Color Changes and Resistance Against Subterranean Termites Attack of Furfuryl Alcohol Impregnated Pine and Sengon Woods Through Graveyard Test

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Abstract. Pine (Pinus merkusii Jungh. & de Vriese) and sengon (Falcataria moluccana (Miq.) Barneby & J.W. Grimes) are common species of woods used for many purposes. Both species are known susceptible against subterranean termite attack. This study aims to analyze the effect of furfuryl alcohol impregnation on color changes and the resistance against subterranean termites of pinewood and sengon after in-ground test for one year. Furfurylated pine and sengon woods reached weight percent gain 31.2% and 79.1%, densities 0.93 g/cm³ and 0.43 g/cm³, moisture content 3.27% and 2.88%, respectively. Furfurylated pine and sengon woods have lost weight 4.07% dan 2.09%, respectively, with the average resistance level of 9.8 on both woods while untreated pine and sengon woods lost weight were 59.02% and 35.58%, with resistance level 4 and 3.8, respectively. Resistance level scoring was conducted by referring to ASTM D1758-06. Higher resistance level and lower weight loss on both furfurylated woods compared to untreated woods showed that furfurylation could increase the wood resistance against termite attack.

1. Introduction
Pine (Pinus merkusii Jungh et de Vriese) is a species of softwood mainly used as furniture, pulp and paper raw material, matchstick, and plywood. Pine belongs to durability class III-V [1] and is known as attractant for termites [2]. Those two characteristics of pine cause the susceptibility of pinewood against subterranean termites attack. Sengon (Falcataria moluccana (Miq.) Barneby & J.W. Grimes) on the other hand, is a kind of hardwood species also prone to subterranean termites attacks because of its low durability class. Susceptibility of pine and sengon against subterranean termites attack cause the need of wood modification to increase the resistance against subterranean termites of both wood.

Furfurylation is a chemical wood modification process which will create bonds through chemical reaction on wood’s cell wall [3]. Furfuryl alcohol is a derivative of furfural which has been widely used as rocket fuels, wood adhesive, pharmaceutical compound, industrial solvent, and wood preservatives [4]. According to Mulyosari et al. [3], furfurylated wood has higher dimensional stability, lower hygroscopicity and higher resistance against decay. Furfuryl alcohol is known as non-toxic and can be obtained from agricultural waste thus considered as a green chemical [4].

Surface color is one of the most important characteristics of woods. Besides of its physical and mechanical properties, consumer’s preference of woods is also determined by its color thus affecting
wood’s market price [5]. The surface color of woods may change because of wood modification and exposure to the outdoor environment [6]. During the in-ground test, woods will be exposed to UV light, water and weather change, therefore it is suspected that surface color of woods will be changed.

Evaluation of wood resistance against subterranean termite attacks through in-ground tests on furfuryl alcohol impregnated pine and sengon woods as well as untreated pine and sengon woods needs to be carried out. In-ground test can resemble actual outside wood use conditions. It was thus chosen as the testing method in this research. Such testing is necessary to compare the interaction of furfuril alcohol with wood types towards the discoloration that occurs as well as in improving the resistance of wood against subterranean termite’s attack.

2. Method
2.1. Sample preparation
Pine and sengon woods were acquired from Bogor, West Java. Samples were cut into 20 cm in length and 2 cm x 1 cm in cross-section, and then kiln-dried until 12% moisture content is reached. Samples physical properties were then tested on this research according to ASTM D 143-94 [7].

2.2. Impregnation process
Samples were impregnated by referring to Hadi et al. [8] with furfuryl alcohol and tartaric acid 5% (b/v) as catalyst. Before the impregnation process, samples were oven-dried for 48 hours under the temperature of 60±2°C. Samples then weighted for its initial weight (B0). Impregnation process was conducted under 5 atm pressure for 30 minutes. Samples were then wrapped using aluminum foil and then heated using oven at 100°C for 24 hours for the polymerization process [9]. Samples then weighted for its final weight (B1) after the impregnation process. The formula below shows the calculation of weight percent gain (WPG).

\[
WPG = \frac{B1 - B0}{B0} \times 100\%
\]

2.3. In-ground testing
In-ground testing conducted in this research refers to Hadi et al. [10] with a modification on the duration of testing. Samples were weighted before in ground test for it’s initial weight (W1). After 12 months, samples were dug and cleaned and then weighted (W2) for the calculation of weight loss. Weight loss calculation was conducted by referring to SNI 7207:2014 [11] using the formula below:

\[
WL = \frac{W1 - W2}{W1} \times 100\%
\]

Degradation analysis was conducted by comparing the total area of damage to the total surface area of said samples using a milimeter block. Resistance level analysis of degradation was conducted by refering to ASTM D 1758-06 [12] as shown in Table 1.

| Resistance levels | Attacks conditions                        |
|-------------------|-------------------------------------------|
| 10                | No attack                                 |
| 9                 | Nibbles to 3% of cross section            |
| 8                 | Penetration reached 3-10% of cross section area |
| 7                 | Penetration reached 10-30% of cross section area |
| 6                 | Penetration reached 30-50% of cross section area |
| 4                 | Penetration reached 50-75% of cross section area |
| 0                 | Failure                                   |
2.4. Color changes analysis

CIElab method was used for color change analysis with the help of Adobe Photoshop software. All samples were scanned using a scanner in order to obtain images of samples on the same level of contrast, brightness, and clarity [12]. The numerical value of lightness level (L*), red-green level (a*), and blue-yellow level (b*) of each sample was obtained using color picker feature on adobe photoshop. The formula below was used to calculate the color changes of each sample.

\[ AE^* = \sqrt{((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)} \]

- \( AE^* \): Numerical value of color change
- \( \Delta L^* \): Numerical value of change on lightness level
- \( \Delta a^* \): Numerical value of change on red-green level
- \( \Delta b^* \): Numerical value of change on blue-yellow level

Classification of color changes on each sample was conducted according to Klement and Marko [14] as shown in Table 2.

| Numerical value of color changes | Classification of color changes                  |
|----------------------------------|--------------------------------------------------|
| \(< 0.2\)                        | Not visible difference                            |
| \(0.2 < AE^* < 2.0\)             | Small difference                                  |
| \(2.0 < AE^* < 3.0\)             | Color difference visible with high quality screen |
| \(3.0 < AE^* < 6.0\)             | Color difference visible with medium quality screen |
| \(6.0 < AE^* < 12\)              | High color difference                             |
| \(AE^* > 12\)                   | Different color                                    |

2.5. Data Analysis

Data analysis method used in this research was factorial completely randomized design with five repetitions on each treatment. Microsoft Excel and IBM SPSS Statistics (Statistical Product and Service Solution) ver. 26 was used to analyze the data. There are two factors in this research which were species of woods (pine, sengon) and treatments (control, furfurylated).

3. Results and discussion

The densities of furfurylated pine and sengon woods and untreated pine and sengon woods were 0.93, 0.49, 0.63, and 0.39 g/cm³, respectively. Weight percent gain on pine wood and sengon wood after the impregnation process reached 31.2% and 79.1%. According to Mulyosari et al. [3], impregnation process will cause the furfuryl alcohol entering lumen and wood’s cell wall, which led to the increase of densities on both furfurylated woods in line with Hadi et al. [8] and Sejati et al. [15]. Impregnated pine and sengon woods reached WPG of 31.2% and 79.1%, respectively. According to Lande et al. [16], WPG value of woods that have been undergo impregnation process should be over 30% in order to have significant impact on its characteristics. In this research, WPG on both impregnated woods were over 30%, thus the effect of impregnation is considered feasible.

3.1. Moisture content

Results for moisture content (MC) of samples are shown in Table 3. Both furfurylated woods had lower moisture content compared to untreated woods. According to Mulyosari et al. [3], furfuryl alcohol is known to be hydrophobic, thus led to the low level of moisture content on furfurylated woods. Moreover, furfuryl alcohol inside the lumen will reduce the ability of wood to absorbs water. Besides, furfurylated wood is indicated to have poly-FA which will react with wood components, especially lignin thus leading to the hydrophobicity of furfurylated wood [17]. Statistical analysis showed that different treatment has a significant impact on samples moisture content (Table 4).
Table 3. Moisture content, weight loss, and resistance level of samples

| Type of wood | Treatment          | Moisture content (%) | Weight loss (%) | Resistance level |
|--------------|--------------------|----------------------|-----------------|-----------------|
| Pine         | Furfurylated       | 3.27±0.31            | 4.07±0.43       | 9.8±0.45        |
|              | Untreated (control)| 12.64±0.63           | 59.02±25.85     | 4±2.45          |
| Sengon       | Furfurylated       | 2.88±0.74            | 2.09±0.95       | 9.8±0.45        |
|              | Untreated (control)| 11.26±0.54           | 35.58±12.7      | 3.8±3.77        |

Table 4. Variance analysis summary of moisture content, weight loss, and resistance level

| Parameter                  | Moisture content (%) | Weight loss (%) | Resistance level |
|----------------------------|----------------------|-----------------|-----------------|
| Wood species               | ns                   | ns              | ns              |
| Treatments                 | **                   | **              | **              |

Remarks: ** Highly significantly different (p ≤ 0.01); ns = not significantly different

3.2. Weight loss
The weight loss percentage of the samples after 12 months of in-ground test are presented in Table 2. Both furfurylated woods had lower weight loss than untreated woods. Lower weight loss shows higher resistance of woods against subterranean termite attack. A previous study by Hadi et al. [17] also reported that furfurylated wood weight loss percentage only reached 3.0-3.5% after three months of in-ground test. Low weight loss percentage on previous study and furfurylated woods shows that furfurylation could increase wood resistance against subterranean termite attack. Higher weight loss on furfurylated pine woods were caused by attractant characteristics of pine wood [2]; thus, subterranean termites prefer to attack pine wood over sengon wood. Statistical analysis showed that difference in treatment has significant impact on samples weight loss.

3.3. Resistance level
The resistance levels of samples are presented in Table 3. Both furfurylated woods had higher resistance levels compared to untreated woods. According to ASTM D 1758 [12], resistance level 9.8 means that only 3% of cross-section is damaged. Hadi et al. [18] reported that resistance level of furfurylated wood after 3 months of in-ground test reached 9.9. In line with previous research, high resistance level of furfurylated woods on this research shows that furfurylation will increase woods resistance against subterranean termite attacks. Statistical analysis shows that difference in treatment has a significant impact on the samples resistance level.

3.4. Color changes of furfurylated wood
After 12 months of in-ground testing, both furfurylated woods and pine wood undergo change in color that belongs to different color category, according to Klement and Marko [13]. Based on Hadi et al [19] research, furfurylation process led to darker surface color of wood. According to Cirteioglu et al [20], consumers prefer woods with darker color rather than lighter color thus making difference in Lightness value (L*) as the main parameter on wood’s color change. Higher value of L* shows that the color of woods after in-ground test of 12 months is lighter compared to after only 3 months of in-ground test. Value of L*, a*, b*, and ΔE of furfurylated woods can be seen in Table 5. Lighter woods after in-ground test may be caused by weathering phenomenon. According to Cui et al. [21], weathering will cause changes in color, chemical, physical and mechanical properties of wood surface.

Table 5. Color changes of furfurylated pine and sengon woods after in-ground test

| Type of wood | Test period (month) | L* value  | a* value  | b* value  | ΔE    |
|--------------|---------------------|-----------|-----------|-----------|-------|
| Pine         | 12                  | 27.6±3.5  | 4.4±1.5   | 15.3±4.9  | 10.07±1.29 |
|              | 3                   | 23.1±3.4  | 4.73±1.8  | 6.26±4.4  | 0     |
| Sengon       | 12                  | 29.8±3    | 7.47±2.3  | 17.4±3.5  | 9.31±0.49 |
|              | 3                   | 25.7±3.6  | 6.73±1.9  | 12.73±4.3 | 0     |
4. Conclusion
Based on findings on this research, furfurylation caused difference in moisture content, weight loss, colour, and resistance level between furfurylated and untreated pine and sengon woods. Lower weight loss percentage and higher resistance level on furfurylated woods proves that impregnation of furfuryl alcohol increased pine and sengon woods resistance against subterranean termite attacks. Twelve months of in-ground test results in lighter color of woods.

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