Fast-Growing Wood-Polymer Nano Composite Characteristics through Nano-SiO_2 Impregnation

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Abstract

Ganitri (*Elaeocarpus sphaericus* (Gaertn.) K. Schum.) and jabon (*Anthocephalus cadamba*) are fast-growing wood species that have low strength and durability class. One of methods for improving the characteristics of ganitri and jabon woods is impregnation. This study objectives were to analyze the effect of impregnation of Melamine Formaldehyde Furfuryl Alcohol (MFFA) copolymer and 0.5% Nano-SiO_2 on the physical, mechanical and durability properties of ganitri and jabon woods. The impregnation process was carried out by applying a 0.5 bar vacuum for 1 hour and followed by 2 bar pressure for 2 hours. The results showed that impregnation with MFFA and Nano-SiO_2 could improve optimally the physical and mechanical properties and durability of fast-growing woods.

Keywords: ganitri, impregnation, jabon, MFFA, Nano-SiO_2

Introduction

Ganitri (*Elaeocarpus sphaericus* (Gaertn.) K. Schum.) and jabon (*Anthocephalus cadamba*) are fast growing species. Ganitri wood has 100% juvenile wood at the age of 6 years (Laksono 2019). Ganitri tree cultivation techniques do not require certain growth requirements and this tree has fast growth (Rahman 2012). Ganitri wood has a soft and light structure with large size, upright, cylindrical stems and light gray to brownish bark. The wood is used for carpentry, and has a useful tree function to protect highways as an urban forest (Prihatini *et al*. 2020b). Based on the research by Prihatini *et al.* (2020b) the mechanical properties (Modulus of Rupture) and physical properties (specific gravity) of ganitri wood are included in the strength class III-IV. The durability of this wood belongs to durable class V (Sani 2015).

According to Darmawan *et al.* (2013) jabon wood that is 7 years old still contains 100% juvenile wood. According to Pandit *et al*. (2011) jabon tree is fast-growing plant, has a relatively high level of cylindrical stems, relatively few knots, and the wood has good mechanical properties for light construction (rafters, battens, window frames, etc). Jabon wood has a yellowish white color and the texture is quite smooth to rough and shiny (Pandit *et al.* 2011). Jabon wood also has low durability, namely durable class V and has a fairly low quality value, namely strong class IV-V (PPKI NI-5 1961).

Jabon and ganitri woods have inferior wood quality, so they need to be modified to improve the quality of the wood (Prihatini 2020a). Wood modification is divided into thermal modification, surface modification and chemical modification. The modification of wood that has been carried out so far is chemical modification, to be precise, the impregnation method. Impregnation is a method that is carried out by inserting impregnant materials or substances into wood with the aim of improving its quality (Hill 2006).

The impregnant material that is often used is Furfuryl Alcohol (FA). FA is derived from the hydrolyzate of agricultural waste which is rich in pentosan, has a strong polarity, a colorless hydrophilic liquid, but forms a hydrophobic dark brown polymer gel when heated in the presence of an acid catalyst (Thygesen 2009). According to Hazarika and Maji (2013) the use of FA impregnation was quite effective in increasing the dimensional stability of wood, but the strength or mechanical properties of wood did not change that much. To overcome this, it is necessary to have a mixture of other materials to improve the mechanical properties of wood, such as Melamine Formaldehyde (MF).

MF resin is one of the very hard and very stiff thermoset polymers that can provide good performance on wood. MF is an amino resin that has various material advantages, such as better hardness, transparency, good boiling resistance, thermal stability, scratch resistance, fire resistance, moisture resistance and makes the wood surface smooth (Bajia *et al.* 2009). According to Yao *et al.* (2017), the mechanical properties of wood that has been treated with MF are higher because MF easily reacts with acidic, alkaline or neutral media. The drawback of using MF is the emission of formaldehyde which can be harmful to health. Mixing Melamine Formaldehyde and Furfuryl Alcohol (MFFA) can reduce the impact of formaldehyde emissions and can improve wood quality, both mechanical properties and durability.

Nanotechnology applications have penetrated into various fields including wood technology. The use of nanotechnology in wood modification can be a good opportunity to help fast growing wood in Indonesia in an effort to improve wood quality. Hazarika and Maji (2013) proved that the addition of Nano-SiO_2 to MFFA could increase the durability and resistance of wood to fire. The application of Nano-SiO_2 to sengon wood produces density values and dimensional stability that increase effectively (Rahayu *et al.*

2020). Nano-SiO_2 is a white powder consisting of high purity amorphous silica. Nano-SiO_2 particles have advantages such as strong surface adsorption, large specific surface area and surface energy, good dispersion ability (Zhuang and Chen 2019). One of the applications of Nano-SiO_2 is as a composite filter. Nano-SiO_2 can significantly affect the compression, tensile and shear properties of epoxy resin composites (Chira *et al.* 2016). Based above findings, this study aims to analyze the effect of Melamine Formaldehyde Furfuryl Alcohol (MFFA) copolymer and 0.5% Nano-SiO_2 impregnation on the physical and mechanical properties and durability of ganitri and jabon wood.

Materials and Methods

Materials

Ganitri wood (*Elaecocarpus sphaericus* (Gaertn.) K. Schum), jabon wood (*Anthocephalus cadamba*) and dry wood termite (*Cryptotermes cynocephalus*) worker caste were the materials used in this study. Apart from that, there are also other materials used such as melamine, formaldehyde, furfuryl alcohol (Sigma Aldrich Pte. Ltd. China), 70% alcohol, demineralized water, NaOH, Nano-SiO_2 (particle diameter 15 ± 5 nm).

Preparation of Impregnation Solution

The manufacture of MFFA copolymers refers to the research by Prihatini (2020a), Hazarika and Maji (2013) and Yao *et al.* (2017). Melamine, formaldehyde, furfuryl alcohol are placed in a beaker with a mole ratio of 1:3:5. The first step is to mix the melamine and formaldehyde to hydroxymethylated melamine by mechanical stirring. The pre-reaction initiated when the pH of the solution was modified by putting 10% NaOH solution until the pH ranged from 9.4-9.6 and the temperature was slowly incerased to 98 °C. The second step was to react the solution formed with furfuryl alcohol until the solution looked clear which was carried out for 10 minutes. The third step was adding 1.5% anhydrous maleic catalyst which was carried out for 10 minutes. The results of this MFFA copolymer impregnation were made at a concentration of 50%.

After the MFFA is ready, also prepare Nano-SiO_2 which has been soaked in FA for 24 hours by stirring using a magnetic stirrer and sonicated for 30 minutes. After the MFFA is ready, prepare Nano-SiO_2 0.5% which has been soaked in FA for 24 hours by stirring using a magnetic stirrer and sonicated for 30 minutes. Then the MFFA copolymer was poured slowly into the Nano-SiO_2 solution with a magnetic stirrer. The prepared Nano-SiO_2 MFFA mixture was then added to FA with a volume ratio of 1:1. After that, it was continued with the sonication process for 15 minutes.

Impregnation Process

The impregnation method used in this study refers to previous research by Prihatini (2020a) with a MFFA solution and Nano-SiO_2 0.5%. Prior to the impregnation process, the sample was dried in the oven at 103 ± 2 °C until the weight was constant. The wood samples and MFFA solution and MFFA Nano-SiO_2 0.5% are ready to be put into the container. After that, the container containing the wood sample and solution was placed inside the impregnation tube. The sample and solution were given a vacuum of 0.5 bar for 1 hour, followed by a pressure of 2 bar for 2 hours. Then the wood samples were wrapped in aluminum foil and put in the oven at 60 °C for 12 hours. This process is called polymerization process. Then the aluminum foil was opened, the samples were put back into the oven at 103 ± 2 °C for 24 hours.

Weight Percent Gain (WPG) and Density

The analysis were carried out according to the BS 373:1957. The parameters used are WPG and density which can be obtained using the following formula:

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

$$\rho\ (g/cm^3) = \frac{B}{V}$$

Information :
W_1 = Weight of oven dry sample before treament (g)
W_2 = Weight of oven dry sample after treatment (g)
B = Weight after or before treatment (g)
V = Volume after or before treatment (cm^3)

Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and Hardness

The MOE, MOR and hardness samples were made measuring 2.5 cm x 2.5 cm x 41 cm which refers to the ASTM D 143-94. This test used the Instron brand Universal Testing Machine (UTM). The hardness analysis was performed by inserting half a steel ball with a diameter of 1 cm and a cross-sectional area of 1 cm^2 into the wood. The ball is pressed 0.5 cm deep. MOE, MOR and hardness values can be obtained using the formula:

$$MOE\ \left(\frac{kg}{cm^2}\right) = \frac{\Delta PL^3}{4\Delta Ybh^3}$$

$$MOR\ (kg/cm^2) = \frac{3PmaxL}{2bh^2}$$

$$H\ \left(\frac{kg}{cm^2}\right) = \frac{Pmaks}{A}$$

Information :
MOE = Modulus of Elasticity (kg/cm^2)
MOR = Modulus of Rupture (kg/cm^2)
H = hardness value (kg/cm^2)
Pmax = Maximum load (kg)

ΔP = Load under proportion limit (kg)
ΔY = Deflection at load P (cm)
L = Spacing distance (cm)
b = Sample width (cm)
h = Sample thickness (cm)
A = cross-sectional area (cm^2)

Resistance to Dry Wood Termite Attack

Testing for dry wood termites was carried out referring to the Indonesian National Standard (SNI) 7207: (2014). Prepare a sample measuring (2.5 x 2.5 x 5) cm, then trim it using a cutter and code the sample according to the treatment given. The wood sample was then dried in an oven at 103 ± 2 °C until a constant weight was then weighed (W_1). Glass pipes (paralon) are sterilized by wiping a tissue or cotton that has been given 70% alcohol. The pipe is glued to the sample of wood with hot glue. As many as 50 healthy and active worker caste dry wood termites of uniform size were prepared. Termites had to be collected carefully using chicken feathers from the colony container and then put into a petri dish. Fifty dry wood termites of the worker caste were put into a glass tube and then covered with cotton. The wood samples were stored in a dark room at room temperature for 12 weeks. Every 4 weeks, termite activity is observed by removing the cotton and then putting it back on. After 12 weeks, the glass tube was disassembled and the number of live termites on the surface of the sample was counted. After that, clean the wood sample and put it in the oven at 103 ± 2 °C until the weight is constant. then weighed (W_2). Then, calculate the percentage of termite mortality and the percentage of weight loss. The classification of wood resistance to dry wood termites can be seen in Table 1. A sketch of testing the resistance of wood to dry wood termites *Cryptotermes cynocephalus* on a laboratory scale can be seen in Figure 1.

$$\text{Mortality (\%)} = \frac{D}{50} \times 100\%$$

$$WL = \frac{(W_1 - W_2)}{W_1} \times 100\%$$

Where :
D = Number of dead termites after testing
50 = Number of initial termites
WL = Percentage of weight loss (%)
W_1 = Initial oven-dry weight sample (g)
W_2 = Oven-dry weight sample after testing (g)

Graveyard Field Test

Testing for subterranean termites was carried out according to ASTM D 1758-06. Samples measuring (2.5 x 2.5 x 41) cm were sanded until smooth and one end was coated with paint. Sample dimensions were measured with calipers. Samples were oven-dried at 103 ± 2 °C to constant weight and weighed (W_1). Then the samples were planted for 12 weeks in the Arboretum of the Faculty of Forestry and Environment. The distance between the test samples was 30 cm x 60 cm (for the treated samples) (Figure 2). A map of the location of each sample that has been planted in the field is made to facilitate observation and data collection. The condition of the samples was observed every four weeks.

Observations are made to check the condition of the sample which is seen above the soil surface (observations may not remove the sample). After 12 weeks, the sample was removed carefully. The sample was cleaned from the soil and then dried for ± 7 days then put into the oven at 103 ± 2 °C until the weight was constant and weighed (W_2). Then calculate the percentage of weight loss with the formula:

Table 1. Classification of wood durability to dry wood termites *Cryptotermes cynocephalus* (SNI 01-7207-2014)

Class	Durability	Weight Loss (%)
I	Very Durability	< 2.0
II	Hold	2.0 – 4.3
III	Moderate	4.4 – 8.1
IV	Not Durability	8.2 – 28.1
V	Very intolerable	>28.1

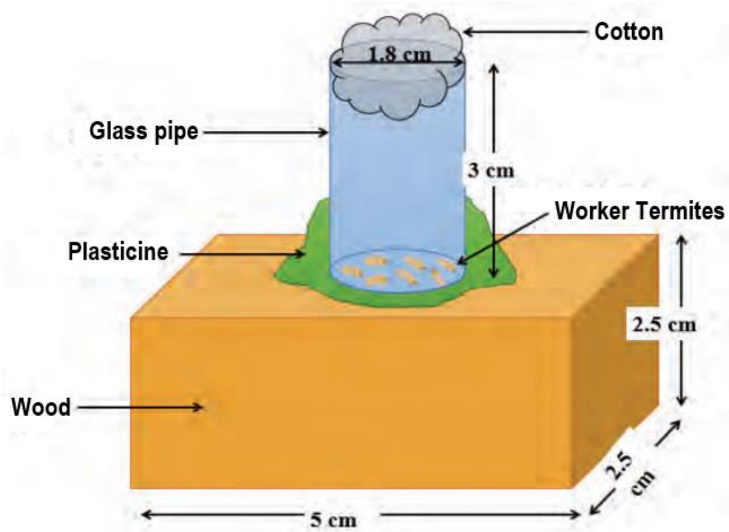

Figure 1. Sketch of testing wood's resistance to dry wood termites.

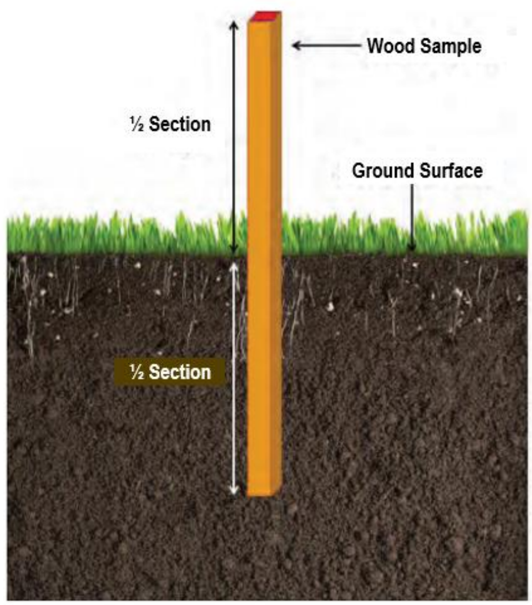

Figure 2. Test sample planting sketch.

$$WL=\frac{(W_1\text{-}W_2)}{W_1}\times 100\%$$

Information :
WL = Percentage of weight loss (%)
W_1 = Initial oven-dry weight sample (g)
W_2 = Oven-dry weight sample after testing (g)

Data Analysis

The data analysis used in this study was a completely randomized design with two factors; impregnation solution treatment factor (control, MFFA and MFFA Nano-SiO_2 0.5%) and wood species factor (ganitri and jabon).

Results and Discussion

Weight Percent Gain (WPG) and Density

WPG values of ganitri and jabon wood changed when treated with MFFA Nano-SiO_2 0.5% as shown in Figure 3. This shows that the WPG value increased due to the addition of MFFA and MFFA Nano-SiO_2 0.5%. The highest WPG values for ganitri and jabon wood were produced by MFFA Nano-SiO_2 0.5% which had respective values of 59.15% and 75.68%.

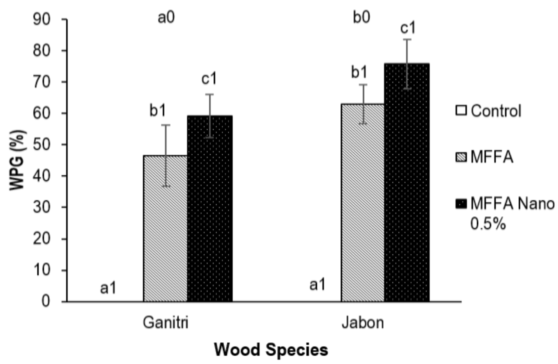

Figure 3. WPG ganitri and jabon woods.

Analysis of variance showed that the interaction between the concentration of the impregnation solution and the wood species factor had a significant effect on WPG. The results of Duncan's further test showed that the WPG in each treatment was not significantly different.

This is in line with Prihatini (2020a) that the addition of MFFA and MFFA Nano-SiO_2 can improve the value of WPG. The higher WPG value for jabon wood is due to the larger pore diameter of jabon wood compared to ganitri wood. According to Martawijaya *et al.* (2005) which states that the pore diameter of jabon is 130-220 µm, and the number of pores is 2-5 per mm^2, while ganitri wood has 84.06-117.94 µm with a number of pores of 5-7 per mm^2.

The density of ganitri and jabon wood obtained from the test showed an increase with the addition of MFFA and MFFA Nano-SiO_2 0.5% solutions. The resulting density value is shown in Figure 4. The highest density values of ganitri and jabon wood were produced by MFFA Nano-SiO_2 0.5%, respectively 0.74 g/cm^3 and 0.59 g/cm^3.

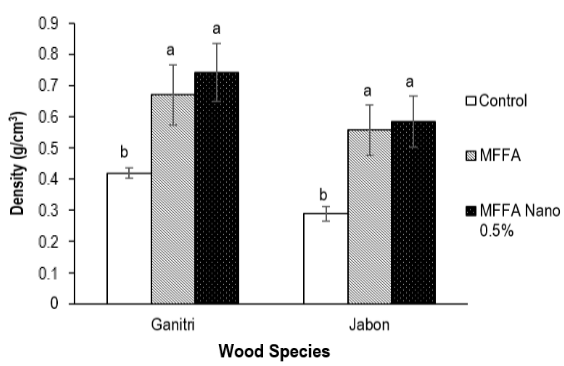

Figure 4. Density ganitri and jabon woods.

The results of the analysis of variance showed that the factors of wood type and impregnant solution had a significant effect on density, but the interaction of the two factors had no significant effect on density. In the further Duncan test results, the control treatment was significantly different from the other two treatments, while MFFA and MFFA Nano-SiO_2 0.5% were not significantly different.

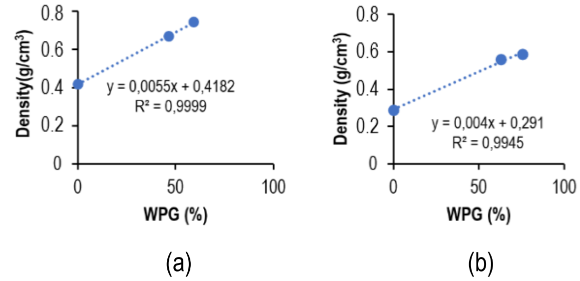

Figure 5. Density comparison with WPG: (a) ganitri; (b) jabon woods.

Based on Figure 5, it is known that the WPG value is directly proportional to the density value of gantri and jabon woods. This is presumably due to the penetration of the impregnant solution to fill in the voids in the cell walls and wood lumen. This is in line with the research of Hazarika and Maji (2013) which stated that when the MFFA and Nano-SiO_2 were treated, the empty cell walls and lumens were filled. This causes the WPG value and density to increase.

Modulus of Elasticity (MOE)

The elastic modulus shows the ratio between strain and stress below the elastic limit, so that the object will return to its original shape when released (*Mardikanto et al.* 2011). The MOE value generated in this research is presented in Figure 6. Impregnation treatment of MFFA and MFFA Nano-SiO_2 0.5% increased MOE compared to the control shown in Figure 6. The values of ganitri and jabon woods impregnated with MFFA Nano-SiO_2 0.5% were 8214.29 MPa and 7127.27 MPa, respectively.

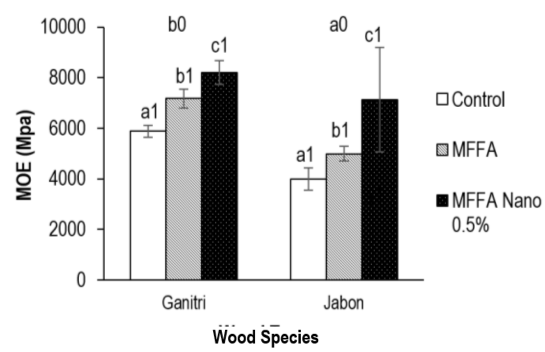

Figure 6. MOE of ganitri and jabon woods.

The results of the analysis of variance showed that the interaction of the impregnation solution concentration factor and the type of wood did not significantly affect the MOE value, but the impregnation solution concentration factor and the wood species factor had a significant effect on the MOE value. Duncan's further test showed that the MOE values of the control, MFFA, and MFFA Nano-SiO_2 0.5% were significantly different.

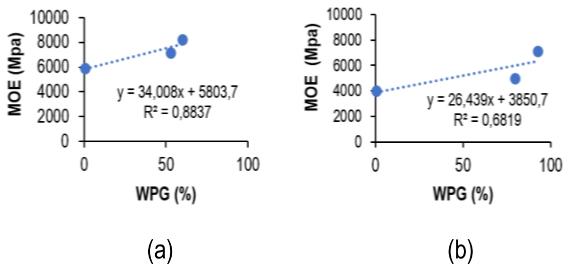

Figure 7. Relationship between MOE and WPG values: (a) ganitri; (b) jabon woods.

Based on Figure 7, the increase in MOE value is directly proportional to the increase in WPG. A high WPG value will be followed by an increased MOE value, and vice versa. This is in accordance with research by Riadhi (2017) which stated that the MOE value of sengon wood produced increased in each treatment because Monoethylene Glycol (MEG) and Nano-SiO_2 entered the wood cell walls and filled the empty cell cavities.

Modulus of Rupture (MOR)

MOR in wood shows the resilience of wood in resisting deflection caused by the maximum load received by the wood (Mardikanto *et al.* 2011). The MOR value generated in this study is presented in Figure 8.

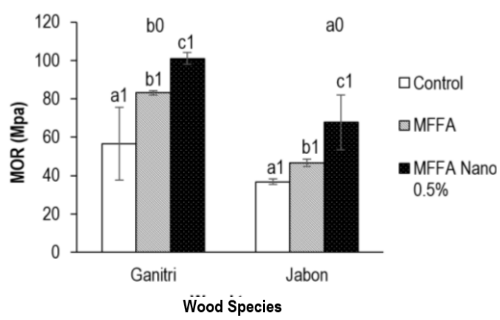

Figure 8. MOR of ganitri wood and jabon woods.

Based on Figure 8 it is known that MFFA and MFFA Nano-SiO_2 0.5% impregnation treatment can increase MOR compared to control. The highest MOR values were obtained in the MFFA Nano-SiO_2 0.5% treatment of ganitri and jabon woods, respectively 101.08 MPa and 67.69 MPa. Nano SiO_2 in the impregnation solution which is already present in the wood and fills the cavities and cell walls of the wood through impregnation, causing the resulting MOR value to be greater than the previous treatment. The wood species factor gives the MOR value of ganitri wood higher than jabon wood. As can be seen from Figure 8, the results of the MOR value with MFFA Nano-SiO_2 0.5% treatment is the optimal treatment. This is in line with Prihatini (2020a) which shows that the MFFA Nano SiO_2 concentration of 0.5% is the optimum concentration for impregnation of ganitri and jabon woods.

Analysis of variance showed that the impregnant solution concentration factor and the wood type factor had a significant effect on the MOR value, but the interaction factor of the impregnant solution concentration and wood species had no significant effect on the MOR value.

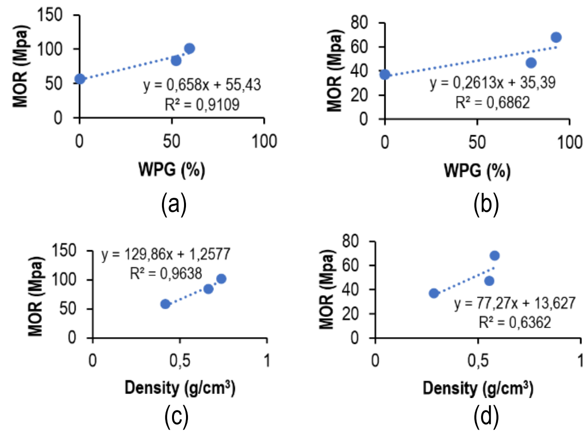

Figure 9. Relationship MOR with WPG of ganitri (a) and jabon woods (b); the relationship between MOR and density of ganitri (c) and jabon woods (d)

Based on Figures 9a and 9b it is known that the WPG value is directly proportional to the MOR value of gantri and jabon woods. Similarly, density is directly proportional to MOR (Figure 9c and 9d). This is thought to be due to polymers penetrating into the wood cell walls and wood cavities. The addition of Nano-SiO_2 concentration can increase the MOR value due to dense wood pores thereby increasing the stiffness of wood (Hoseini *et al.* 2014). The higher the density, the stronger the tested wood is marked by the high MOR value, this is in accordance with the statement of Bowyer *et al.* (2007) that the density of a material is directly proportional to the resulting MOR value.

Hardness

The hardness value of wood can be influenced by several factors, such as density, wood tenacity, adhesion between wood fibers and arrangement of wood fibers (Mardikanto *et al.* 2011). Because wood is anisotropic, it is known that there is radial hardness and tangential hardness. The hardness values produced in this study are presented in Figures 10 and 11.

Figure 10. Radial hardness of ganitri and jabon woods.

Based on Figure 10, the radial hardness value obtained has increased in each treatment. Impregnation of MFFA Nano-SiO_2 solution significantly increased the hardness of ganitri and jabon woods, but the increase in hardness of MFFA-impregnated specimens was not significant. Impregnation results in the MFFA Nano-SiO_2 0.5% treatment showed the highest values for the radial hardness of ganitri and jabon wood, respectively 776.73 kg/cm^2 and 479.89 kg/cm^2.

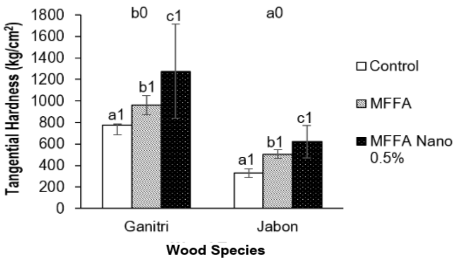

Figure 11. Tangential hardness of ganitri and jabon woods.

The tangential hardness value increased when given the treatment shown in Figure 11. Impregnation treatment with MFFA and MFFA Nano-SiO_2 solution can increase the hardness value obtained. Impregnation results in the MFFA Nano-SiO_2 0.5% treatment showed the highest tangential hardness values of ganitri and jabon woods, 1275.91 kg/cm^2 and 621.74 kg/cm^2 respectively.

Analysis of variance showed that the interaction between the concentration of the impregnant solution and the wood species did not show a significant effect on the radial hardness value, but the interaction had a significant effect on the tangential hardness. The concentration factor of the impregnant solution and the factor of the wood species showed a significant effect on the radial and tangential hardness.

Ganitri wood has higher radial and tangential hardness values than jabon wood. The MFFA Nano-SiO_2 0.5% treatment gave the highest value of all treatments. The results of Duncan's further test showed that the radial and tangential hardness values for each treatment were significantly different.

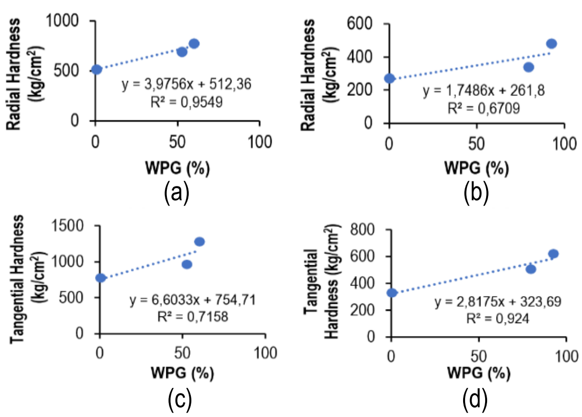

Figure 12. Radial hardness relationship with WPG of ganitri (a) and jabon woods (b); tangential hardness relationship with WPG of ganitri (c) and jabon woods (d).

Based on Figure 12 it shows that the hardness value increases with the addition of the WPG value. Small Nano-SiO_2 particles can spread over a wider surface and have a stronger hardness value on the surface (Zhuang and Chen 2019). The results showed that the tangential hardness was higher than the radial hardness. This is caused by differences in the thickness of the cell wall and the orientation of the constituent cells in each plane. In general, the tangential wall is thicker than the radial wall because there are more holes on the radial wall so that the hardness is lower. According to Bowyer *et al.* (2007) on the radial side, the incoming force will be greeted by the radius cells which are in an open (widened) condition so that the steel ball can penetrate the surface of the wood because it is known that the fingers are the cells that make up wood with thin to very thin walls (Pandit *et al.* 2011).

Resistance to Dry Wood Termite Attack

The value of resistance to attack by drywood termites is indicated by the value of the proportion of mortality and weight loss of wood after being fed drywood termites (*Cryptothermes cynocephalus*). The proportion of wood mortality in treated ganitri and jabon wood increased, this caused the proportion of weight loss in ganitri and jabon wood to be lower. The results of the mortality test produced in the study are shown in Figure 13 and the proportion of weight loss in Figure 14.

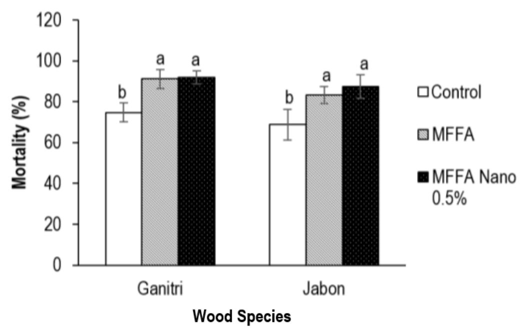

Figure 13. Average mortality percentage of samples after three weeks of feeding *C. Cynocephalus*

Based on Figure 13, the percentage of mortality increased in each treatment. The presence of Nano-SiO_2 in the MFFA solution can increase the durability of wood. Impregnation results in the MFFA Nano-SiO_2 0.5% treatment showed the highest mortality percentage values for ganitri (92%) and jabon (87.6%) wood. The results of Duncan's further test stated that the control treatment was significantly different from the other treatments, while the MFFA and MFFA Nano-SiO_2 0.5% were not significantly different. The results of the analysis of variance showed that the impregnant solution type concentration factor and the wood species factor had a significant effect on the mortality percentage of dry wood termites, while the interaction factor between the impregnant solution concentration and wood species had no significant effect on the mortality percentage value.

According to Prihatini (2020a) based on the results of SEM (Scanning Electron Microscope) analysis, jabon and ganitri woods before being treated had empty holes, but after being treated with MFFA and MFFA Nano-SiO_2 0.5%, they became evenly covered. It is suspected that this causes the percentage value of mortality to increase which can also increase the toxicity of wood. An indication of the presence of Nano-SiO_2 can be detected by the presence of some white precipitates on the cell walls and gaps between the cells of the jabon and ganitri wood after being impregnated.

The addition of MFFA and MFFA Nano SiO_2 0.5% resulted in a decrease in the percentage value for weight loss as shown in Figure 14. The percentage value for weight loss in the MFFA Nano-SiO_2 0.5% treatment for ganitri and jabon woods had the lowest value of 2.08% and 2.16%, respectively. Ganitri and jabon woods added with Nano SiO_2 can increase resistance to dry wood termite attack. The addition of 0.5% Nano-SiO_2 into the MFFA solution can produce a low value of the proportion of weight loss for each wood. The toxic substances present in wood make it difficult for termites to eat wood. This is supported by research by El-bandary and El-Halaly (2013) which showed that plants treated with Nano-SiO_2 particles could increase their toxicity to insect attacks. Based on research by Zhang *et al.* (2011) Nano-SiO_2 particles are toxic particles apart from ZnO_2, TiO_2 and Al_2O_3.

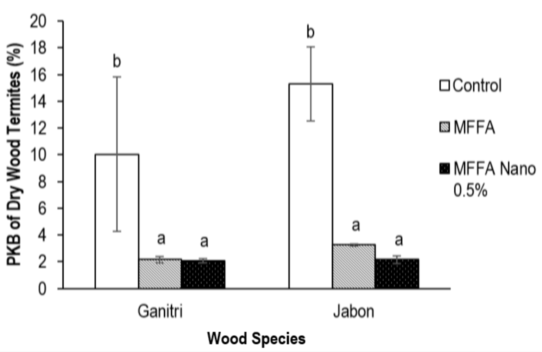

Figure 14. Percentage of weight loss in dry wood termite testing

The results of Duncan's further test stated that the control treatment was significantly different from the other treatments, while the MFFA and MFFA Nano-SiO_2 0.5% treatments were not significantly different. The results of the analysis of variance showed that the interaction factor between the concentration of the impregnant solution and the wood species did not have a significant effect on the proportion of weight loss after dry wood termite testing, but the concentration of the impregnant solution and the wood species had a significant effect on the proportion of weight loss.

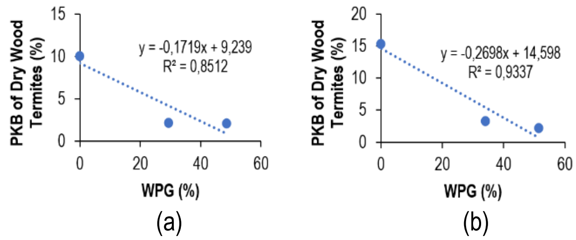

Figure 15. Relationship between weight loss percentage and WPG: (a) ganitri and (b) jabon woods.

The relationship between the WPG value and the percentage of weight loss is inversely proportional, if the WPG value is high, then the percentage value of weight loss is low. This can be seen in Figure 15. According to Zhang *et al.* (2011), Nano-SiO_2 particles are toxic particles, so that the resistance of wood to attack by wood destroying organisms can be increased which is marked by a low percentage of weight loss.

Graveyard Field Test

Graveyard Field Tests can be seen through the percentage of wood weight loss caused by wood destroying factors. The lower the weight loss of the wood produced, the higher the level of durability of the wood. The results of the wood grave test produced in the study are shown in Figure 16.

Based on Figure 16, it shows that MFFA and Nano-SiO_2 impregnation treatment can increase the durability of wood. The lowest value was obtained from the MFFA Nano-SiO_2 0.5% treatment for ganitri and jabon woods, respectively 7.82% and 7.76%. The impregnation treatment of MFFA and MFFA Nano-SiO_2 0.5% had a significant effect on the percentage of weight loss. The results of Duncan's further test showed that the ganitri and jabon graveyard test values in the control treatment were significantly different from the other two treatments, while MFFA and MFFA Nano-SiO_2 0.5% were not significantly different.

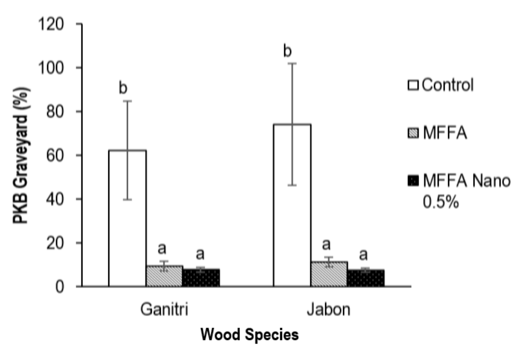

Figure 16. Percentage of Weight Loss (PKB) graveyard test

Ganitri and Jabon Statistical test results of analysis of variance showed that the concentration of the impregnant solution and the type of wood had a significant effect on the weight loss percentage of the ganitri and jabon wood grave tests, while the interaction factors between the two had no significant effect.

Nano-SiO_2 can increase the durability of wood, this is indicated by the decrease in the percentage of weight loss produced. This is supported by Khoerudin (2021) who shows that silica nanoparticles added to the impregnation solution can increase the resistance of sengon and jabon woods in destroying organisms which is reflected in the low percentage value of weight loss.

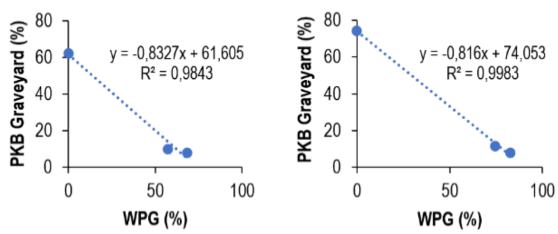

Figure 17. Relationship between Weight Loss Percentage (PKB) and WPG: (a) ganitri; (b) jabon woods.

The relationship between the WPG value and the percentage of weight loss is inversely proportional, if the WPG value is high, then the percentage value of weight loss is low. This can be seen in Figure 17. This is presumably because the Nano-SiO_2 particles can increase the resistance of wood to wood destroying organisms. The factor of the addition of MFFA and Nano-SiO_2 makes the value of wood hardness increase which makes it more difficult for wood termites to eat, so that the resistance of the wood also increases (Tampubolon *et al.* 2015).

Conclusions

Impregnation treatment using a mixture of 0.5% Nano-SiO_2 MFFA was able to increase the values of density, MOE, MOR, hardness and the percentage value of dry wood termite mortality and reduce the percentage of weight loss after being fed to dry wood termites and grave tests.

Ganitri and jabon woods treated with MFFA Nano-SiO_2 with a concentration of 0.5% is the optimum value for now in this study which can increase the strength and durability of the wood. The strong class of ganitri wood has changed, namely from strong class III-IV to III, as well as to jabon wood which initially had a strong class IV-V to IV. In addition, the durability class has also changed in ganitri and jabon woods from durable class IV-V to II.

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