Journal of Tropical Forest Science 36(3): 338–350 (2024)
https://doi.org/10.26525/jtfs2024.36.3.338
ISSN: 0128-1283, eISSN: 2521-9847

EXPLORING OTHER USES OF HARTINDO AF21 FLAME RETARDANT MATERIAL FOR BUILDING STRUCTURE PROTECTION AGAINST SUBTERRANEAN TERMITES

Roszaini K*, Mohamad-Nasir MA & Muhammad-Al-Amin AH

Forest Research Institute Malaysia (FRIM), Kepong 52109, Kuala Lumpur, Malaysia

**roszaini@frim.gov.my*

Submitted January 2024; accepted April 2024

The study was carried out to determine the effectiveness of Hartindo AF21 as a wood preservative against subterranean termites, specifically *Coptotermes curvignathus* Homgren (Rhinotermitidae) in Malaysian conditions. The aim was to examine the performance of Hartindo AF21 in preventing termite attacks on *Koompassia malaccensis* and *Hevea brasiliensis*. The tests involved using various concentrations of Hartindo AF21 in both single choice (no-choice) (ASTM D3345) and above-ground (IHM/WEL/1) scenarios. The findings from the laboratory and above-ground tests revealed that concentrations of Hartindo AF21 above 20% created a sufficient chemical barrier or resulted in high mortality rates for *C. curvignathus* after 15 days. Additionally, both wood species treated with Hartindo AF21 displayed typical repellent wood preservative behavior, with reduced feeding and mass loss as the concentration of preservative increased.

Keywords: Nanoparticle, durability, *Coptotermes curvignathus*, weight loss, visual rating

INTRODUCTION

Fire retardants are chemicals that are used to reduce the flammability of wood and other materials. They can also provide some defense against fungal and termite infestations. Some fire retardants may contain boron compounds, which have biocidal properties and are used as wood preservatives. However, it is important to note that these compounds are not typically formulated or marketed for this specific purpose (LeVan & Winady 1990, Umit et al. 2010, Kartal et al. 2007). It is crucial to recognise that the effectiveness of fire retardants in combating fungal and termite attacks can vary depending on the type of wood being treated and the specific fire retardant used. Furthermore, fire retardants can potentially have negative effects on wood, such as reduced strength, altered appearance, and the release of toxic fumes when exposed to heat or flame (Ibáñez et al. 2023). Therefore, relying solely on fire retardants for protection against fungal and termite attacks is not recommended.

In order to ensure primary protection against fungal and termite attacks, it is recommended to utilise wood preservatives specifically formulated for this purpose. Example of such preservatives include boron-based or copper-based solutions (Salamah & Zaitun 1989). These preservatives are typically applied during the manufacturing process, before the wood is used in construction. By doing so, they provide long-lasting defence against fungal decay and termite infestations.

The decision to explore the impact of Hartindo AF21 as a fire protection solution on wood durability against termites was motivated by several key considerations. Firstly, the dynamic nature of the pressure impregnated wood industry underscores the necessity of maintaining market stability, prompting a focus on developing modified wood products that align with principles of recyclability and life cycle sustainability. Secondly, the persistent demand for advanced surface treatment products highlights the urgent need for innovative solutions like Hartindo AF21. Thirdly, the escalating emphasis on sustainable and eco-friendly wood preservation techniques presents an opportunity for scaling up the production of fire protection solutions such as Hartindo AF21. Additionally, the rising need for effective fire protection treatments underscores the significance of solutions like Hartindo AF21. Notably, exemplified by inorganic borates, certain compounds possess a unique array of properties ideally suited for safeguarding wood, encompassing insecticidal, fungicidal, and flame-retardant characteristics (Ibáñez et al. 2023).

Hartindo AF21 is a water-based solution that contains inorganic compounds and a unique combination of fire-inhibiting ingredients. According to a patent document (US Patent No. US9920250B1), it consists of approximately 65–75% water, 25–35% of various nitrogen and salt-based compounds that form a quaternary salt compound, and approximately 1% of a confidential formula protected as a trade secret. Developed in Indonesia, Hartindo AF21 is a liquid fire inhibitor solution used for coating lumber, making it fire-resistant. It plays a vital role in EcoBlu Products, Inc's wood protection arsenal, which utilises environmentally friendly chemistry to safeguard against mold, fungus, rot-decay, wood ingesting insects, and termites. EcoBlue Products, incorporating fire retardant coatings, offer the highest level of protection, preservation, and fireplace safety to wooden building components, including joists, beams, paneling, floors, and ceilings. Moreover, it has been documented as non-harmful, non-damaging, biodegradable, eco-friendly, and provides long-lasting fire protection once applied.

The aim of this study is to identify cost-effective chemicals that serve multiple purposes. In addition to the fire hazard, wooden structures are also susceptible to termite infestations. Therefore, we conducted a study to determine if the fire retardant chemicals available in the Malaysian market could also act as preservatives to protect wood from pests, specifically termites. The outcomes of this investigation not only able to reduce production expenses but also expand the range of chemical applications, thereby enhancing the potential for developing new wood preservatives for the wood industry. In this study, we evaluated the termiticidal properties of Hartindo AF21 against economically significant subterranean termite species in Malaysia, specifically *Coptotermes curvignathus* Holmgren (Rhinotermitidae), through laboratory and field experiments.

MATERIALS AND METHODS

Materials

Two selected Malaysian woods namely *Koompassia malaccensis* Maingay (kempas) and *Hevea brasiliensis* Muell. Arg. (rubberwood), were used for this study. The reason for the selection of these two species is their high susceptibility to treatment. The properties of these wood species are presented in Table 1.

For the purpose of this study, each wood species was cut into two different sizes: 25 mm × 25 mm × 6 mm for laboratory tests and 100 mm × 40 mm × 20 mm in height for above-ground tests. Prior to treatment, all specimens were conditioned to a moisture content of approximately 12 % and were carefully inspected to ensure that they were free from knots, visible resin concentrations, and any signs of mold, stain, or wood-destroying fungi.

Chemical

The chemical used for impregnation, Hartindo AF21, was directly obtained from the market.

Characterisation of Hartindo AF21

The chemical used for the impregnation, Hartindo AF21, was purchased directly from the market. The chemical composition and physical properties of Hartindo AF21 were characterised using Fourier Transform Infrared Spectroscopy (FTIR) to identify functional

Table 1 Properties of wood tested

Wood species	Density (kg m^{-3})	Durability class
K. malaccensis	770–1120	Moderate durable
H. brasiliensis	560–640	Non-durable

(Roszaini 2011; MS544: Part 2 (MS2001))

groups, and Thermogravimetric Analysis (TGA) to determine thermal stability.

Impregnation process

In both laboratory and field tests, the test specimens were impregnated with Hartindo AF21 chemical at various concentrations (2%, 4%, 6%, 8%, and 20%). The selection of these concentrations was based on a comprehensive evaluation of the efficacy of Hartindo AF21 in a range of concentrations. The lower concentrations (2%, 4%, 6% and 8%) were selected to determine the minimum effective concentration required for adequate protection of wood against termites, taking into account economic and environmental factors. These concentrations represent typical ranges used in the industry and allow comparison with commonly used treatment levels. The inclusion of the 20% concentration serves several purposes. Firstly, it provides information on the maximum achievable concentration of Hartindo AF21 and its potential impact on wood durability and termite resistance. This concentration represents an upper limit that may be feasible for specific applications where maximum protection is required, such as in high-risk environments or for particularly susceptible wood species. Each wood species and concentration of Hartindo AF21 had five replicates for laboratory tests and ten replicates for field tests, resulting in a total of 90 pieces including control samples. The retention of Hartindo AF21 at each concentration was calculated using the following formula (Razak et al. 2004).

$$\text{NDSR (kg m}^{-3}\text{)} = \frac{\text{Uptake (1)}}{\text{Volume (m}^3\text{)}} \times \frac{\text{Treating solution concentration}}{100}$$

where uptake is the amount of preservative absorbed by samples and volume is the volume of the samples.

Asian subterranean termites

Active subterranean termites, specifically *Coptotermes curvignathus* Holmgren, were collected by breaking and carefully tapping infested rubber trees (*H. brasiliensis*) at the Forest Research Institutes Malaysia (FRIM). The termites were then placed into plastic trays containing moist paper towels to prevent moisture losses. Termite species were identified using the key from Tho and Laurence (1992). The stock of termites was returned to the laboratory on the same day the test began and separated between worker and soldier termites manually.

Bioassay test (no-choice test) against termites

For the bioassay test against termites, the ASTM D3345 (2017) standard method with slight modifications was utilised. A glass bottle measuring 8 cm in diameter and 15 cm in height was filled with 200 g of sterilised sand and 30 ml of distilled water (Figure 1). This bottle was left overnight to establish laboratory conditions before the testing commenced. A block was positioned on the bottom surface of the moist sand, and 400 fresh termites (360 workers and 40 soldiers) were introduced into each bottle. All

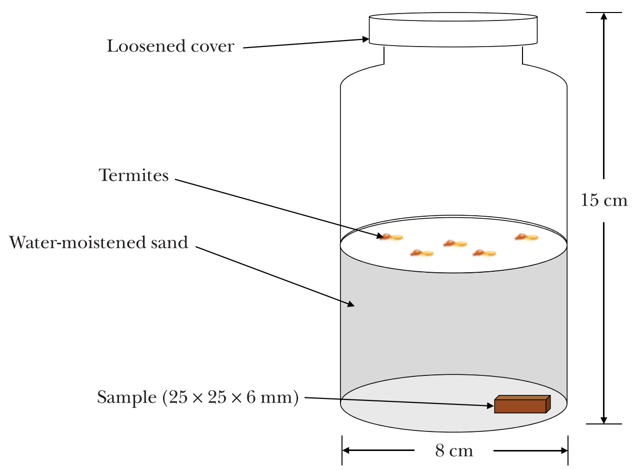

Figure 1 The arrangement of wood samples according to ASTM D3345 (2017)

the bottles were kept in a chamber room with a temperature of 22 ± 2 °C and a relative humidity of 65 ± 5% for a duration of 28 days. If all the termites were observed dead, the bottle was removed, and the number of days until 100% mortality was noted. After 4 weeks of exposure, all test blocks were taken out, cleaned of dirt, dried overnight, and reweighed. The samples were then meticulously evaluated using a visual method on a scale of 1–10, where 10 represents excellent performance and 0 signifies complete failure.

Above-ground termite test

The above-ground termite test was conducted on the FRIM campus, following the internal standard methods of FRIM (IHM/WEL/1 2004). The relative ambient temperature was maintained between 22 to 28 °C to observe heightened termite activity over a span of 16 weeks. Twelve drums containing samples for the variables tested were installed in areas where at least one species of subterranean termites was known to exist. A layer of a highly susceptible wood substrate, *H. brasiliensis*, was placed at the bottom of each drum, followed by a sheet of galvanized mesh (25 mm square) on top of the wood substrate. All test specimens, flanked with *H. brasiliensis*, were placed on the mesh. To prevent any contact between them, the specimens were arranged randomly (Figure 2) and left undisturbed for a period of 16 weeks. After the 16-week period, the samples were taken out, cleaned by removing any sticky soil and cardboard fragments, and then dried in an oven overnight. The weight of the samples and the amount of weight loss were recorded. The condition of the test samples was also visually assessed (Table 2).

Statistical analysis

Variations in retention of Hartindo AF21, weight loss, visual rating, and termite mortality with different treatment of Hartindo AF21 applied to both *H. brasiliensis* and *K. malaccensis* were compared and analysed by a one-way analysis of variance (ANOVA) using Microsoft Excel 2003 to determine which groups differed significantly at the 5% significance level (α) when ANOVA indicated a significant difference between level of concentration used and also between percentage weight loss and visual assessment in samples of both wood species. The assumptions of normality were tested on the raw data using the Shapiro–Wilk test at α = 0.05. If the assumptions were met, a ANOVA was performed using PROC GLM, followed by a comparison of means using the Duncan Multiple Range Test (DMRT). If the assumptions were not met, a logarithmic transformation was used to normalise the data.

Table 2 Visual rating system for above ground test (IHM/WEL/1 2004)

Rating	Description
0	Sound
1	Trace attack
2	Slight attack
3	Moderate attacks, penetration
4	Severe attack
5	Failure by termite attack

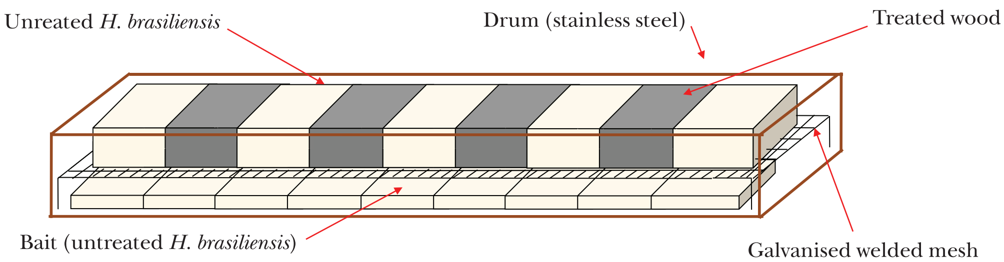

Figure 2 Arrangement of test samples for above-ground test

RESULTS AND DISCUSSION

Retention of Hartindo AF21

The study analysed the termiticidal effect of different concentrations of Hartindo AF21 on the retention and percentage of weight loss of *H. brasiliensis* and *K. malaccensis* wood. The laboratory and above ground test results are shown in Figure 3.

In both the no-choice and above-ground test samples, the retention of Hartindo AF21 in *K. malaccensis* was higher compared to *H. brasiliensis*. The highest retention percentages (3.87% and 4.24%) were recorded in both the laboratory and above-ground samples of *K. malaccensis* treated with 20% Hartindo AF21, while the lowest retention percentages (0.40% and 0.43%) were observed in *H. brasiliensis* samples treated with 2.0% Hartindo AF21, respectively. This trend of increasing retention with increasing chemical concentration is consistent with the findings reported by Nayeri et al. (2017), who found that the maximum retention of black liquor was achieved when wood blocks were impregnated with 2% monoethanolamine black liquor compared to 1%. Pan et al. (2015) also reported that the permeability of chemicals varies depending on the type of preservative, wood species, impregnation time, and the combined effects of these parameters. According to Baraúna et al. (2014), the ability of chemicals to penetrate wood is influenced by the distribution and diameter of the vessel. Conversely, in many hardwoods, the lateral flow of liquids occurs from ray via vessel-ray pits to the vessels (Murmanis & Chudnoff 1979). In a study by Nayeri et al. (2011), it was found that *K. malaccensis* had a higher number of vessel distribution/mm2 and larger vessel size compared to *H. brasiliensis* (6.58 to 7.83/mm2 and 144 to 177 µm), making it easier for chemicals or liquids to penetrate.

No-choice test

In the no-choice test, the control samples of *K. malaccensis* and *H. brasiliensis* showed the highest percentage weight loss of 3.10% and 15.10%, respectively (Figure 4). Both samples also obtained visual ratings of 5.8 and 7.0, indicating severe attack and moderate/severe attack, respectively (Table 3). On the other hand, samples of both timber species treated with 20% of Hartindo AF21 had the lowest percentage weight loss of 2.01% and 5.88%, respectively. Both samples obtained visual ratings of 7.8 and 7.6, indicating moderate attack (3–10% of cross-sectional area affected), respectively. The significant reduction in weight loss and visual damage in the treated samples confirms the effectiveness of Hartindo AF21 in

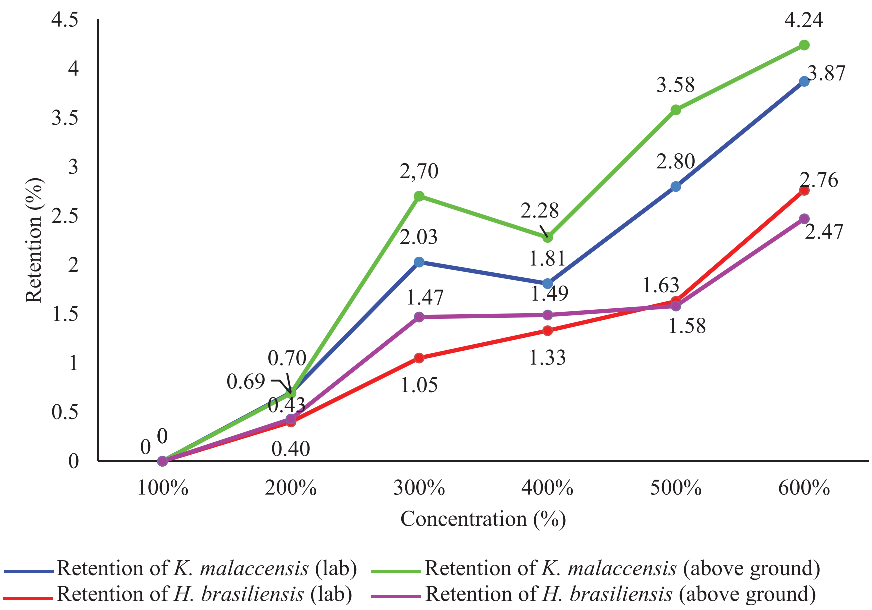

Figure 3 Retention of Hartindo AF21 at different concentrations in *K. malaccensis* and *H. brasiliensis* samples for laboratory and above ground tests

Table 3 Average visual rating in laboratory test of *H. brasiliensis* and *K. malaccensis* treated with Hartindo AF21 against *C. curvignathus*

Timber species	Concentration (%)	Visual rating
K. malaccensis	0	7.0c
	2	7.6ab
	4	7.4b
	6	7.8a
	8	7.6ab
	20	7.8a
H. brasiliensis	0	5.8d
	2	7.0c
	4	7.6ab
	6	7.4b
	8	7.9a
	20	7.6a

Mean of 5 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0.05 level of probability.

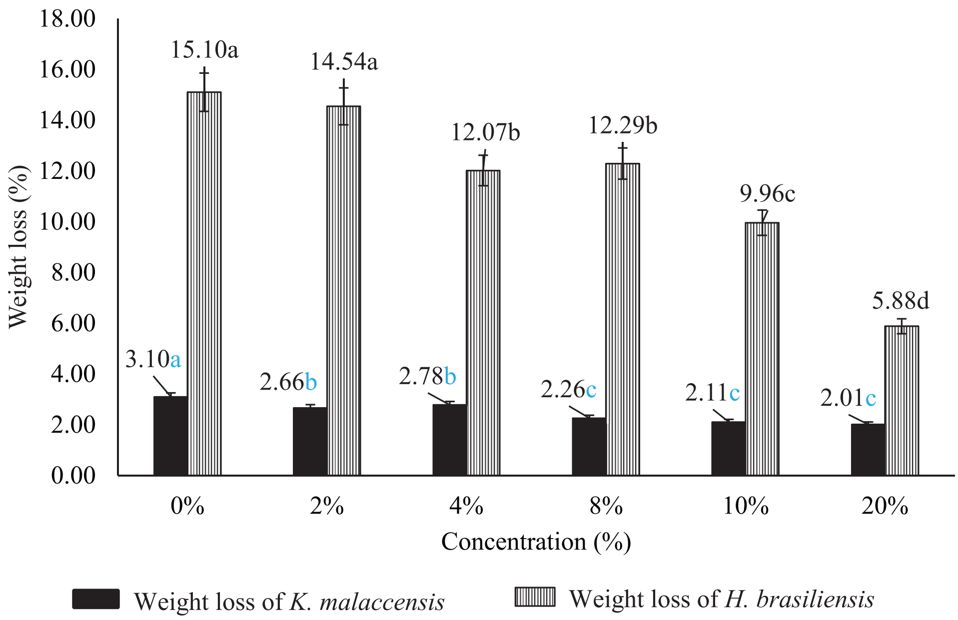

Figure 4 Termiticidal effect of concentration levels of Hartindo AF21 on percentage weight loss of *K. malaccensis* and *H. brasiliensis* wood for laboratory test

Each value represents the means of 5 replicates. Mean values for retention (w/w) and percentage of weight loss (%) by the same letter are not significantly (P<0.05) different

controlling termite infestation and maintaining wood integrity.

The observation on the treated samples showed lower weight loss and higher visual rating compared to the untreated controls was consistent with the findings of Dadzie et al. (2015), who hypothesised that higher weight loss and lower visual rating indicated shorter life of wood preservatives. This conclusion emphasised the importance of the results of the current study as they suggested the application of Hartindo AF21 helped to extend the life of treated wood products by increasing their resistance to termite attack. Furthermore, the remarkable difference in performance between treated and untreated samples emphasised the potential of Hartindo AF21 as a viable solution for protecting wood from termite damage. This result was of great importance to the industry which relies on wood products, as it suggested that the use of Hartindo AF21 could lead to a significant improvement in wood durability and longevity, reducing the need for frequent replacement and mitigating the economic losses associated with termite damage.

The results of this study showed that as the concentration of Hartindo AF21 in the samples increased, the weight loss of the treated samples decreased. This trend was observed in both *K. malaccensis* and *H. brasiliensis* samples. This finding is consistent with previous studies by Salman et al. (2017), who found that samples treated with a 10% vinylic monomer solution had higher durability against termites (*Reticulitermes flavipes* ex. *santonensis*) and less weight loss compared to samples treated with 5% of the same solution. However, the permeability of the wood species significantly influences the depth of chemical penetration into the wood and surface absorption (Ma et al. 2013). Moreover, achieving effective protection is not possible unless there is sufficient preservative remaining in the wood after penetration (Bessin 2016). Figure 5 provides evidence of termite attack in a no-choice test.

Above-ground test

Figure 6 shows the average weight loss observed in treated and untreated *K. malaccensis* and *H. brasiliensis* during the above-ground termite test. Based on the results obtained, *K. malaccensis* treated with Hartindo AF21 exhibited higher resistance compared to *H. brasiliensis* at all tested concentrations. The weight loss for *K. malaccensis* ranged from 3.20% to 5.55%, while *H. brasiliensis* experienced weight loss between 6.00% and 15.64%. The resistance to *C. curvignathus* increased with higher concentrations of Hartindo AF21, but even at a concentration of 20%, it was insufficient to fully prevent termite attack on the tested samples. Figure 6 demonstrates that resistance to *C. curvignathus* is closely linked to the retention of Hartindo AF21, as higher retention levels resulted in fewer attacks on both treated wood species. This indicated that a higher retention value corresponds to a greater presence of chemicals in the treated wood. As stated by Ma et al. (2013), the effectiveness against decay and termite resistance is determined by the surface retention per unit area of the treated wood surface. Kirker and Lebow (2021) also emphasised that the protection of wood from decay and insects relies entirely on the achieved retention and penetration during application or use. Even if the most effective preservatives or chemicals are utilised, they cannot provide optimal protection if the penetration is inadequate or the retention level is below standard. According to the findings of this study, it is evident that *K. malaccensis* treated with any concentration of Hartindo demonstrates significant resistance against *C. curvignathus*. When treated with a 20% concentration, *K. malaccensis* only experienced a weight loss of 3.20%, while *H. brasiliensis* showed a weight loss of 6.00% (approximately twice as much) at the same concentration and over three times as much at a 4% concentration. The visual observations align with the weight loss results. Weight loss means that part of the sample has been eaten by termites, which changes the original shape of the sample and thus affects the visual assessment. This trend is also evident in a recent study by Olaniran et al. (2024) on 25-year-old *Gmelina arborea* in the graveyard test against termites.

Table 4 illustrates that *C. curvignathus* preferred the Hartindo-treated samples of *K. malaccensis* the least, with a visual rating ranging from 0 to 1.6, indicating minimal damage (Figure 7). On the other hand, *H. brasiliensis* had a visual rating between 2.7 to 3.5, indicating severe to moderate/severe attacks with penetrations (Figure 8). These findings suggest that both *H. brasiliensis* and *K. malaccensis*, when treated with fire-resistant materials like Hartindo AF21, are less vulnerable to termite attacks compared to untreated wood.

Based on the results obtained, it was found that *K. malaccensis* treated with Hartindo AF21 showed higher resistance compared to *H. brasiliensis* at all tested concentrations. The weight loss in *K. malaccensis* was between 3.20% and 5.55%, while *H. brasiliensis* showed a weight loss between 6.00% and 15.64%. Resistance to *C. curvignathus* increased with higher concentrations of Hartindo AF21, but even at a concentration of 20% it was not sufficient to completely prevent termite infestation of the tested samples. Figure 6 shows that resistance to

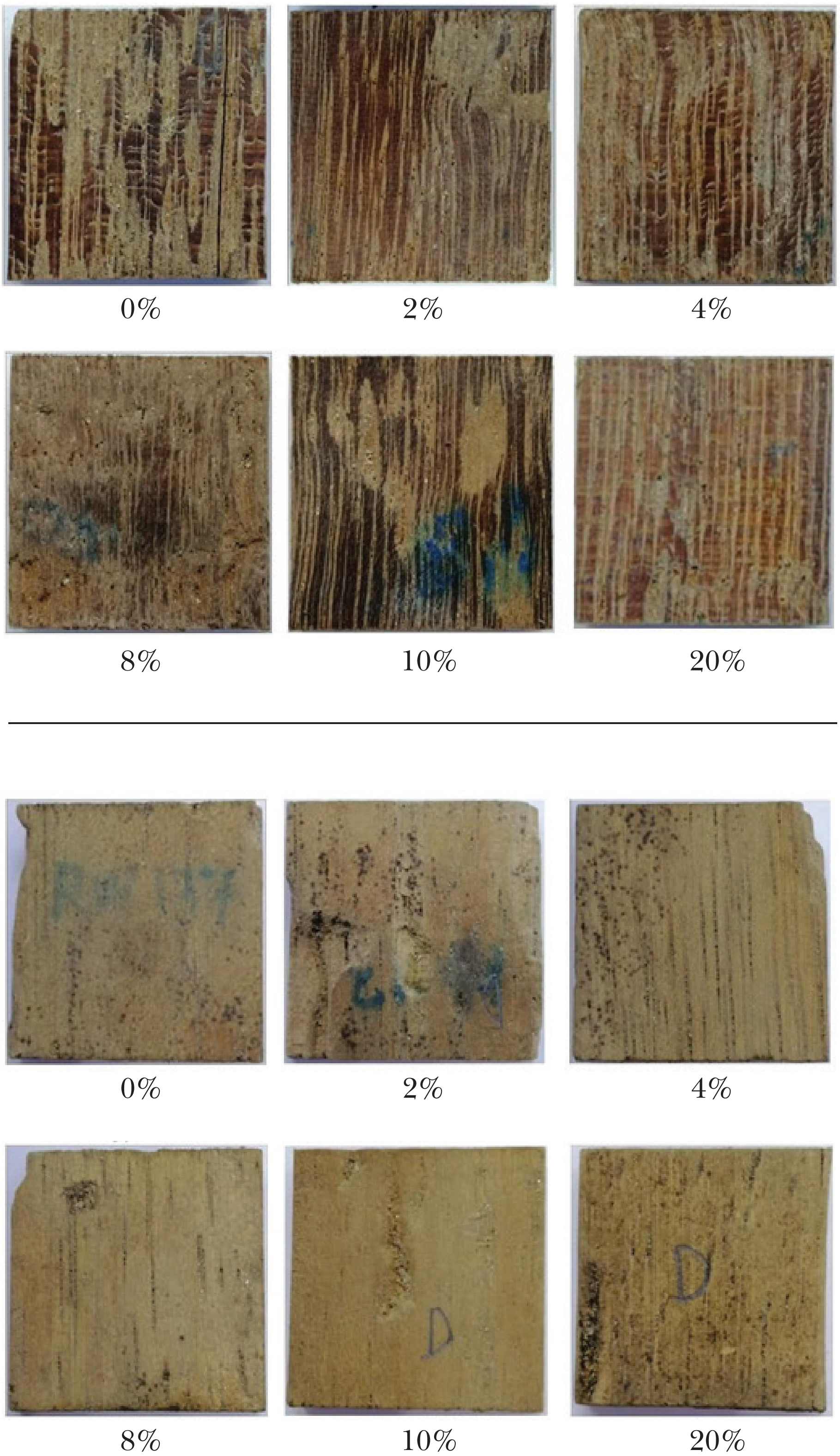

Figure 5 Termites attack on *K. malaccensis* (top) and *H. brasiliensis* (below) treated with different chemical concentrations in laboratory exposure

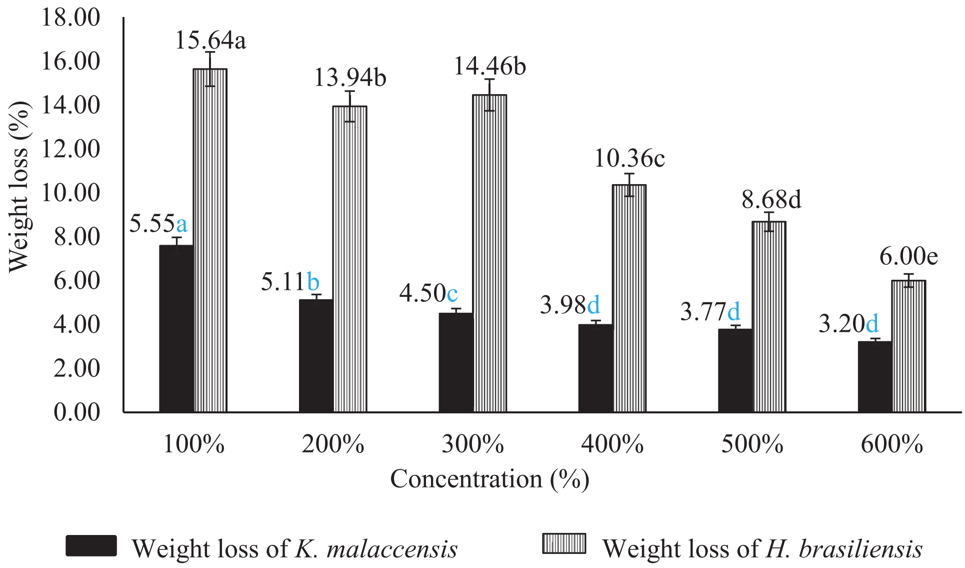

Figure 6 Termiticidal effect of concentration levels of Hartindo AF21 on % weight loss of *K. malaccensis* and *H. brasiliensis* wood for above-ground test

Each value represents the means of 10 replicates. Mean values for retention (w/w) and percentage of weight loss (%) by the same letter are not significantly (P<0.05) different

Table 4 Average visual rating in laboratory test of *H. brasiliensis* and *K. malaccensis* treated with Hartindo AF21 against *C. curvignathus*

Timber species	Concentration (%)	Visual rating
K. malaccensis	0	1.6a
	2	1.6a
	4	1.8a
	6	1.5a
	8	1.4b
	20	0c
H. brasiliensis	0	3.5a
	2	3.0b
	4	3.2b
	6	3.0b
	8	3.0b
	20	2.7b

Mean of 10 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0.05 level of probability.

C. curvignathus is closely related to the retention of Hartindo AF21, as higher retention values resulted in fewer attacks on both treated wood species. This indicates that a higher retention value is associated with a greater presence of chemicals in the treated wood. As Ma et al. (2013) found, the effectiveness against decay and termite resistance is determined by the surface retention per unit area of the treated wood surface. Kirker and Lebow (2021) also emphasised that the protection of wood from decay and insects depends entirely on the retention and penetration achieved during application or use. Even if the most effective preservatives or chemicals are used, they cannot provide optimal protection if the penetration is insufficient or the retention level is below standard.

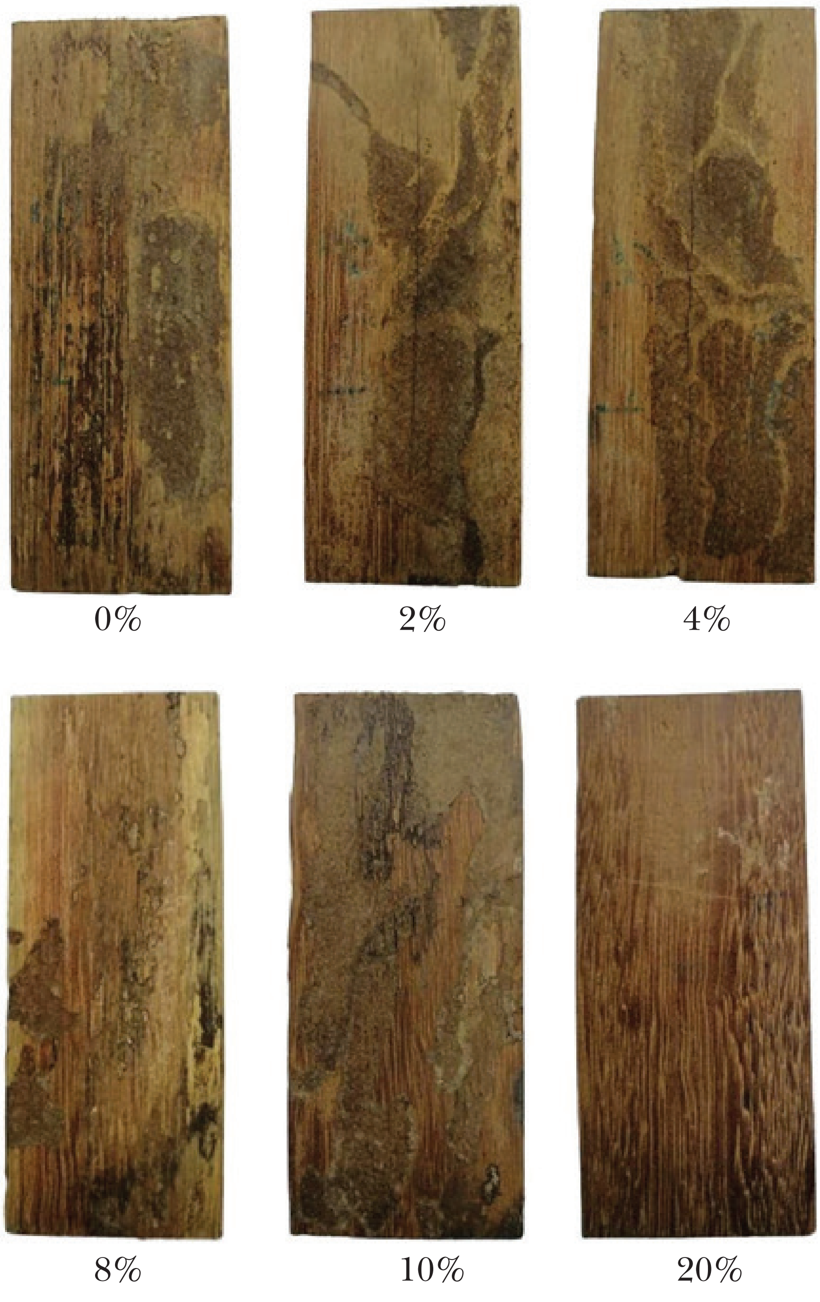

Figure 7 Termites attack on *K. malaccensis* treated with different chemical concentrations in above-ground exposure

0% 2% 4%

8% 10% 20%

Figure 8 Termites attack on *H. brasiliensis* treated with different chemical concentrations in above-ground exposure

In particular, *H. brasiliensis* showed a weight loss of 6.00% (about twice as much) at the same concentration and more than three times as much at a concentration of 4% compared to *K. malaccensis*. This discrepancy in weight loss is consistent with the visual observations in Table 4 that *C. curvignathus* least favoured the Hartindo-treated samples of *K. malaccensis*, with a visual score of 0 to 1.6, indicating minimal damage (Figure 7). In contrast, *H. brasiliensis* visual scores ranged from 2.7 to 3.5, indicating severe to moderate/severe attacks with penetrations (Figure 8). These results emphasise the superior resistance of *K. malaccensis* compared to *H. brasiliensis*, especially when treated with fire-resistant materials such as Hartindo AF21. The significant reduction in termite damage observed in the *K. malaccensis*-treated samples emphasises the effectiveness of Hartindo AF21 in protecting the wood from termite infestation, increasing its durability and lifespan.

CONCLUSION

The current study emphasises the potential advantages of utilizing Hartindo AF21 as a wood preservative to prevent subterranean termite infestation. Its ability to protect against termite attacks, combined with its fire resistance properties, makes it a valuable option for safeguarding wooden structures. This conclusion is supported by laboratory experiments and above-ground tests. Hartindo AF21 has proven effective in protecting both wood species from *C. curvignathus*, although concentrations above 20% are recommended for optimal results. These promising termiticidal properties make Hartindo AF21 a viable choice for wood preservation in Malaysian conditions. However, further research is needed to assess its long-term effectiveness and potential environmental impact.

ACKNOWLEDGEMENT

The authors would like to extend their heartfelt appreciation to the dedicated team at the Wood Entomology Laboratory and Wood Analytical and Preservative Laboratory at FRIM for their invaluable support throughout this project. This work was financially supported by Eleventh Malaysia Plan (Grant No. 23410107002).

REFERENCES

Baraúna EEP, Lima JT, Renato da Silva VJ, Moreira da Silva R & Monteiro1 TC. 2014. Effect of anatomical and chemical structure in the permeability of “Amapa” wood. *Cerne* 20: 529–534. https://doi.org/10.1590/01047760201420041501

Bessin R. 2016. Wood preservation – Methods of applying wood preservatives. https://www.uky.edu/Ag/Entomology/PSEP/cat17applic.html

Dadzie PK, Amoah M, Frimpong-Mensah K & Oheneba-Kwarteng F. 2016. Some physical, mechanical and anatomical characteristics of stemwood and branchwood of two hardwood species used for structural applications. *Material Structure* 49: 4947–4958. https://doi.org/10.1617/s11527-016-0835-3

EcoBlu signs exclusive licensing agreement with Hartindo fire protection supplier Megola. 2009. https://www.globenewswire.com/news-release/2009/11/19/409465/12086/en/EcoBlu-Signs-Exclusive-Licensing-Agreement-With-Hartindo-Fire-Protection-Supplier-Megola.html

Environment friendly – Hartindo anti fire products. 1999. http://newstarchemicals.com/af21.html

Fire inhibitor formulation Patent No. US9920250B1. 2016. https://patents.google.com/patent/US9920250B1/en

FRIM In-House Method (IHM/WEL/1). 2004. Working procedure (PK) A1: FRIM test protocol for wood entomology: test method for determining the relative protective effectiveness of a wood preservative above ground contact. Forest Research Institute Malaysia, Kepong.

Ibáñez CM, Katzenstein G, Mantero C, Benítez V, Camargo A, Berberian N & Bollazzi M. 2023. Ammoniacal zinc borate for wood protection against fungi and insects. *Forests* 14: 1152. https://doi.org/10.3390/f14061152

Kartal SN, Ayrilmis N & Imamura Y. 2007. Decay and termite resistance of plywood treated with various fire retardants. *Building Environment* 42: 1207–1211. https://doi.org/10.1016/j.buildenv.2005.11.018

Kirker GT & Lebow ST. 2021. Chapter 15: Wood preservatives. Page 543 in *Wood handbook–wood as an engineering material*. General Technical Report FPL-GTR-282. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison.

Levan SL & Winandy JE. 1990. Effects of fire retardant treatments on wood strength: A review. *Wood Fiber Science* 22: 113–131.

Ma X, Jiang M, Wu Y & Wang P. 2013. Effect of wood surface treatment on fungal decay and termites resistance. *BioResources* 8: 2366–2375. https://doi.org/10.15376/biores.8.2.2366-2375

Megola Sells Hartindo™ AF21, A total fire inhibitor, to one of the world’s largest textile and chemical manufacturers. 2010. https://www.chemicalonline.com/doc/megola-sells-hartindo-af21-a-total-fire-0001

MS (Malaysian Standard) 544-PART 2: 2001. Code of practice for structural use of timber: Part 2: Permissible stress design of solid timber. Department of Standards Malaysia, Putrajaya.

Murmanis L & Chudnoff O. 1979. Lateral flow in Beech and Birch as revealed by the electron microscope. *Wood Science and Technology* 13: 79–87. https://doi.org/10.1007/BF00368601

Nayeri HR, Mohd Hamami S, Nobuchi T & Edi Suhaimi B. 2011. The effect of growth rate on wood density and anatomical characteristics of rubberwood (*Hevea brasiliensis* Muell. Arg.) in two different clonal trails. *Journal of Natural Products and Resources* 1: 71–80.

Nayeri HR, Asghar T, Ali A & Ghanbar E. 2017. Decay resistance of wood impregnated with monoethanolamine and sodkum bisulfite pulping black liquours. *Maderas Ciencia y Tecnologia* 19: 507–516. https://doi.org/10.4067/S0718-221X2017005000043

Olaniran SO, Iyiola EA & Oyekola AA. 2024. Investigation of wood properties and resistance of 25-year-old *Gmelina arborea* wood selected from crown region to termite attack. *Maderas Ciencia y Tecnologia* 26: 1–8. https://doi.org/10.22320/s0718221x/2024.16

Pan C, Ruan G, Chen H & Zhang D. 2015. Toxicity of sodium fluoride to subterranean termites and leachability as a wood preservative. *European Journal of Wood and Wood Products* 73: 97–102. https://doi.org/10.1007/s00107-014-0849-x

Razak W, Mahmud S & Ahmad MY. 2004. Preservatives penetration and net dry salt retention of treated 2 and 4-year-old bamboo *Gigantochloa scortechinii* Gamble. *Borneo Science* 15: 67–82.

Roszaini K. 2011. *Wood extractives as natural preservatives against termites and fungi.* PhD Thesis. University of Bangor, United Kingdom.

Salamah S & Zaitun S. 1989. Copper-chrome-arsenic distribution in selected Malaysian timbers after full cell process. *Journal of Tropical Forest Science* 4: 1–6.

Salman S, Thévenon MF, Pétrissans A, Dumarçay S, Candelier K & Gérardin P. 2017. Improvement of the durability of heat-treated wood against termites. *Maderas Ciencia y Tecnologia* 19: 317–328. https://doi.org/10.4067/S0718-221X2017005000027

Tho YP & Laurence GK. 1992. *Termites of Peninsular Malaysia.* Malayan Forest Records No 36. Forest Research Institute Malaysia, Kepong.

Umit C, Usta M, Ustaőmer D, Yildiz S & Tomak ED. 2010. The effects of some fire retardant chemicals on the decay resistance of medium density fiberboard (MDF). *International Research Group on Wood Preservation* 41 IRG/WP 10-30536. Annual Conference, Biarritz, France.