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Mechanical Properties and Durability of Impregnated Sengon Wood Using Monoethylene Glycol and SiO_2 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_2 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_2 0.5%, and MEGSiO_2 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_2 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_2 1% treatment.

Keyword: Durability, Impregnation, Mechanical Properties, MEG, Sengon, SiO_2 Nanoparticles

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^3, hardness of 112 – 122 kg/cm^2, 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_2) and hydrogen sulfide (H_2S). 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_2 nanoparticles to enhance sengon wood's quality, especially in its mechanical properties and durability against termites. SiO_2 nanoparticles are usually found as filler, absorbent, drying powder, catalyst substrate, and anticorrosion agent [25]. SiO_2 can act as a support material for homogeneous catalysts used in MEG synthesis. Additionally, SiO_2 can be used in the synthesis of alkoxysilanes, which are useful chemicals derived from SiO_2 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_2 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_2 nanoparticles is a brilliant idea for producing high-quality and innovative modified wood. The stability of SiO_2 nanoparticles' dispersions in ethylene glycol is excellent at room temperature [36]. The zeta potential of SiO_2 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_2 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_2 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_2 nanoparticles and chemical wood components [38]–[40]. By decreasing the solubility of dissolved ions in MEG, SiO_2 nanoparticles create these phenomena that interact with the wood matrix and promote crystal growth as temperature and nanoparticles increase [41]. SiO_2 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_2 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_2 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_2 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_2 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^3)	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_2 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_2 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).

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

$$MOR\ (MPa) = \frac{3PmaxL}{2bh^2} \tag{2}$$

where ΔP is the load changes that occur under the proportion limit (kg), L is the span of supports (cm), Δy 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 Pmax 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^2 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).

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

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 cynocephalus*) 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).

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

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

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.

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

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].

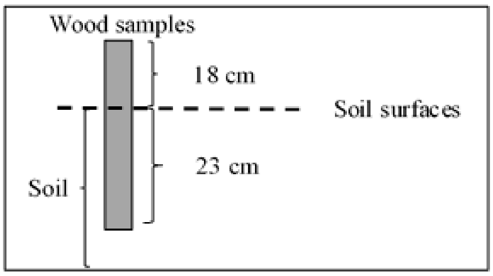

Figure 2. The illustration of graveyard field test

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_2 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_2 1% wood. This occasion was suspected due to the solution containing MEG and SiO_2 nanoparticles successfully penetrating and filling the wood cell wall. Dirna et al. [19] mentioned that the addition of SiO_2 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_2 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_2 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 SiO2 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^2)**
	WPG (%)	**Density (g/cm^3)**			
Untreated	0^a	0.3 ± 0.02^a	$4{,}285.04 \pm 214.25^a$	30.22 ± 1.51^a	101.31 ± 5.07^a
50% MEG	26.4 ± 7.2^b	0.3 ± 0.03^{ab}	$4{,}637.51 \pm 185.50^{ab}$	34.30 ± 1.37^{ab}	108.83 ± 3.26^b
MEGSiO_2 0.5%	29.6 ± 9.7^b	0.4 ± 0.03^{bc}	$5{,}463.37 \pm 136.58^{bc}$	39.14 ± 0.98^{bc}	125.88 ± 2.52^c
MEGSiO_2 1%	32.4 ± 12.0^b	0.4 ± 0.05^c	$6{,}019.50 \pm 120.39^c$	41.58 ± 0.83^c	129.35 ± 2.59^c

[a-c] 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_2 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_2 1% achieving the highest MOR. Statistical analysis also proved the significant difference in all treatments of impregnated sengon wood along with increased SiO_2 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_2 1% wood. Wang et al. [56] disclosed that the cage of SiO_2 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_2

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_2 nanoparticles can penetrate well into the wood cell walls and cross-link with the wood matrix.

SiO_2 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_2 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_2 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_2 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_2 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_2 nanoparticles and the highest mortality is reached in the MEGSiO_2 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_2 0.5% and 1% did not make any differences. This is because the addition of SiO_2 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_2 addition combined with melamine formaldehyde furfuryl alcohol against the dry wood termite resistance in *ganitri* wood. The presence of SiO_2 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^a	22.37
50% MEG	84.00 ± 2.52^b	17.07
MEGSiO_2 0.5%	94.00 ± 1.88^c	15.27
MEGSiO_2 1%	98.67 ± 1.97^c	13.11

[a-c] 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_2 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_2 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_2 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_2 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_2 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_2 nanoparticles.

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

Treatments	Weight loss (%)
Untreated	81.86 ± 4.09^a
50% MEG	17.52 ± 0.53^b
MEGSiO$_2$ 0.5%	16.24 ± 0.49^b
MEGSiO$_2$ 1%	16.10 ± 0.48^b

$^{a-b}$ 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_2 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$_2$ 0.5%**	**MEGSiO$_2$ 1%**
1	0	0	8	9
2	0	4	7	8
3	0	6	8	9

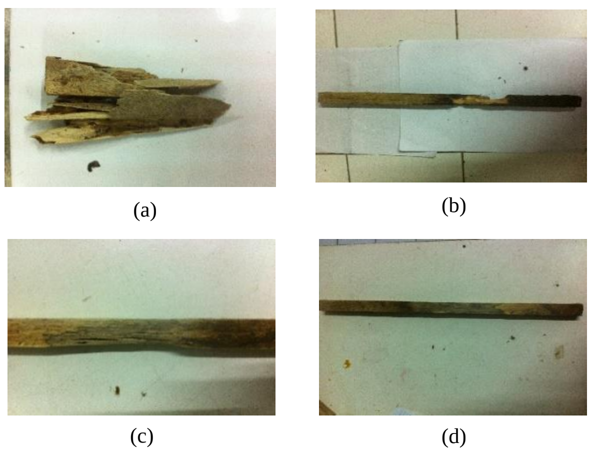

Figure 3. Sengon wood condition after damaged by the subterranean termites (a) untreated wood, (b) 50% ME, (c) MEGSiO$_2$ 0.5%, and (d) MEGSiO$_2$ 1%

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_2 nanoparticles with increasing concentrations. Even though the results did not significantly differ statistically, the wood appearance of $MEGSiO_2$ 1% wood (Figure 3d) became better compared to 50% MEG wood (Figure 3b) which experienced moderate damage, and $MEGSiO_2$ 0.5% wood (Figure 3c) which had light damage. Therefore, in this case, impregnation of MEG and SiO_2 nanoparticles can improve the sengon wood grade in terms of durability from IV-V to IV, based on SNI 01 – 7207 – 2014 [46].

(a) (b)

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_2 nanoparticles. MEG and SiO_2 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 $MEGSiO_2$ 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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