Resistance of Smoked Glued Laminated Lumber to Subterranean Termite Attack

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Abstract

Timber from plantation forest mostly contains sapwood, and the heartwood part has a lot of juvenile wood, which has low resistance to attack by subterranean termites (*Coptotermes curvignathus*). Wood smoke created through pyrolysis contains numerous polycyclic aromatic hydrocarbons that could prevent termite attack. Three-layer glued laminated lumber (glulam) was created using either the same wood species (mangium [*Acacia mangium*], manii [*Maesopsis eminii*], or sengon [*Falcataria moluccana*]) for all layers or a combination of mangium as the face and back layers and a core layer of manii or sengon. Glulam samples were exposed to smoke from mangium wood for 15 days, preserved with imidacloprid, or left untreated. All glulams were tested against subterranean termites according to the Indonesian standard. Gas chromatography revealed that smoke from mangium predominantly contained acetic acid, cyclobutanol, and phenolic compounds. Smoked glulam was more resistant to subterranean termite attack than untreated glulam, but less resistant than the imidacloprid-preserved glulam. On the basis of the resistance classification in an Indonesian standard, untreated glulam belonged to the moderate (class III) to very poor (class V) resistance classes with an average of 4.4, and smoked glulam ranked as moderate to poor (class IV) resistance with an average of 3.2. Imidacloprid-preserved glulam belonged to the very resistant (class I) to resistant (class II) classes with an average of 1.8, corresponding to resistance to subterranean termite attack.

Indonesian log production in 2013 reached 22.2 million m^3, with 88 percent of the logs being harvested from plantation forests and the remainder from natural forests. To support a sustainable log supply, about 10 million hectares of production forest is being developed with fast-growing tree species, such as sengon (*Falcataria moluccana* Miq.), manii (*Maesopsis eminii* Engl.), and mangium (*Acacia mangium* Willd.) (Ministry of Forestry 2014). Plantation forests have a short harvesting rotation, ranging from 5 to 10 years, that generally produces small-diameter logs having a less than 30-cm diameter at breast height with defects such as knots. In addition, the timber mostly consists of sapwood, and heartwood contains a substantial amount of juvenile wood, which has inferior physical and mechanical properties and low resistance to termite attack (Hadi et al. 2010a, Fajriani et al. 2013).

Physical and mechanical properties of the low-quality timber can be improved by processing it into glued laminated lumber (glulam), which is constructed from specifically selected and prepared pieces of wood. This wood has either a straight or curved form, and the grain of all pieces is essentially parallel to longitudinal axial of the member (Moody et al. 1999). Komariah et al. (2015) developed glulam made from sengon, manii, and mangium, with either the same wood species being used for all layers or mangium being used for the face and back layers, with a core layer of manii or sengon. The physical and mechanical properties of the glulam did not show any significant difference from that of solid wood of the same species. Such samples successfully fulfilled the JAS 234 (Japanese Agricultural Standard 2003) standard; however, the resistance of the glulam to termite attack has not yet been investigated.

Subterranean termite attack in Indonesia is a very severe problem for built structures. Rilatupa et al. (2007) reported that wooden parts on the 32nd floor of apartment buildings in Jakarta showed damage from the subterranean termite

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Forest Prod. J. 66(7/8):480–484.
doi:10.13073/FPJ-D-15-00085

(*Coptotermes curvignathus* Holmgren). Furthermore, Nandika (2015) found that damage attributable to subterranean termite attack occurs in all districts in Jakarta and in other areas in the country. It was also estimated that economic losses in wooden buildings throughout the country could reach US$1 billion in 2015. Preservation techniques using relatively toxic wood preservative compounds are commonly applied to extend the service life of timber, but these chemicals can be hazardous for living organisms, including humans. Therefore, alternative preservation methods that are safer to use and more environmentally friendly should be investigated.

Several alternative methods of wood preservation have already been studied, and the resultant products were much more resistant to subterranean termite attack than untreated wood. Such methods have included acetylation of particleboard and fiberboard (Hadi et al. 1995, Rowell et al. 1998) and treatment of wood with polystyrene (Hadi et al. 1998, Abdul Khalil et al. 2014), furfuryl alcohol (Hadi et al. 2005, Esteves et al. 2011), smoke (Hadi et al. 2012), and methyl methacrylate (Kartal et al. 2004, Hisham and Anwar 2005, Hadi et al. 2015). Wood smoke contains a large number of polycyclic aromatic hydrocarbons and is mainly composed of phenols, aldehydes, ketones, organic acids, alcohols, esters, and various heterocyclic compounds (Stołyhwo and Sikorski 2005). Hadi et al. (2010b) treated mindi wood (*Melia azedarach*) and sugi wood (*Cryptomeria japonica*) with smoke from burning mangium wood for 15 days. Based on the Indonesian termite test standard, the smoke treatment increased wood resistance to termite attack, matching the highest resistance class against subterranean termites and providing resistance equal to that of wood treated with polystyrene or preserved with borax. The smoke treatment is one choice for reducing the use of more toxic preservatives to increase glulam resistance to subterranean termite attack. The purpose of the current study was to determine the resistance of smoked glulam to subterranean termite attack in laboratory conditions according to the Indonesian standards.

Methods

Glulam test specimen preparation

Glulam test specimens were manufactured by Komariah et al. (2015) and consisted of three-layer glulam made of either the same wood species for all layers (sengon, manii, or mangium) or mangium for the face and back layers with a core layer of manii or sengon. The glulam test specimens consisted of sapwood for sengon, and consisted mostly of sapwood with a little part of heartwood for manii and mangium. The adhesive used for the glulam was isocyanate PI-3100, a water-soluble polymer consisting of base resin and hardener obtained from PT Polychemi Asia Pasifik, Jakarta, Indonesia.

Glulam test specimens sized according to Indonesian standard SNI 01.7207-2006 (5 by 2 by 1 cm for thickness, width, and length, respectively; Standar Nasional Indonesia 2006) were used to determine termite attack resistance, and a solid wood test specimen of each species was also prepared for comparison purposes. Each wood species and treatment consisting of three glulam test specimens as replications were exposed to smoke from air-dried mangium wood being pyrolyzed to produce charcoal over the course of 15 days. A second group of samples underwent chemical preservation treatment in which imidacloprid was brushed on the glulam surface four times. A third group of samples was left untreated as controls. All glulams were conditioned at room temperature for 1 month before the test. Chemical compounds in smoke were determined by analyzing liquid condensates of the smoke by gas chromatography–mass spectrometry (GC-MS; Py-GCMS-QPXP-2010, Shimadzu).

Subterranean termite test

Each glulam or solid wood test specimen was placed in a glass container with 200 g of sterilized river sand, 50 mL of water, and 200 healthy and active workers of *C. curvignathus* subterranean termites from a laboratory colony. The containers were put in a dark room at a temperature of 25°C to 30°C and 80 to 90 percent relative humidity for 4 weeks and weighed each week. If the moisture content of the sand decreased by 2 percent or more, water was added to achieve a 25 percent moisture content. At the end of the 4-week test, the samples were oven-dried. The wood sample weight loss, termite mortality, and termite feeding rate were determined using the following formulae.

$$\text{Weight loss} = (W_1 - W_2)/W_1 \times 100\%$$

where W_1 is the weight (g) of ovendried samples before the test, and W_2 is the weight (g) of ovendried samples after the test.

$$\text{Termite mortality} = (T_1 - T_2)/T_1 \times 100\%$$

where T_1 is the number of live termites before the test, and T_2 is the number of live termites after the test.

To calculate the feeding rate, we assumed that termites died linearly with time, and feeding rate was calculated according to the following equation:

$$\begin{aligned}\text{Feeding rate}\ (\mu\text{g/termite/day}) \\ = (\text{weight of wood eaten by termites}) \\ \div (\text{live termites} \times \text{test period})\end{aligned}$$

Wood resistance class against subterranean termites was determined by referring to SNI (2006) as shown in Table 1.

Statistical analysis of test results

Data were analyzed by using a completely randomized block design. The block factor was wood species, namely sengon, manii, or mangium; mangium–sengon; and mangium–manii. The treatments included untreated (as the control), smoked, and imidacloprid-treated glulam samples. Tukey's test was used for further analysis if the treatment factor was significantly different at $P \leq 0.05$ (Mattjik and Sumertajaya 2002).

Table 1.—Resistance class against subterranean termite.

Resistance class	Classification	Mass loss (%)
I	Very resistant	<3.52
II	Resistant	3.52–7.50
III	Moderate	7.50–10.96
IV	Poor resistance	10.96–18.94
V	Very poor resistance	>18.94

Results and Discussion

On the basis of GC-MS spectra, mangium wood smoke predominantly contained acetic acid (32.1%), cyclobutanol (30.1%), and phenolic compounds (14.1%). Results of termite mortality and feeding rates, wood sample weight loss, and resistance class of glulam and solid wood are shown in Table 2. The three untreated wood species of glulams had the same resistance, class V (very poor resistance), because the wood was from fast-growing species cut from standing trees younger than 10 years old; the sengon test specimen consisted of sapwood, and manii and mangium woods mostly consisted of sapwood with a small part of heartwood. The resistance classes of solid wood from each species were also class V, and there was no difference in resistance class between solid wood and glulams, but glulams had smaller weight loss compared with solid wood.

The analysis of variance of the test results is presented in Table 3. It was found that wood species did not affect termite mortality, but the effect of treatment on termite mortality was highly significantly different. Untreated manii glulam had very high termite mortality compared with the others, but statistically was not different because of high standard deviations in some treatments. Table 4 shows Tukey's test results for further data analysis, which indicates that untreated and smoked glulam did not differ from each other for termite mortality rate. However, imidacloprid-preserved glulam differed from both. The imidacloprid-preserved wood specimens were associated with a 100 percent mortality rate, indicating that the preservative was an effective barrier to termite attack. Smoke had a little effect on preventing termite attack, as indicated by a higher termite mortality rate compared with untreated glulam; statistically the values did not differ because of the high standard deviations.

Table 3.—Analysis of variance.[a]

	Mortality	Weight loss	Feeding rate
Treatment	**	**	**
Wood species	NS	*	**

[a] * = significantly different at $P < 0.05$; ** = highly significantly different at $P < 0.01$; NS = not significantly different.

Termite mortality of glulams was higher than that of solid wood, which would be related to the effect of manufacturing parameters of composite product. The termite mortality of solid wood was still high, 49.5 percent for sengon and 61.7 percent for mangium, compared with the results of Arinana et al. (2012) whose termite mortality rates of sengon and mangium solid woods reached 23 and 27 percent, respectively. The differences of these values are a result of environmental test conditions: Arinana et al. (2012) performed their research in a conditioned laboratory in Kyoto, Japan, and our research was conducted in the tropical atmosphere of Bogor, Indonesia.

Wood species and treatment affected glulam weight loss (Table 3). Weight loss for untreated glulam was significantly different from those of smoked and imidacloprid-preserved glulams, which did not differ from each other. With regard to the amount of glulam weight loss and the Indonesian standard classification in Table 1, untreated glulams were classified to resistance classes III to V with an average of 4.4, smoked glulams to classes III to IV with an average of 3.2, and imidacloprid-preserved glulam to classes I to II with an average of 1.8. The reduction in weight loss from untreated wood (21.8%) to smoked wood (9.4%) was more than 50 percent, indicating that smoke treatment was effective in protecting the glulam against termite attack. The dominant chemical compounds in the

Table 2.—Mortality and feeding rates of termites, sample weight loss, and resistance class of glued laminated lumber (glulam) and solid wood.

Treatment	Sengon	Manii	Mangium	Mangium–Sengon	Mangium–Manii	All wood species
			Mortality (%)			
Untreated glulam	82.2 (7.7)[a]	99.3 (1.2)	87.3 (6.4)	87.7 (10.7)	85.2 (12.7)	88.3 (7.7)
Smoked glulam	97.7 (2.0)	96.7 (5.8)	87.0 (2.3)	95.8 (7.2)	99.3 (1.2)	95.3 (3.7)
Imidacloprid-treated glulam	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)
Solid wood	49.5 (5.9)	51.3 (9.3)	61.7 (5.4)			
			Weight loss (%)			
Untreated glulam	22.0 (8.6)	40.6 (16.8)	21.2 (20.0)	10.5 (1.9)	15.0 (5.6)	21.8 (10.6)
Smoked glulam	10.1 (3.4)	11.6 (5.4)	7.7 (2.7)	7.8 (2.2)	9.9 (2.8)	9.4 (3.3)
Imidacloprid-treated glulam	4.6 (1.0)	5.0 (3.9)	2.6 (1.0)	2.3 (0.2)	3.5 (2.1)	3.6 (1.6)
Solid wood	23.4 (9.4)	23.7 (2.6)	26.6 (18.8)			
			Feeding rate (μg/termite/day)			
Untreated glulam	31.8 (13.7)	93.4 (37.6)	57.4 (52.6)	24.9 (5.5)	36.3 (9.6)	48.7 (23.8)
Smoked glulam	30.0 (6.7)	55.3 (25.8)	38.9 (13.5)	36.4 (7.9)	56.8 (15.2)	43.5 (13.8)
Imidacloprid-treated glulam	14.2 (3.8)	27.9 (22.1)	13.6 (3.7)	10.6 (2.4)	18.2 (11.2)	16.9 (8.7)
Solid wood	53.5 (15.4)	66.9 (5.8)	63.6 (26.1)			
			Resistance class[b]			
Untreated glulam	V	V	V	III	IV	4.4
Smoked glulam	III	IV	III	III	III	3.2
Imidacloprid-treated glulam	II	II	II	I	II	1.8
Solid wood	V	V	V			5.0

[a] Values in parentheses are standard deviations.
[b] According to SNI 01.7207-2006 (Standar Nasional Indonesia 2006).

Table 4.—Tukey's test of treatment.

Treatment	Mortality (%)	Weight loss (%)	Feeding rate (μg/termite/day)
Control	88 A[a]	21.8 A	48.7 A
Smoke	95 B	9.4 B	43.5 A
Imidacloprid	100 B	3.6 B	16.9 B

[a] The same letter in a column indicates that the values are not significantly different.

smoke (acetic acid, cyclobutanol, and phenolic compounds) were assumed to enhance the resistance of glulam, but the resistance of smoke-treated glulam was still inferior compared with that of imidacloprid-preserved glulam, which had a weight loss of only 3.6 percent. In Arinana et al. (2012), the weight loss of untreated solid sengon (24.2%) did not differ much from our result (23.4%), but the result for mangium (11.6%) was much lower than ours (26.6%). The difference could be explained by the variation in test specimens in terms of sap- and heartwood portions, tree age, harvest site of the tree, and also test environment.

The effects of wood species and treatment were highly significant for termite feeding rate (Table 3). As shown in Table 4, untreated and smoked glulams were not different from each other, but both differed from imidacloprid-preserved glulam. Smoked treatment had little effect on reducing the termite feeding rate, but it significantly reduced weight loss of the test specimens. This observation may be explained by the calculation of dead termites being averaged over the test; in other words, living termites were counted only at the beginning and end of the test periods. The actual number of living termites should be observed every day, so the number of dead termites can be precisely known during the test period, which would enable a more accurate calculation of the feeding rate. For this purpose, test methodology should be reorganized to make counting the living or dead termites easier, as according to Japanese Industrial Standard 1571 (JIS 2004), the dead termites should be easier to count during the test period. The same matter occurs with weight loss. According to Arinana et al. (2012), the termite feeding rate of solid sengon was 49 μg per termite per day, which is not much different from our result (53.5 μg per termite per day). However, their result for mangium (43 μg per termite per day) is lower than ours (63.6 μg per termite per day).

For future work on smoke treatment for enhancing wood resistance to biodeterioration attack, wood species producing smoke via pyrolysis could be desirable for investigation because the chemical compounds of the wood species would be different from each other. Also, the chemical compounds of smoke, single or mixed, could be used as preservatives in some research methods, and fixation techniques of chemical compounds to the wood or glulam would be useful to extend the service life of the final products.

Conclusions

1. Mangium wood smoke predominantly contained acetic acid, cyclobutanol, and phenolic compounds.
2. Untreated wood from the three fast-growing tree species used in this research has very poor resistance to subterranean termite attack (class V according to the Indonesian standard); untreated glulam also has moderate (class III) to very poor resistance with an average of 4.4.
3. It seems that smoke treatment could increase resistance of the samples to termite attack, providing moderate to poor (class IV) resistance with an average of 3.2.
4. Smoked glulam had higher termite mortality, lower sample weight loss, and lower termite feeding rate compared with those of untreated glulam. However, imidacloprid-preserved glulam was classified as very resistant (class I) to resistant (class II), with an average of 1.8 and was thus better than smoked glulam.

Acknowledgments

We acknowledge the sponsorship of this research by the Ministry of Research Technology and Higher Education of Indonesia, through a Competency Research Grant, and are grateful to S. Hiziroglu of Oklahoma State University, Stillwater, for his suggestions and improvements of the manuscript.

Literature Cited

Abdul Khalil, H. P. S., R. Dungani, I. A. Mohammed, M. S. Hossain, N. A. S. Aprilia, E. Budiarso, and E. Rosamah. 2014. Determination of the combined effect of chemical modification and compression of agatis wood on the dimensional stability, termite resistance, and morphological structure. *Bioresources* 9(4):6614–6626.

Arinana, K. Tsunoda, E. N. Herliyana, and Y. S. Hadi. 2012. Termite-susceptible species of wood for inclusion as a reference in Indonesian standardized laboratory testing. *Insects* 3:396–401.

Esteves, B., L. Nunes, and H. Pereir. 2011. Properties of furfurylated wood (*Pinus pinaster*). *Eur. J. Wood Prod*. 69:521–525. DOI:10.1007/s00107-010-0480-4

Fajriani, E., J. Ruelle, J. Dlouha, M. Fournier, Y. S. Hadi, and W. Darmawan. 2013. Radial variation of wood properties of sengon (*Paraserianthes falcataria*) and jabon (*Anthocephalus cadamba*). *J. Indian Acad. Wood Sci*. 10(2):110–117. DOI:10.1007/s13196-013-0101-9

Hadi, Y. S., I. G. K. T. Darma, F. Febrianto, and E. N. Herliyana. 1995. Acetylated rubber-wood flakeboard resistance to bio-deterioration. *Forest Prod. J.* 45(10):64–66.

Hadi, Y. S., D. S. Nawawi, E. N. Herliyana, and M. Lawniczak. 1998. Termite attack resistance of four polystyrene impregnated woods from Poland. *Forest Prod. J.* 48(9):60–62.

Hadi, Y. S., T. Nurhayati, J. Jasni, H. Yamamoto, and N. Kamiya. 2010a. Smoked wood resistance against termite. *J. Trop. Forest Sci*. 22:127–132.

Hadi, Y. S., T. Nurhayati, J. Jasni, H. Yamamoto, and N. Kamiya. 2010b. Smoked wood as an alternative for wood protection against termites. *Forest Prod. J.* 60:496–500.

Hadi, Y. S., T. Nurhayati, J. Jasni, H. Yamamoto, and N. Kamiya. 2012. Smoked wood resistance to subterranean and dry wood termites attack. *Int. Biodeterior. Biodegrad*. 70:79–81. DOI:10.1016/j.ibiod.2011.06.010

Hadi, Y. S., I. S. Rahayu, and S. Danu. 2015. Termite resistance of jabon wood impregnated with methyl methacrylate. *J. Trop. Forest Sci*. 27:25–29.

Hadi, Y. S., M. Westin, and E. Rasyid. 2005. Resistance of furfurylated wood to termite attack. *Forest Prod. J.* 55(11):85–88.

Hisham, H. N. and U. M. K. Anwar. 2005. Effects of polymethyl methacrylate on properties of manau and dok canes. *J. Trop. Forest Sci*. 17:488–496.

Japanese Agricultural Standard (JAS). 2003. Glued laminated timber. JAS 234:2003. Ministry of Agriculture, Forestry, and Fisheries, Tokyo.

Japanese Industrial Standard (JIS). 2004. Test methods for determining the effectiveness of wood preservatives and their performance requirement. JIS K 1571-2004. Japanese Standard Association, Tokyo.

Kartal, S. N., T. Yoshimura, and Y. Imamura. 2004. Decay and termite resistance of boron-treated and chemically modified wood by in situ co-polymerization of allyl glycidyl ether (AGE) with methyl methacrylate (MMA). *Int. Biodeterior*. *Biodegrad*. 53:111–117.

Komariah, R. N., Y. S. Hadi, M. Y. Massijaya, and J. Suryana. 2015. Physical–mechanical properties of glued laminated timber made from tropical small-diameter logs grown in Indonesia. *J. Korean Wood Sci. Technol*. 43:156–167.

Mattjik, A. A. and I. M. Sumertajaya. 2002. Perancangan percobaan dengan aplikasi SAS dan minitab jilid I [Experimental design with SAS application and minitab, Volume I]. Bogor Agricultural University Press, Bogor, Indonesia.

Ministry of Forestry. 2014. Forestry statistics of Indonesia 2013. Ministry of Forestry, Jakarta, Indonesia.

Moody, R. C., R. Hernandez, and J. Y. Liu. 1999. Glued structural timbers. *In:* Wood Handbook—Wood as an Engineering Material. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Nandika, D. 2015. Satu abad perang melawan rayap [One century fight to termite]. Seminar of Termite Invasion in Indonesia, Jakarta, April 16, 2015.

Rilatupa, J., S. Surjokusumo, Y. S. Hadi, and N. Nugroho. 2007. Karakteristik serangan rayap dan pendugaannya pada indeks kondisi bangunan tinggi [Termite attack characteristics and its prediction for construction condition index of high building]. Forum Pascasarjana, Graduate School, Bogor Agricultural University, Bogor, Indonesia 30(4):333–345.

Rowell, R. M., B. S. Dawson, Y. S. Hadi, D. D. Nicholas, T. Nilsson, D. V. Plackett, R. Simonson, and M. Westin. 1998. Worldwide inground stake test of acetylated composite boards. Doktorsavhandlingar vid Chalmers Tekniska Hogskola, Goteberg, Sweden.

Standar Nasional Indonesia, Indonesian National Standard (SNI). 2006. Wood and wood products resistance test to wood-destroying organism. SNI 01.7207-2006. Indonesian National Standard Bureau, Jakarta, Indonesia.

Stołyhwo, A. and Z. E. Sikorski. 2005. Polycyclic aromatic hydrocarbons in smoked fish: A critical review. *Food Chem*. 91:303–311.