yasni and HadiYS 2012 Resistance of jabon timber modified with styrene and methyl acrylate against drywood termites and subterranean termites Proceedings of 9th Pacific Rim Termite Research Conference 2012 Feb 27-28 (Hanoi, Vietnam)

[9] HadiYS, RahayuIS and Danu S 2013 Physical and mechanical properties of methyl metacrylate impregnated jabon wood J. Ind. Academy of Wood Sci. DOI 10.1007/s13196-013-0098-3

[10] HadiYS, RahayuIS and Danu S 2015 Termite resistance of jabon wood impregnated with methyl
methacrylate J. of Trop. For. Sci. 27(1) 25-29
[11] Rahayu I, Darmawan W, Zaini LH and Prihatini E 2020 Characteristic of fast growing wood impregnated with nano particles J. For. Res. 31(2) 677-685
[12] Dirna FC 2017 Characteristics of Sengon Wood Impregnated with Monoethylene Glycol and Nano SiO2 Skripsi (Bogor: Bogor Agricultural University)
[13] Riadi MR 2017 Mechanical Properties and Durability of Monoethylene Glycol and Nano-SiO2 Impregnated Sengon Wood Skripsi (Bogor: Bogor Agricultural University)
[14] Saputri ED 2017 Resistance of Jabon Wood and Sengon Wood Impregnated Monoethylene Glycol and Nano-SiO2 from Wood Weathering Fungus Attack Skripsi (Bogor: Bogor Agricultural University)
[15] Dong Y, Yan Y, Zhang S and Li J 2014 Wood/polymer nanocomposites prepared by impregnation with furfuryl alcohol and nano-SiO2 BioResources 9(4) 6028-6040
[16] Fufa SM and Hovde PJ 2010 Nano-based modifications of wood and their environmental impact: review World Conference on Timber Engineering
[17] Ding TP, Zhou JX, Wan DF, Chen ZY and Zhang F 2009 Silicon isotope fractionation in bamboo and its significance to the biogeochmical cycle of silicon Geochimica et Cosmochimica Acta 72 1381–1395
[18] Kumar SD 2014 Role of micronutrient in Rice Cultivation and Management Strategy in Organic Agriculture Agricultural Sciences 5 765-769
[19] Dirna FC 2019 Characteristics of Fast-Growing Wood Resulting from Nano Silica Impregnation of Bamboo Leaves Betung [thesis] (Bogor: Bogor Agricultural University)
[20] Tiyaboontchawan W 2003 Chitosan nanoparticles: A promising system for drug delivery Naresuan Univ. J. 11(3) 51-66
[21] Buzea C, Blandino IIP and Robbie K 2007 Nanomaterial and nanoparticles: sources and toxicity Biointerphases 2(4) 17-71
[22] [BS] British Standard 1957 Methods of Testing Small Clear Specimen of Timber  BS 373:195 In Annual Book of BS Standard (London: British Standard Institution)
[23] Christie RM 2007 Colour Chemistry (Cambridge: The Royal Society of Chemistry Science Park)
[24] [ASTM] American Standard for Testing and Materials 1996 Standard Methods of Testing Small Clear Specimens of Timber ASTM D 143-05 In Annual Book of ASTM Standard (New York: American Standard Institution)
[25] [JIS] Japanese Industrial Standard 2004 Test Methods for Determining The Effectiveness of Wood Preservatives and Their Performance Requirements (Tokyo: Japanese Standards Association)
[26] Thompson DW, Kozak RA and Evans P 2005 Thermal modification of color in red alder veneer: Effects of temperature, heating time and wood type Wood Fiber Sci. 37 653-661
[27] Hunter Lab 2008 Hunter L,a,b Color Scale [online] http://www.hunterlab.com
[28] [SN] Indonesian National Standard 2014 Test of Resistance of Wood and Wood Products against Wood Destroying Organisms (Jakarta: National Standardization Agency)
[29] Sastrosupadi A 2000 Practical Experiment Design in Agriculture (Yogyakarta: Kanisius)
[30] Hill CAS 2006 Wood Modification: Chemical, Thermal, and Other Processes (West Sussex: JohnWileyand sons Ltd)
[31] Bowyer JL, Shmulsky R and Haygreen JG 2007 Forest Product and Wood Science an Introduction Fifth Edition ((US): Blackwell Publishing Professional. Iowa)
[32] Hoseini SB, Hedjazi S, Jamalirad L and Sukhtesaraie A 2014 Effect of nano-SiO2 on physical and mechanical properties of fiber reinforced composite (FRCs) J. Indian Aca. Wood Sci. 11(2) 116-121 DOI 10.1007/s13196-014-0126-y
[33] Mardikanto TR, Karlinasari L and Bahtiar ET 2011 Mechanical Properties of Wood (Bogor: IPB Press)
[34] Martawijaya A, Barly and Permadi P 2001 Wood Preservation for Handicrafts (Bogor: Bogor Forestry Research and Development Center)
[35] Nandika D, Rismayadi Y and Diba F 2003 Termites: Biology and their Control (Surakarta:
Arinana, Tsunoda, Herliyana EN and Hadi YS 2011 Determination of resestance of woods against subterranean termites by laboratory tests using Indonesian and Japanese Standards Proceedeng of the Conference of The Pacific Rim Termite Research Group.

Furuno T and Imamura Y 1998 Combinations of wood and silicate Part 6 Biological resistances of wood-mineral composites using water glass-boron compound system Wood Sci. and Tech. 32 161-176

Tampubolon AE, Oemry S and Lubis L 2015 Viability test of subterranean termites (Coptotermes curvignathus Holmgren) (Isoptera: Rhinotermitidae) in various wood media in the laboratory Online Journal of Agroecotechnology 3(3) 864-869

Supriana 1983 Feeding Behaviour of Termites (Insecta: Isoptera) on Tropical Timber and Treated Materials [Thesis] (University of Southampton England)

Surini T, Charrier F, Malvestio J, Charrier B, Moubarik A, Castera P and Grelier S 2011 Physical properties and termite durability of maritime pine (Pinus pinaster Ait.) heat-treated under vacuum pressure Wood Sci. Technol. 46(1) 487 501

El-bandary HM and El-Helaly AA 2013 First record nanotechnology in agricultural: Silica nanoparticles a potential new insecticide for pest control App. Sci. Report. 4(3) 241-246

Zhang XQ, Yin LH, Tang M and Pu YP 2011 ZnO$_2$, TiO$_2$, SiO$_2$, and Al$_2$O$_3$ Nanoparticle – induced Toxic Effect on Human Fetal Lung Fibroblast Biomedical and Environt. Sci. 24(6) 661-669

Hadikusumo SA 2004 Wood Preservation (Yogyakarta: Universitas Gadjah Mada Press)