Shear strength and subterranean termite resistance of polystyrene impregnated sengon (Falcataaria moluccana) glulam

Nurhanifah¹, D Hermawan¹*, Y S Hadi¹, W O M Arsyad², and I B Abdillah¹
¹Forest Products Department, Faculty of Forestry, IPB University, 16680, Bogor, Indonesia
²Forest Products Research and Development Centre, Ministry of Environment and Forestry, 16610, Bogor, Indonesia

*Email: mr.dede.hermawan@gmail.com

Abstract. The purpose of this study is to evaluate shear strength and improve the resistance of glulam from sengon (Falcataaria moluccana) wood through the preliminary treatment of polystyrene impregnation. Sengon lamina were impregnated with polystyrene and made into two-layer glulam using isocyanate adhesives. The glulam was tested for shear strength according to American Standard for Testing Materials D-905-98, and exposed to subterranean termite attack in the laboratory scale according to Indonesian standard SNI 7207-2014. The untreated glulam and solid wood were used as a comparison purposes, and the tested samples were six replicas. The polymer loading of polystyrene glulam was 28.7%. The results showed that shear strength of solid wood was not significantly different from glulam, it means that impregnation process of the styrene on sengon wood does not affect the gluing process. The polystyrene impregnated glulam had better resistant to termite attack than solid wood, but it was not significantly different from the untreated glulam. To get better resistance it could be further study for higher polymer loading in glulam manufacturing.

1. Introduction
Indonesian log supply as raw material for the industry was shifting from natural forests to plantations. The ratio of wood supply from natural forests is less than that of plantations forest [1]. Since wood from plantations dominantly planted with fast-growing wood species that have a short cycle [2]. One type of fast-growing wood that comes from plantations is sengon wood (Falcataaria moluccana). Sengon wood has a specific gravity of 0.33, strength class IV-V, and wood resistance class IV/V [3]. Sengon wood has sapwood and heartwood, which are usually difficult to distinguish [4]. Also, sengon wood commonly used as furniture, housing, and packaging boxes [5]. According to Basri et al. [6] and Fajriani et al. [7], fast-growing wood species had inferior properties because they contain juvenile wood. Juvenile wood has a low fiber dimension, so the density and strength of the wood are low [8]. One of several methods that can be done is to make biocomposite products such as glue-laminated lumber (glulam).

Glulam was composed of wood laminate with parallel laminae toward the preparation of fibers and then glued with an adhesive [9]. Glulam has advantages, one of which resulted in a higher strength beam than solid wood in the same dimension [10]. Glulam can be produced from small-diameter wood by
utilizing low-density wood [11]. However, glulam products made from fast-growing wood still have low-grade durability [12]. Therefore, preliminary treatment is needed in order to increase service life. Some methods have been developed to improve the quality of wood. One of several methods of wood modification is chemical treatment [13].

One of these chemicals is styrene. Styrene is one of the monomers commonly used for wood modification by filling cells in wood. Research on the impregnation of polystyrene on wood have been carried out on the topic such as physical and mechanical properties [14,15], and also termite and fungi resistance on tropical and subtropical wood [12,16,17]. Devi and Maji [18] were impregnated rubberwood with styrene and glycidyl methacrylate (GMA) showed that the presence of GMA as a crosslinking monomer improved the properties of Wood Plastic Composite (WPC). Impregnation of wood within mixing styrene and methyl methacrylamide (MMA) could increase the dimensional stability and resistance of wood [15]. Darma et al. [16] have been researched wood with a mixture of styrene monomers, vinyl acetate, and Copper Chrome Boron (CCB) with tertbutyl hydroperoxide as a catalyst showed produced a high level of resistance to fungus T. palustris. Also, Hadi et al. [17] and Hadi et al. [12] had researched several types of subtropical wood from Poland and tropical wood, resulting in that wood more resistance to dry wood and subterranean termite attacks and in a field test. However, information on impregnated polystyrene of the glulam is still limited. Therefore, the purpose of this research is to improve the quality of glulam from sengon wood through pretreatment with polystyrene impregnation.

2. Materials and Methods

2.1. Wood preparation

Glulam was made from sengon wood from Ciampea, Bogor, West Java, Indonesia. Each log had a diameter of around 20 cm and was cut into laminas with dimensions of 2.5 x 5 x 30 cm (thickness, width, and length, respectively). The best laminas were dried in the kiln to a moisture content of approximately 12%. The pretreatment of the lamina was done through immersion processes 24 hours with filling cell voids with a styrene monomer solution. To accelerate the polymerization process, the solution was added with potassium peroxodisulfate 0.5% (w/v). Polymer Loading (PL) was determined through weighing the wood specimen before treatment (W1) and after treatment (W2) at oven-dried condition. The PL was calculated using the following formula (1):

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

2.2. Glulam manufacturing

Glulam samples were made for size (5 x 5 x 30 cm). The sample consists of two-layers of laminas. The laminas were bonded with isocyanate adhesive type PI-3100 with a glue spread of 280 g/m² [18], followed by cold pressing with specific pressure of 10 kg/cm². The glulam samples were conditioned at room temperature for ten days before testing. For comparison, solid wood was prepared. Six test specimens were used for each treatment.

The physical and mechanical properties were tested according to JAS 234-2003 standard [19] and ASTM D-905-98 standard [20]. Physical properties were tested based on the Moisture Content (MC) and density, for mechanical properties were tested with a Universal Testing Machine (UTM) Chun Yen to determine the shear strength.

2.3. Subterranean termite test methods

The subterranean termite test using a laboratory scale. The test was based on Indonesian standard SNI 7207-2014 [21]. Before the test, the wood samples were oven-dried at a temperature of 103 ± 3°C until reaching constant weight (S1). Each test specimen was placed in a glass container with 200 g of sterilized sand with enough water to reach a moisture content of 7% under water-holding capacity. Two hundred healthy and active subterranean termite (Coptotermes curvignathus Holmgren) workers from a laboratory colony were added to each container (M1). The containers were put in a dark room at a
temperature of 25 to 30°C and 80 to 90% relative humidity for four weeks and weighed weekly. If the moisture content of the sand decreased by 2% or more, water was added to achieve moisture content standards. At the end of the 4-week test, the active subterranean termites were counted (M₂), and the wood samples were oven-dried at a temperature of 103 ± 3°C until reaching constant weight (S₂). Wood percent weight loss and termite mortality were determined using the following formula:

\[
\text{Percent weight loss (WL)} = \frac{(S_1 - S_2)}{S_1} \times 100\% \quad (2)
\]

\[
\text{Termite mortality} = \frac{(M_1 - M_2)}{M_1} \times 100\% \quad (3)
\]

Wood resistance class against subterranean termites was determined by referring to SNI 7207-2014, as shown in Table 1.

Table 1. Resistance class against subterranean termite

| Resistance class | Sample condition | Weight loss (%) |
|------------------|------------------|-----------------|
| I                | Very resistant   | < 3.52          |
| II               | Resistant        | 3.52-7.50       |
| III              | Moderately resistant | 7.50-10.96     |
| IV               | Poorly resistant | 10.96-18.94     |
| V                | Very poorly resistant | > 18.94       |

2.4. Data analysis
To analyze the effect of type of materials upon all responses (i.e. moisture content, shear strength, mortality, percent weight loss, and resistance class), a simple completely randomized design was used for data analysis. The data was analyzed using Microsoft Excel and IBM SPSS Statistics (Statistical Product and Service Solution) version 22. The factor was the type of materials (solid wood, untreated glulam, polystyrene glulam). Also, Duncan’s multiple range tests were used for further analysis if a factor was significantly different at \( p \leq 0.05 \).

3. Results and Discussion
The densities of solid sengon wood, untreated glulam, and polystyrene glulam were 0.28, 0.34, and 0.28 g/cm³, respectively. The PL of polystyrene glulam is 28.7%. These results are in line with the research of Hadi et al. [12], who impregnated with vacuum-pressure. Therefore, the impregnation of styrene monomers using the immersion method in sengon wood in this study is feasible.

Table 2. Moisture content, shear strength, mortality, percent weight loss, and resistance class

| Material          | Moisture content (%) | Shear strength (kg/cm²) | Mortality (%) | Weight loss (%) | Resistant class |
|-------------------|----------------------|-------------------------|---------------|-----------------|-----------------|
| Untreated glulam  | 11.44 (0.38)b        | 43.07 (13.25)a          | 70.0 (46.1)b  | 11.78 (1.56)b   | IV              |
| Polystyrene glulam| 11.60 (0.32)b        | 46.27 (25.21)a          | 71.1 (44.2)b  | 10.79 (2.91)b   | III             |
| Solid wood        | 9.79 (0.51)a         | 67.79 (5.80)            | 8.3 (2.7)     | 44.48 (9.65)    | V               |

Note: Values followed by the same letter in a column are not statistically different. The letter in the column is Duncan’s multiple range test

3.1. Moisture content
Results for MC of samples is shown in Table 2. The average value of the MC of all treatment amounted ranged from 9.79 to 11.60%. The MC of samples met the JAS 234-2003 standard, which requires a maximum value of 15%. Solid wood has a lower moisture content. Based on Duncan’s multiple range test of MC in Table 2, moisture content of untreated glulam and polystyrene glulam were same but
significantly different from solid wood. It caused the thin lamina will be easy to adjust to the surrounding environment, other than that the water contained in the adhesive will be trapped in the glulam. The thin lamina will be easy to adjust to the surrounding environment, other than that the water contained in the adhesive will be trapped in the glulam.

Table 3. Variance analysis of moisture content, shear strength, mortality, percent weight loss, and resistance class

| Parameter          | Sig.   |
|--------------------|--------|
| Moisture content   | 0.000* |
| Shear strength     | 0.131ns|
| Mortality          | 0.015**|
| Weight loss        | 0.000**|
| Resistant class    | 0.000**|

Note: **p < 0.01; ns, not significant

3.2. Shear strength

The shear strength values of the samples can be seen in Table 2. The average value of the shear strength of all materials ranged from 43.07 to 67.79 kg/cm². If we compared with the JAS 234-2003 standard, all glulam produced has met the JAS 234-2003 standard, which requires a minimum shear strength of 54 kg/cm². The results of the variance analysis (Table 3) showed that the type of material did not significantly different. It can be assumed that the pretreatment of polystyrene impregnation on sengon wood lamina does not affect the gluing process that occurs at the level of PL 28.7%. However, solid wood had a higher mean of shear strength.

According to Cahyono et al. [23], the value of solid wood shear strength will be higher than the glulam because, during the test, the wood was damaged, not on the glue line. Gluing quality can be affected by the type of wood, thickness of the lamina, and pressing process [24]. According to Komariah et al. [18], the lower the moisture content causes the shear strength value will be higher. The value of MC can influence the value of shear strength, if the MC is low, then the cell wall is more compact and dense so that the attractive force between cellulose molecules becomes stronger [25]. The value of sengon glulam shear strength in this study was similar to Lestari et al. [26], which made glulam from sengon wood with an isocyanate adhesive that is 47.2 kg/cm².

3.3. Resistance to subterranean termite attack

Results of mortality, percent weight loss, and resistance class of the samples can be seen in Table 2. Termite mortality for all type of material ranged from 8.3 to 71.1%. The type of materials has significantly different on mortality (Table 3). Solid wood has lower mortality than glulam. Based on Duncan’s multiple range test of mortality, untreated glulam and polystyrene glulam were same but significantly different from solid wood. This is due to styrene monomers in wood [27], and isocyanate adhesives [28] applied to composite products increase product durability, which causes many termites to die. The criteria for the level of toxicity of an impregnation material can be seen based on its percentage of mortality [29]. Mortality shows the number of termites that die during the testing process [30].

According to Arinana et al. [31], several other factors cause termites to die, namely the surrounding temperature, humidity, and light around the termites. According to Sari et al. [32], the vacuum-pressure method made styrene deeper into the cell walls, while the immersion method only enters to the lumen level of the wood. In this study, termites that died were most likely due to obstructions by styrene found in the lumen of the wood so that the termites were difficult to eat the wood. According to Hill [13], the impregnation of a monomer in the existing lumen of wood can form a barrier even though the barrier can change with time of use. In this research, the polystyrene impregnation process is said to be useful because it has a mortality value of more than 70%. According to Hadikusumo [33], if the mortality value of a test is a minimum of 70%, then the preservation treatment is effective.

The impact of weight loss (WL) is in line with the three types of materials. The percent WL of glulam ranged from 10.78 to 11.78%. That result was 3.9 times higher than WL from solid wood. The type of
materials has significantly difference on WL (Table 2). Based on Duncan’s multiple range test of WL, untreated glulam and polystyrene glulam were same but significantly different from solid wood. It could be assumed that the PL of polystyrene into sengon wood should be higher, so that polystyrene glulam is more resistant than untreated glulam. The PL at the level of 28.7% has been able to improve the resistance of sengon wood even though the results are not significantly different from the untreated glulam. These results are in line with research by Fatriasari et al. [34], Hadi et al. [12], and Wardani et al. [27], which showed that wood with low resistance could be improved through product modification and chemical modification. Regarding the Indonesian standard, all samples had average resistance classes ranged from 3.0-5.0, respectively. In other words, impregnation styrene enhanced resistance class to be 1.67 classes higher. Based on the analysis of variance, untreated glulam and polystyrene glulam were same but significantly different from solid wood. The treatment of styrene on wood lamina can increase the class of resistance to termite attack, from class V (solid wood) to class III on polystyrene glulam. We speculate that the styrene and glue line protected it from attack by termites.

4. Conclusion
The shear strength value of solid wood and glulams was not significantly different. The polystyrene impregnation process does not affect the adhesion process. Moisture content, mortality, and percent weight loss of polystyrene glulam have the same values as untreated glulam. Impregnation of polystyrene on sengon wood with the addition PL of 28.7% can increase the wood resistance class from class V (solid wood) to class III (polystyrene glulam). In order to get higher resistance class, a higher polymer loading is needed.

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