TECHNICAL NOTE: SUBTERRANEAN TERMITE RESISTANCE OF SMOKED GLUED LAMINATED LUMBER MADE FROM FAST-GROWING TREE SPECIES IN INDONESIA

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Abstract. The purpose of this study was to determine the resistance of smoked glued laminated lumber (glulam) against subterranean termites (*Coptotermes curvignathus* Holmgren) using Japanese standard JIS K1571-2004. Glulam was made from fast-growing wood species, namely *Acacia mangium* (mangium), *Maesopsis eminii* (manii), and *Falcataria moluccana* (sengon). The glulam was constructed with either the same species for all layers or mangium as the face and back layers and a core layer of manii or sengon. Glulams were smoked for 15 or 30 da using smoke of mangium wood, and glulam preserved with imidacloprid and untreated glulam were prepared for comparative purposes. Mangium smoke was found to predominantly produce acetic acid, cyclobutanol, phenolic compounds, and other polycyclic aromatic hydrocarbons that improved glulam resistance against subterranean termite attack. Smoked glulam had the same resistance against subterranean termites as imidacloprid-preserved glulam and was much more resistant than untreated glulam. Glulam smoked for 15 da had the same resistance as that smoked for 30 da.

Keywords: Smoked glulam, fast-growing tree species, subterranean termite, GC-MS, preservation.

INTRODUCTION

Glued laminated lumber (glulam) is constructed from suitably selected and prepared pieces of wood, either in a straight or curved form, with the grain of all pieces essentially aligned to be parallel along their longitudinal axes (Moody et al 1999). Glulam is an alternative product for structural material that uses wood from plantation forests, the amount of which increases every year (Massijaya 2014).

Most wood species in plantation forests are fast-growing trees that generally have a small diameter (less than 30 cm), short cutting cycles (5-10 yr), and inferior properties in terms of the amount of

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defects, durability, and strength compared with mature wood from a natural forest. Approximately 10 Mha of land is being developed for fast-growing tree species, such as sengon (*Falcataria moluccana*), manii (*Maesopsis eminii*), and mangium (*Acacia mangium*). These species are commonly planted in plantation forests and could feasibly replace timber from natural forests (Massijaya et al 2011).

Komariah et al (2015) measured physical–mechanical properties of glulam made from sengon, manii, and mangium, with either the same wood species for all layers or mangium face and back layers with a core layer of manii or sengon. Laminas were 10 and 17 mm thick. The results showed that glulam and solid wood of the same species did not differ and that the glulam successfully fulfilled the JAS 234-2003 standard. Although the glulam met the strength standard, it is likely that it could be attacked by destructive organisms such as termites because glulam made from fast-growing species usually consists of juvenile wood (Fajriani et al 2013). Pandit and Kurniawan (2008) reported that mangium can be categorized as durability class IV and sengon as durability class III. The service life of glulam can be extended with various preservative or chemical treatment methods. Imidacloprid improves wood resistance against termite attack (Majid et al 2007), but it is dangerous to organisms such as rabbits, birds, plants, and fish (Cox 2001). Kumar et al (2013) reported a human case that presented with severe gastrointestinal symptoms along with respiratory distress and neuropsychiatric features following accidental inhalational exposure to imidacloprid. Smoking is another alternative for improving glulam durability. Hadi et al (2010a, 2010b, 2015a) reported that smoked wood was more resistant to termite attack than untreated wood and its resistance classification increased by one class.

The purpose of this study was to perform a chemical analysis of mangium wood smoke by gas chromatography–mass spectrometry (GC-MS) and to determine the resistance of smoked glulam against subterranean termite attack in laboratory tests. Glulam specimens were treated with mangium wood smoke for 15 and 30 da, and imidacloprid-preserved and untreated glulams were also prepared for comparative purposes.

MATERIALS AND METHODS

Materials

The specimens consisted of three-layer and five-layer glulams constructed with either the same wood species for all layers or mangium for the face and back layers and a core layer of manii or sengon (Komariah et al 2015). The adhesive for glulam manufacturing was isocyanate PI-3100, a water-soluble polymer that consists of base resin and hardener (PT Polychemi Asia Pasifik, Jakarta, Indonesia).

Glulam Preservation

Glulam samples were made according to JIS (2004) but were modified for size (50 × 20 × 10 mm) and used to determine termite attack resistance. Air-dried mangium wood was pyrolyzed at 400°C to produce charcoal, and the resulting smoke (a by-product) was used for smoking the specimens for 15 and 30 da, respectively (Pari et al 2006). For the chemical preservation treatment, glulam surfaces were brushed with imidacloprid four times. All treated glulams were conditioned at room temperature for 1 mo prior to testing.

Smoke Analysis

Identification of chemical compounds in mangium wood smoke was performed using the wood vinegar that resulted from the condensation of the smoke. GC-MS was used to analyze the chemical compounds.

Subterranean Termite Test Methods

Test specimens were placed on a plastic net to avoid direct contact with the moistened layer of dental cement on the bottom of the cylindrical acrylic containers. *Coptotermes curvignathus* (150 workers and 15 soldiers) were put into each test container. Figure 1 depicts a diagram of the test method according to JIS (2004). Test

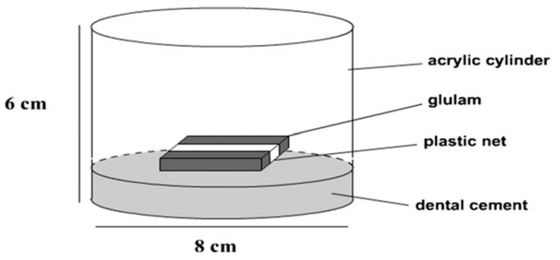

Figure 1. Diagram of the JIS K 1571-2004 standard (Arinana et al 2012).

containers holding termites were maintained at 28°C and 80% RH for 3 wk in a dark room (Arinana et al 2012).

Percentage weight loss of the individual glulam specimen was calculated by the difference in weight prior to and after the test according to Eq 1:

$$\text{Percentage weight loss} = (W_1 - W_2)/W_1 \times 100\% \quad (1)$$

where W_1 = oven-dried weight of specimen prior to the test (g), W_2 = oven-dried weight of specimen after the test (g).

In addition to the percentage weight loss, termite mortality was calculated according to Eq 2:

$$\text{Termite mortality}\,(\%) = \frac{\text{number of dead workers}}{150} \times 100\% \quad (2)$$

The feeding (wood consumption) rate was the most useful for comparing results obtained for wood species of different densities. For feeding rate calculations, termites were assumed to die linearly with time (Hadi et al 2015). Based on that assumption, the feeding rate was calculated according to Eq 3:

$$\text{Feeding rate}(\mu\text{g/termite/da}) = (\text{weight of wood eaten by termites}, \mu\text{g}) / \text{termites/test period(da)} \quad (3)$$

Data Analysis

According to Hadi et al (2014) and Pandit and Kurniawan (2008), sengon and mangium woods do not have differing resistance against attacks by subterranean termites. Therefore, data analysis for this study used completely randomized blocks in a factorial 2 × 4 design with three replications. The block factor was wood species (sengon, manii, mangium, mangium–sengon, and mangium–manii), the first factor in the factorial was the preservation method (untreated, smoked 15 da, smoked 30 da, and preserved with imidacloprid), and the second factor was the number of layers (three- and five-layer glulams). Tukey's test was used for further analysis if a factor was significantly different (Mattjik and Sumertajaya 2002).

RESULTS AND DISCUSSION

Smoke Analysis

GC-MS analysis revealed that mangium smoke consisted of acetic acid, cyclobutanol, trideuteroacetonitrile, phenol compounds, 1,6-anhydro-β-D-glucopyranose (levoglucosan), 1-acetoxycyclopenten-3-one, tetrahydro-2*H*-pyran-2-one (CAS) (5-valerolactone), propenoic acid, and 2,5-dimetoxytoluene (Table 1). The dominant compounds were acetic acid, cyclobutanol, phenolic compounds, and other polycyclic aromatic hydrocarbons (PAH).

The chemical compounds of mangium smoke were assumed to improve the resistance of glulam against subterranean termite attack, as suggested by Oramahi et al (2014) who reported that phenol and acetic acid were effective as wood preservatives against termite attack. Mangium wood smoke also contained several PAH, which are known to be formed during incomplete combustion or pyrolysis of organic material and are often produced through burning oil, gas, coal, and wood for energy. PAH compounds compose a class of complex organic chemicals that includes carbon and hydrogen with a fused ring structure containing at least two benzene rings (Ravindra et al 2008). PAH in environmental matrices have attracted substantial research interest in the last three decades because many of them are carcinogenic and mutagenic, causing irreversible changes in the

Table 1. Chemical analysis of the mangium wood vinegar using GC-MS.

No	Retention time(s)	Chemical compound	Concentration (%)
1	5.25	Acetic acid (CAS), ethylic acid	32.06
2	3.165	Cyclobutanol (CAS), cyclobutyl hydroxide	30.82
3	3.067	Trideuteroacetonitrile	8.78
4	13.95	4-Methyl-phenol (CAS), *p*-cresol	4.86
5	18.324	1,6-Anhydro-β-D-glucopyranose (levoglucosan)	3.99
6	13.782	2-Methoxy-phenol (CAS), guaiacol	3.92
7	18.517	1-Acetoxy-cyclopenten-3-one	3.60
8	16.583	2,6-dimetoxy-phenol (CAS), 2,6-dimethoxyphenol	3.23
9	13.575	Tetrahydro-2*H*-pyran-2-one (CAS), 5-valerolactone	2.58
10	14.928	2-Methoxy-4-methylphenol	2.04
11	15.426	2-Propenoic acid, 2 methyl, ethylester (CAS), ethylmethacrylate	1.71
12	15.767	2,5-Dimetoxytoluene	1.47
13	3.728	Acetic acid, methylester (CAS), methylacetate	0.93

Table 2. Weight loss, termite mortality, and feeding rate in the subterranean termite test.

		Preservation method for glulam			
Number of layers	Block factor	Imidaclopride	Smoked 15 da	Smoked 30 da	Untreated
		Weight loss (%)			
3	Sengon	1.1 ± 1.3	3.1 ± 2.2	2.8 ± 1.5	25.3 ± 8.4
	Manii	1.2 ± 1.2	3.5 ± 0.9	3.0 ± 0.2	14.0 ± 13.2
	Mangium	0.5 ± 0.4	2.3 ± 1.3	2.3 ± 0.9	15.0 ± 7.5
	Mangium-sengon	0.9 ± 0.6	3.1 ± 1.1	3.0 ± 0.1	13.9 ± 2.2
	Mangium-manii	2.3 ± 1.7	2.6 ± 0.7	2.8 ± 0.6	26.0 ± 17.8
5	Sengon	1.0 ± 1.0	1.8 ± 0.5	2.8 ± 2.5	55.2 ± 52.6
	Manii	0.3 ± 0.4	1.4 ± 1.8	3.3 ± 0.7	15.7 ± 9.9
	Mangium	0.7 ± 0.6	4.1 ± 1.0	3.0 ± 0.9	10.0 ± 8.5
	Mangium-sengon	0.5 ± 0.1	3.6 ± 0.8	4.0 ± 1.0	25.7 ± 7.2
	Mangium-manii	2.0 ± 2.7	2.0 ± 1.5	3.1 ± 0.7	20.2 ± 7.6
		Mortality (%)			
3	Sengon	100 ± 0	100 ± 1	100 ± 0	83 ± 9
	Manii	100 ± 0	100 ± 1	97 ± 6	90 ± 9
	Mangium	100 ± 0	100 ± 0	100 ± 0	95 ± 1
	Mangium-sengon	100 ± 0	100 ± 0	100 ± 0	76 ± 27
	Mangium-manii	100 ± 0	100 ± 0	100 ± 0	86 ± 5
5	Sengon	100 ± 0	100 ± 0	98 ± 2	74 ± 31
	Manii	100 ± 0	100 ± 1	100 ± 0	93 ± 8
	Mangium	100 ± 0	97 ± 5	100 ± 0	94 ± 5
	Mangium-sengon	100 ± 0	100 ± 1	100 ± 0	81 ± 21
	Mangium-manii	100 ± 0	100 ± 0	100 ± 0	78 ± 29
		Feeding rate (μg/termite/da)			
3	Sengon	2 ± 3	7 ± 6	5 ± 3	116 ± 78
	Manii	2 ± 2	8 ± 1	7 ± 1	145 ± 41
	Mangium	2 ± 1	8 ± 5	7 ± 4	175 ± 105
	Mangium-sengon	2 ± 2	9 ± 4	8 ± 0	163 ± 53
	Mangium-manii	7 ± 5	8 ± 3	7 ± 1	375 ± 70
5	Sengon	2 ± 3	5 ± 3	9 ± 4	698 ± 114
	Manii	1 ± 1	2 ± 3	9 ± 2	172 ± 114
	Mangium	2 ± 2	11 ± 2	10 ± 3	122 ± 104
	Mangium-sengon	1 ± 0	9 ± 4	9 ± 6	239 ± 91
	Mangium-manii	7 ± 10	7 ± 4	10 ± 3	227 ± 103

structure and function of living organisms (Marynowski et al 2004).

Glulam Resistance Against Termite Attack

Parameters for measuring glulam resistance against termite attack were weight loss percentage of a specimen and mortality and feeding rate of termites. Table 2 shows the results of a 3-wk laboratory test based on the Japanese standard (JIS 2004).

Weight Loss

Untreated glulam had a weight loss in the termite test of 22.5 ± 20.1%, whereas weight loss of glulam smoked 15 da, glulam smoked 30 da, and imidacloprid-preserved glulam lost 2.7 ± 1.3%, 3.0 ± 1.0%, and 1.0 ± 1.2% of their weight, respectively. The analysis of variance (ANOVA) presented in Table 3 shows that only preservation method had a significant effect on weight loss; number of layers, interactions, and wood species did not affect weight loss. Tukey's test of preservation method (Table 4) showed that smoked glulam and imidacloprid-preserved glulam had the same weight loss, which was lower than that of untreated glulam. These results align with those of Hadi et al (2010a, 2010b, 2012) who found that smoked wood had less weight loss than untreated wood.

Mortality

Termite mortality reached 99% and 100% with smoked and imidacloprid-preserved glulams, respectively, ie, nearly all termites died. These values averaged approximately 15.5% greater than termite mortality with untreated glulam (85% mortality). The ANOVA showed that mortality was only significantly affected by preservation method and number of layers, interactions, and species did not affect termite mortality (Table 3). Tukey's test showed smoked glulams (smoked for 15 and 30 da) were associated with the same high termite mortality as imidacloprid-preserved glulam. This level of mortality was greater than that found with untreated glulam for *C. curvignathus* subterranean termites (Table 4).

Table 3. ANOVA of subterranean termite test.

Item	Preservation method (A)	Number of layers (B)	Interaction (AB)	Species (block)
Mortality	*	NS	NS	NS
Weight loss	*	NS	NS	NS
Feeding rate	*	NS	NS	NS

* Significance level 0.05. NS, not significant.

Table 4. Tukey's test analysis of subterranean termite test.[a]

Preservation method	Weight loss (%)	Mortality (%)	Feeding rate (μg/termite/da)
Untreated glulam	22.5 ± 20.1[a]	85 ± 17[a]	224 ± 170[a]
Smoked 15 da	2.7 ± 1.3[b]	100 ± 1[b]	7 ± 4[b]
Smoked 30 da	3.0 ± 1.0[b]	99 ± 2[b]	8 ± 3[b]
Imidacloprid	1.0 ± 1.2[b]	100 ± 0[b]	3 ± 4[b]

[a] Values followed by the same superscript letter within a column are not significantly different ($p < 0.05$).

Feeding Rate

Termite feeding rates (μg/termite/da) shown in Table 2 were determined for specimens of each type of glulam, based on construction and wood species. The feeding rate associated with untreated glulam was the greatest compared with the other samples. Based on an ANOVA, feeding rate was only affected by preservation method; wood species, number of layers, and interactions among the factors did not affect the feeding rate. Tukey's test showed that feeding rate was the same for smoked glulam and imidacloprid-preserved glulam and this rate was lower than that for untreated glulam.

Based on weight loss, mortality, and feeding rate parameters, smoked glulam had the same resistance as imidacloprid-preserved glulam and both of these glulams had much better termite resistance than untreated glulam. The increased resistance of smoked glulam was attributed to chemical compounds on the glulam surface that were toxic for the termite.

CONCLUSIONS

Based on the findings of this research, it can be concluded that mangium smoke predominantly produced acetic acid, cyclobutanol, phenolic compounds, and other PAH that improved glulam resistance against subterranean termite attack. Smoked glulam had the same resistance against subterranean termite attack as imidacloprid-preserved glulam, and this resistance was much greater than that of untreated glulam. Glulam smoked for 15 da had the same resistance as glulam smoked for 30 da.

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