



# Mechanical Properties and Durability of Impregnated Sengon Wood Using Monoethylene Glycol and SiO<sub>2</sub> Nanoparticles

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## ABSTRACT

Sengon wood (*Falcataria moluccana* Miq.) is a short-rotation wood which has weak quality characteristics, i.e., low specific gravity, strength, durability, density, and dimensional stability. This study aimed to find out the impact of monoethylene glycol (MEG) and SiO<sub>2</sub> nanoparticle impregnation treatment on mechanical properties (MOE, MOR, and hardness) and wood durability. Four kinds of solution were used to impregnate sengon wood: untreated (water), 50% MEG, MEGSiO<sub>2</sub> 0.5%, and MEGSiO<sub>2</sub> 1%. The impregnation process was initiated by applying 0.5 atm of vacuum for 60 minutes, followed by 2.5 bar of pressure for 120 minutes. The results showed that MEG and SiO<sub>2</sub> nanoparticle impregnation treatment significantly affected the mechanical properties (MOE, MOR, and hardness) and the durability of sengon wood against dry wood and subterranean termite bites. The optimum treatment to increase the properties of sengon wood so that its strength class increases to III-IV and durability class IV was MEG SiO<sub>2</sub> 1% treatment.

**Keyword:** Durability, Impregnation, Mechanical Properties, MEG, Sengon, SiO<sub>2</sub> Nanoparticles



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## 1. Introduction

Sengon wood (*Falcataria moluccana* Miq.) is a short rotation wood widely cultivated in people's forests. Its rapid growth means it can be harvested at a young age. However, this advantage leads sengon wood to have low quality, including low specific gravity, high moisture content, thin cell walls, and poor durability [1]. As a result, this wood is only utilized for building pillars, house ceilings, and so on [2]. Several studies in Indonesia found that sengon wood is commonly used as construction materials [3], wood pellets [4], plywood [5], and pulpwood [6] Meanwhile, this wood also has potential use for pulp and paper in a worldwide [7], wood veneer, medium-density particleboard, hardboard, wood wool board, blackboard, wooden toys, wooden shoes, musical instruments, general turnery [8], wood panel, cabinets, and furniture [9]. Based on the work of Rahayu et al. [10], sengon wood aged 5, 6, and 7 years old consists of 100% juvenile wood. Previous research reported that sengon wood has a specific gravity of 0.33, wood density of 1.3 – 0.5 g/cm<sup>3</sup>, hardness of 112 – 122 kg/cm<sup>2</sup>, strength class of IV – V, durable class of IV – V, and resistance to termite class of III [11].

Several methods have been developed for its quality improvement. One promising method that has recently attracted the interest of many researchers is the wood impregnation method [12]. Wood impregnation is a

treatment inserting chemicals into the lumen, vessels, and cell walls of wood, followed by polymerization to obtain the certain desired properties of wood [13]. This process usually uses non-toxic chemicals to avoid the possibility of damaging wood, and the environment, or even endangering humans [14], [15]. The chemicals commonly used in this process are styrene [16], methyl methacrylate (MMA) [17], furfuryl alcohol (FA) [18], and monoethylene glycol (MEG) [19], and success in improving the physical properties of fast-growing wood.

Monoethylene glycol (MEG) is known to have excellent characteristics. This chemical has perfect solubility in water, in liquid form with a sweet taste, odorless, molecular weight of 62.07 g/mol, and low volatility [20], [21]. On the other hand, this chemical is also known as an organic liquid that has been widely utilized as an antifreeze, coolant, heat transfer agent, raw material for polyester fiber manufacture, prevention gas hydrate formation, and absorb acid gases, namely carbon dioxide (CO<sub>2</sub>) and hydrogen sulfide (H<sub>2</sub>S). MEG can be used to stabilize wood, especially for large pieces like thick round slabs or wooden disks. It helps prevent shrinkage and cracking during drying. When applied to wood, MEG penetrates deeply and hardens upon exposure to air. This creates a protective layer that enhances water resistance and durability [22]. MEG is more cost-effective than some specialized wood stabilizers like Pentacryl [23]. Therefore, the use of MEG is very profitable for wood modification, of course, this is one of the solutions to the global warming issue which is currently widespread [24].

In the present work, MEG is combined with SiO<sub>2</sub> nanoparticles to enhance sengon wood's quality, especially in its mechanical properties and durability against termites. SiO<sub>2</sub> nanoparticles are usually found as filler, absorbent, drying powder, catalyst substrate, and anticorrosion agent [25]. SiO<sub>2</sub> can act as a support material for homogeneous catalysts used in MEG synthesis. Additionally, SiO<sub>2</sub> can be used in the synthesis of alkoxy silanes, which are useful chemicals derived from SiO<sub>2</sub> and alcohols like MEG [26]. Silanol functional groups (Si–OH) are formed on the silica surfaces after they have been exposed to water or alcohol molecules. By the presence of a hydrolytic reaction of siloxane groups (Si–O–Si), it breaks the Si/O bonds. These silanol groups can also dissociate through the solvation provided by other molecules in the medium. The silica surface develops a solvate layer in the liquid phase that has an affinity for stronger hydrogen bonds. This hydrogen bond is established between the liquid molecules and the silanol groups (Si–OH) surface by creating this layer [27].

Previously, SiO<sub>2</sub> nanoparticles have been investigated in combination with other chemicals to modify numerous fast-growing kinds of wood and produce high physical-mechanical properties and characteristics of wood [18], [28]–[31]. The modified wood can exhibit various new features, including thermal stability [32], fire resistance [33], abrasion resistance [34], and durability against UV aging [35]. Thus, combining MEG and SiO<sub>2</sub> nanoparticles is a brilliant idea for producing high-quality and innovative modified wood. The stability of SiO<sub>2</sub> nanoparticles' dispersions in ethylene glycol is excellent at room temperature [36]. The zeta potential of SiO<sub>2</sub> nanoparticles in 50% aqueous ethylene glycol (EG) is about -80 mV. The solubility of silica in monoethylene glycol (MEG) depends on several factors, including temperature, pressure, particle size, pH, and structure. SiO<sub>2</sub> nanoparticles of solubility in MEG increases with temperature. At pH below 8, the solubility ranges from 0.5 to 1 wt% [37].

The same treatment was already performed using SiO<sub>2</sub> nanoparticles synthesized from bamboo stems and leaves, allowing the sengon wood to have high physical properties, dimensional stability, and good characteristics, such as light wood color, high crystallinity, and the presence of Si–O–Si and Si–O–C group bonds between SiO<sub>2</sub> nanoparticles and chemical wood components [38]–[40]. By decreasing the solubility of dissolved ions in MEG, SiO<sub>2</sub> nanoparticles create these phenomena that interact with the wood matrix and promote crystal growth as temperature and nanoparticles increase [41]. SiO<sub>2</sub> nanoparticles have a significant impact on reducing the activation energy by more than 50% that necessary for nucleation and crystallization, contributing to the formation of bigger primary nuclei that form superior crystal structures in MEG solution [42]. However, the data regarding the mechanical properties and resistance to termites of wood-modified MEG and SiO<sub>2</sub> nanoparticles are still restricted. Dong et al. [31] declared that the enhancement occurred in some parameters of mechanical properties, such as hardness, compressive strength, and modulus of elasticity (MOE) of poplar wood. The addition of SiO<sub>2</sub> nanoparticles concentration in the composite can improve the modulus of rupture (MOR) because the nanoparticles occupy the cell cavities and result in the wood being more solid [43]. Accordingly, this study is carried out to determine the impact of MEG and SiO<sub>2</sub> nanoparticles on the durability and mechanical properties of sengon wood.

## 2. Materials and Methods

### 2.1 Materials

Materials used in this study were 5-year-old sengon wood (*Falcataria moluccana* Miq.) originating from a people forest in Cibereum, Bogor, West Java (6°35'09.6"S, 106°43'48.5"E). This wood has a branch-free height of around 10 meters with a diameter of 29.29 cm. The solution was prepared using monoethylene glycol (MEG) (Merck), distilled water, and SiO<sub>2</sub> nanoparticles from Anhui Elite Industrial Co. Ltd., China (particle size of 15 ± 5 nm).

### 2.2 Methods

#### 2.2.1 Wood sample manufacture

Chainsaw and table circular saw were used to cut sengon wood without recognizing sapwood and heartwood portions. The wood samples in the air-dried condition were cut into several dimensions which can be seen in Table 1. A total of 50 wood samples will be utilized in this study, with 10 repetitions for each test to obtain an even data distribution. Subsequently, these samples were oven at 103 ± 2 °C until reached the constant weight before the impregnation process and will be tested for the mechanical properties and durability of sengon wood.

**Table 1.** The wood sample dimensions for various tests

No	Tests	Sample Dimension (cm <sup>3</sup> )	Standards
1	Modulus of elasticity (MOE) test	2.5 × 2.5 × 41	ASTM D143: 22 [44]
2	Modulus of rupture (MOR) test	2.5 × 2.5 × 41	ASTM D143: 22 [44]
3	Hardness test	2.5 × 2.5 × 41	ASTM D143: 22 [44]
4	Field test	2 × 2 × 41	ASTM D1758: 06 [45]
5	Dry wood termites test	2.5 × 2.5 × 5	SNI 7207: 2014 [46]

#### 2.2.2 Wood impregnation process

Before the impregnation began, the mixing process of MEG and SiO<sub>2</sub> nanoparticles was carried out using a sonicator (Cole Parmer) with an amplitude of 40% for 60 minutes to obtain the homogeneous solution. The impregnation was conducted in water (untreated), 50% MEG, and 50% MEG with two levels of concentration of SiO<sub>2</sub> nanoparticles, namely 0.5% and 1%. The specimens were placed in the impregnation tube, then the solution was poured into it. The samples were immersed in the solution under a vacuum condition of 0.5 atm for 60 minutes, followed by 2.5 bar of pressure for 120 minutes. Afterward, the wood samples were wrapped the wood using aluminum foil and keep them in room temperature for 12 hours for the polymerization process, then moved to the oven at 103 ± 2 °C for 12 until reached constant weight [31], [38].

#### 2.2.3 Mechanical properties and durability tests

##### Mechanical properties test

A Universal Testing Machine (UTM) brand Instron 3369 manufactured in Buckinghamshire, UK, was utilized for modulus of elasticity (MOE) and modulus of rupture (MOR) tests via the single-point loading method. This test was conducted in the tangential plane of the wood sample with a loading speed of 3.5 mm/min. These parameters can be measured using the following formulas (Eq. 1 and Eq. 2).

$$MOE (MPa) = \frac{\Delta PL^3}{4\Delta ybh^3} \quad (1)$$

$$MOR (MPa) = \frac{3P_{max}L}{2bh^2} \quad (2)$$

where  $\Delta P$  is the load changes that occur under the proportion limit (kg),  $L$  is the span of supports (cm),  $\Delta y$  is the deflection change due to the load (cm),  $b$  is the width of the cross-section of the sample (cm),  $h$  is sample thickness (height of cross-section) (cm), and  $P_{max}$  is the maximum load (kg). Furthermore, the classification of wood strength classes is analyzed by the Indonesian Construction Wood Regulations standards [47].

The hardness test was carried out by weighing the wood sample by inserting half a steel ball with a diameter of 1.12 cm with a cross-sectional area of 1 cm<sup>2</sup> into the wood, then pressing the half steel ball to a depth of 0.56 cm. The hardness value is the average hardness in the radial and tangential areas. The equation used to determine this parameter is written below (Eq. 3).

$$H \text{ (kg/cm}^2\text{)} = \frac{P_{max}}{A} \quad (3)$$

This test is the comparison between the maximum load (kg) (Pmax) and the cross-sectional area (A).

#### Durability test

The durability test is conducted by feeding 50 dry wood termites (*Cryptotermes cy노cephalus*) to each wood sample for 12 weeks. The untreated and impregnated wood was tested using the medium in the form of a 5 cm long plastic pipe and secured using wax. The percentage of mortality (MR) and weight loss (P) against dry wood termite attacks can be calculated using the following formulas (Eq. 4 and Eq. 5).

$$MR \text{ (\%)} = \frac{D}{50} \times 100\% \quad (4)$$

$$P \text{ (\%)} = \left[ \frac{W_1 - W_2}{W_1} \right] \times 100\% \quad (5)$$

where D is the number of dead termites, 50 is the initial number of termites used, W1 is the air-dried weight of wood before termites feeding (g), and W2 is the air-dried wood after termites feeding (g). The durability wood classification against dry wood termite attacks is based on SNI 01 – 7207 – 2014 [46].

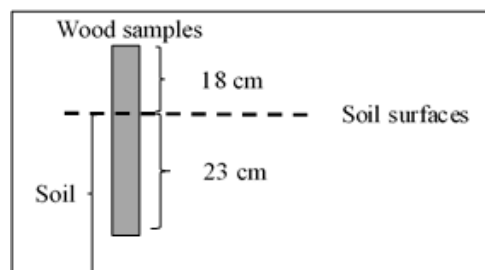


**Figure 1.** The illustration of dry wood termites feeding on sengon wood

The graveyard field test was conducted for 12 weeks in the Forestry Arboretum of IPB University, Dramaga, Bogor, West Java. This area was located at 06°33' South Latitude and 106°45' East Longitude with a height of 207 meters above sea level. In this test, wood samples were oven-dried until reached the constant weight, then wood samples were buried randomly with a 40 cm sample spacing, 60 cm rows spacing, and approximately 23 cm depth. After three months, samples were taken from the soil and cleaned, followed by oven-dried samples until constant weight and weighed it. The weight loss percentage was calculated using the Eq. 6.

$$P \text{ (\%)} = \left[ \frac{W_1 - W_2}{W_1} \right] \times 100\% \quad (6)$$

where W1 is the oven-dried wood samples before being tested and W2 is the oven-dried wood samples after being tested on termites. The value of wood damage due to subterranean termite attacks is based on ASTM D1758 – 06 [45] and SNI 01 – 7207 – 2014 [46].



**Figure 2.** The illustration of graveyard field test

#### Data analysis

A completely randomized design was used in this study and analyzed using ANOVA, followed by the Duncan test at 95% accuracy. This analysis was carried out in IBM SPSS Statistics (Statistical Package for Service Solutions) 23.0 version.

### 3. Result and Discussion

#### 3.1 Mechanical Properties of Impregnated Wood

The mechanical properties of sengon wood are known to experience improvement. As known, the efficiency of a wooden structure is determined by its modulus of elasticity (MOE) [48]. It can be seen in Table 2, that there is a significant improvement in the MOE of sengon wood after being impregnated with MEG and SiO<sub>2</sub> nanoparticles compared to the untreated wood. The increase of MOE for all treated sengon woods was significantly different from each other, and the highest MOE was achieved by the MEGSiO<sub>2</sub> 1% wood. This occasion was suspected due to the solution containing MEG and SiO<sub>2</sub> nanoparticles successfully penetrating and filling the wood cell wall. Dirna et al. [19] mentioned that the addition of SiO<sub>2</sub> nanoparticles can increase the MEG distribution inside the wood lumens, thereby MEG can cover all the wood pores. Moreover, Hill [12] explained that the chemicals that occupied the wood were cross-linked with the free O-H groups in the wood polymer chain surfaces and replaced water molecules. It is also suspected that SiO<sub>2</sub> nanoparticles were crystallized in the wood, thus increasing the mechanical properties of sengon wood.

The increase in wood crystallization is known to be caused by the transformation of wood's chemical composition and microscopic morphology, especially in cellulose and lignin which have an important role in improving the wood elastic modulus [49]. This is supported by several studies that have reported that SiO<sub>2</sub> nanoparticles covered the amorphous regions of wood and significantly enhanced the MOE, MOR, toughness, flexural, compressive, and bending strength, as well as wood hardness [50]-[51]. These results are superior to the MOE results of Rahayu et al. [39] even though they used the same chemical and concentration, but it can be expected that the initial MOE of the sengon wood in this study was higher than those. In addition, a previous study also demonstrated that SiO<sub>2</sub> impregnation can maintain the mechanical properties of rubber wood, including its MOE and MOR, although the wood was exposed to heat treatment [52]. The following is Table 2 which presents the results of the mechanical properties of impregnated sengon wood along with the physical properties such as weight percent gain (WPG) and wood density that have previously been evaluated by Rahayu and the team [40]. That study used the same sengon wood as a material, therefore, the physical properties were not retested in this study.

**Table 2.** The mechanical properties results of sengon wood after impregnation completed

Treatments	Physical Properties [40]		MOE (MPa)	MOR (MPa)	Hardness (kg/cm <sup>2</sup> )
	WPG (%)	Density (g/cm <sup>3</sup> )			
Untreated	0 <sup>a</sup>	0.3 ± 0.02 <sup>a</sup>	4,285.04 ± 214.25 <sup>a</sup>	30.22 ± 1.51 <sup>a</sup>	101.31 ± 5.07 <sup>a</sup>
50% MEG	26.4 ± 7.2 <sup>b</sup>	0.3 ± 0.03 <sup>ab</sup>	4,637.51 ± 185.50 <sup>ab</sup>	34.30 ± 1.37 <sup>ab</sup>	108.83 ± 3.26 <sup>b</sup>
MEGSiO <sub>2</sub> 0.5%	29.6 ± 9.7 <sup>b</sup>	0.4 ± 0.03 <sup>bc</sup>	5,463.37 ± 136.58 <sup>bc</sup>	39.14 ± 0.98 <sup>bc</sup>	125.88 ± 2.52 <sup>c</sup>
MEGSiO <sub>2</sub> 1%	32.4 ± 12.0 <sup>b</sup>	0.4 ± 0.05 <sup>c</sup>	6,019.50 ± 120.39 <sup>c</sup>	41.58 ± 0.83 <sup>c</sup>	129.35 ± 2.59 <sup>c</sup>

<sup>a-c</sup> Duncan's test results indicate significant differences in each treatment

As seen in Table 2, the WPG of sengon wood improved slightly after being incorporated using MEG and SiO<sub>2</sub> nanoparticles whose concentration continues to increase. Although they did not make a significant difference statistically. Likewise, wood density also rose linearly with the WPG of impregnated sengon wood and the results differ from each other. This is a strong reason for the increase in the MOE of sengon wood after the impregnation process. Similar to the MOE, an improvement was also observed in the MOR of sengon wood, with the wood containing MEGSiO<sub>2</sub> 1% achieving the highest MOR. Statistical analysis also proved the significant difference in all treatments of impregnated sengon wood along with increased SiO<sub>2</sub> nanoparticle concentration. It has previously been discovered that the improvement in WPG and wood density has a positive correlation with the improvement of elastic modulus and hardness of the modified wood [53].

MEG is known to be classified as a hydrophilic chemical and has a small molecular weight, so it easily dissolves in water and penetrates through the small wood pores [54]. By MOE and MOR, the hardness of sengon wood also increased after impregnation treatment. Wood hardness is affected by certain parameters, namely wood density, elasticity, wood fiber size, and bonding strength of wood fiber [55]. The highest hardness wood in this study is obtained by the MEGSiO<sub>2</sub> 1% wood. Wang et al. [56] disclosed that the cage of SiO<sub>2</sub> nanoparticles restricts the segmental motion of the chemical chains of its medium via nano-detention, thereby this hybrid material can improve the internal rigidity of the composite. The combination of SiO<sub>2</sub>

nanoparticles with several chemicals such as polyethylene glycol (PEG), polyvinyl alcohol (PVA), melamine formaldehyde furfuryl alcohol (MFFA), urea-formaldehyde (UF), and glyoxal-urea also increases wood dimensional stability against water absorption which is proportionally related to the increase of wood MOE, MOR, compressive and bending strength, hardness, thermal stability, and flame resistance [57]–[61]. These chemicals are known to have a higher molecular weight compared to MEG, so it is ensured that the mixture of MEG and SiO<sub>2</sub> nanoparticles can penetrate well into the wood cell walls and cross-link with the wood matrix.

SiO<sub>2</sub> nanoparticles which are deposited to the wood lumens replace the water content within the wood that has been previously evaporated during the drying process in the oven, then accelerate the mineralization process of wood. The mineralization process involves the incorporation of minerals into organic material, either naturally or through other modification processes [62]. It can occur because of the subsequent SiO<sub>2</sub> nanoparticles deposited within the wood cell walls and decompose to its structure, especially if the amount is excessive [12], [63]. After being dissolved in water, the SiO<sub>2</sub> nanoparticles were depolymerized and their amorphous regions expanded, but they returned to their crystal structure after the polymerization process had been carried out. Chain structures were formed in a linear process resulting from the condensation of two silanol groups during polymerization, leading to the growth of nanoparticles in the wood lumens [64]. Accordingly, it can enhance the wood's mechanical properties as well as its physical properties of sengon wood after the impregnation process has been done. From Table 2, it can also be seen that the hardness of all sengon wood treatments has a significant improvement as shown by the statistical result, which is in line with the improvement of SiO<sub>2</sub> nanoparticle concentration. Based on the increasing value of MOE, MOR, and hardness, it can be inferred that sengon wood after being incorporated by MEG and SiO<sub>2</sub> nanoparticles experienced an improvement from a strength class of IV to IV-III, according to Indonesian Construction Wood Regulations standards [47].

### 3.2 The Resistance of Dry Wood Termite Attacks

The resistance of impregnated sengon wood to the dry wood termite attacks has been tested on a laboratory scale. Table 3 shows the increasing termite mortality happens linearly to the addition of SiO<sub>2</sub> nanoparticles and the highest mortality is reached in the MEGSiO<sub>2</sub> 1% wood. Termites require adequate sustenance. In this laboratory test, they were left without food except for wood samples in the containers to survive. Insufficient food intake during the test period can cause fatalities of termites [65]. The lowest mortality in the untreated wood indicates that this wood is more suitable for termite feed compared to others, in line with the findings of Miyafuji and Minamoto [66]. As reported by Grace and Yamamoto [67], MEG had a significant effect on termite mortality. It can be seen in Table 3 that the addition of chemical components also improved the termite mortality significantly, even though the MEGSiO<sub>2</sub> 0.5% and 1% did not make any differences. This is because the addition of SiO<sub>2</sub> nanoparticle concentration levels leads to termite mortality continuing to rise until it approaches 100%. Rahayu et al. [68] also revealed the same effect in SiO<sub>2</sub> addition combined with melamine formaldehyde furfuryl alcohol against the dry wood termite resistance in *ganitri* wood. The presence of SiO<sub>2</sub> nanoparticles is known to have high toxicity against pests, including dry wood termites [69]. Termite mortality of the untreated wood was relatively high is suspected due to the evaluation conducted in a limited room without controlling the temperature and humidity, as happened in Hadi et al. [70] which mentioned subterranean termite mortality of the untreated jabon wood in a laboratory scale reached 76%.

**Table 3.** The termite mortality and weight loss of the sengon wood

Treatments	Mortality (%)	Weight loss (%)
Untreated	60.67 ± 3.03 <sup>a</sup>	22.37
50% MEG	84.00 ± 2.52 <sup>b</sup>	17.07
MEGSiO <sub>2</sub> 0.5%	94.00 ± 1.88 <sup>c</sup>	15.27
MEGSiO <sub>2</sub> 1%	98.67 ± 1.97 <sup>c</sup>	13.11

<sup>a-c</sup> Duncan's test results indicate significant differences in each treatment

Inversely proportional to the mortality, the weight loss of the untreated wood is the highest as predicted. It is considered that the wood durability increases with the higher proportion of SiO<sub>2</sub> nanoparticles added to the MEG solution, as evidenced by the further reduction in the weight loss rate in impregnated sengon wood. High termite mortality due to the toxic SiO<sub>2</sub> almost completely prevents wood damage that typically occurs when termites consume their food so the wood weight does not decrease too much [71]. Silicon compounds provide a barrier effect at the wood cell wall, thus reducing termite access to wood components [64]. According to SNI

01 – 7207 – 2014 [46], sengon wood which previously possessed a durable class of IV-V then after being impregnated using MEG and SiO<sub>2</sub> nanoparticles classified into the durable class of IV.

### 3.3 Graveyard Field Test

The same result also happened in the graveyard field test, MEG and SiO<sub>2</sub> nanoparticles had an impact on mitigating the sengon wood's weight loss (Table 3). Although the weight loss of all treated sengon woods did not show significantly different results, it gradually decreased in inverse proportion to the addition of SiO<sub>2</sub> nanoparticle concentration. The untreated wood still shows the highest weight loss against termite attacks, meanwhile, the MEG-treated wood still has a higher number of weight loss compared to the wood treated with SiO<sub>2</sub> nanoparticles.

**Table 4.** The weight loss of sengon wood obtained from graveyard field test

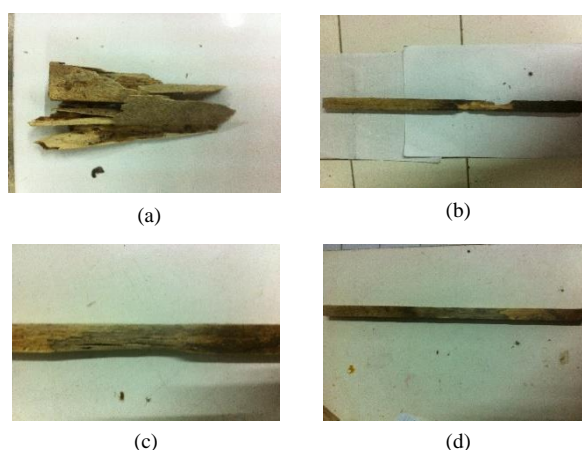
Treatments	Weight loss (%)
Untreated	81.86 ± 4.09 <sup>a</sup>
50% MEG	17.52 ± 0.53 <sup>b</sup>
MEGSiO <sub>2</sub> 0.5%	16.24 ± 0.49 <sup>b</sup>
MEGSiO <sub>2</sub> 1%	16.10 ± 0.48 <sup>b</sup>

<sup>a-b</sup> Duncan's test results indicate significant differences in each treatment

The weight loss obtained through this test is relatively higher than the dry wood test on a laboratory scale. Leaching was the main issue in this study, field testing allows the wood to be exposed to weather conditions. It is known that the rainfall intensity measured in the location was 344.77 mm/month, which is classified as high rainfall [72]. The high rainfall intensity helps the development of termites and the expansion of their underground area [73]. This problem can be overcome by adding SiO<sub>2</sub> nanoparticles which the concentration increases gradually. This was found to result in less weight loss and improved durability of sengon wood [64]. As a result, this test led to wood damage which is presented in Table 5 and Figure 3. The lowest value indicates heavy damage while the highest value shows light damage.

**Table 5.** Damage value of sengon wood after field test

Repetitions	Treatments			
	Untreated	50% MEG	MEGSiO <sub>2</sub> 0.5%	MEGSiO <sub>2</sub> 1%
1	0	0	8	9
2	0	4	7	8
3	0	6	8	9



**Figure 3.** Sengon wood condition after damaged by the subterranean termites (a) untreated wood, (b) 50% ME, (c) MEGSiO<sub>2</sub> 0.5%, and (d) MEGSiO<sub>2</sub> 1%

From Table 5, it can be concluded that the untreated wood has the most devastated wood caused by subterranean termites as indicated by a damage value of zero in all three repetitions. It is also supported by the wood condition shown in Figure 3a which is that sengon wood was shattered leaving only a few pieces or suffering serious damage. Then, the condition of sengon wood improved after adding MEG and SiO<sub>2</sub> nanoparticles with increasing concentrations. Even though the results did not significantly differ statistically,

the wood appearance of MEGSiO<sub>2</sub> 1% wood (Figure 3d) became better compared to 50% MEG wood (Figure 3b) which experienced moderate damage, and MEGSiO<sub>2</sub> 0.5% wood (Figure 3c) which had light damage. Therefore, in this case, impregnation of MEG and SiO<sub>2</sub> nanoparticles can improve the sengon wood grade in terms of durability from IV-V to IV, based on SNI 01 – 7207 – 2014 [46].



**Figure 4.** The subterranean termite worker that are caught in the wood samples

After 12 weeks of testing, it was found that sengon wood was attacked by the subterranean termite worker (Figure 4). This termite was identified as *Microtermes insperatus* Kemner, as previously found by Hadi et al. [74] in their research around the same area. This termite is classified into the subfamilies of Microtermitinae and the genus of *Microtermes* [75]. *Microtermes* sp. is the most dominant subterranean termite species which consumes the wood [76]. Characteristics of the soil where the test was conducted are assumed to contain high amounts of clay and C-organic, thereby facilitating termite colonies to build a nest and modifying clay mineral compositions [77].

#### 4. Conclusion

Significant differences occurred in the mechanical properties (e.g. MOE, MOR, and hardness) of sengon wood after being impregnated using MEG and SiO<sub>2</sub> nanoparticles. MEG and SiO<sub>2</sub> nanoparticle's successful penetration was also proven by the reduction of sengon wood weight loss which was inversely proportional to the high mortality of termites fed. The optimum treatment to obtain the best mechanical properties and durability in this study was MEGSiO<sub>2</sub> 1%. Based on the results acquired in this study, impregnated sengon wood is classified as strength class III-IV and durability class IV.

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