WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.6.10171031
e-ISSN 2729-8906
67(6): 2022 1017-1031 pp.

DIMENSIONAL STABILITY AND DURABILITY OF HYBRID SANDWICH PANEL MADE FROM OIL PALM LUMBER, SENGON AND GMELINA WITH BORON-ALUM IMPREGNATION

JAMALUDIN MALIK, ERLINA NURUL AINI, DEAZY RACHMI TRISATYA,
SONA SUHARTANA
RESEARCH CENTRE FOR BIOMASS AND BIOPRODUCTS
INDONESIA

IMAM WAHYUDI, SARAH AUGUSTINA
IPB UNIVERSITY
INDONESIA

(RECEIVED MAY 2022)

ABSTRACT

In this study, sandwich panels made from oil palm lumber, sengon, and gmelina wood -were impregnated with a boron-alum solution to improve their water and termite resistance. Water resistance testing was evaluated using a thickness swelling test following the method in SNI 03-2105. The sandwich panel was also tested for its durability against dry wood termites, according to SNI 01-7207. The weight loss, mortality, and attack degree were used as the parameters for evaluating termite durability. The results showed that the treatment with a boron-alum solution can increase the stability, water resistance, and weight loss properties up to 73%, 41%, and 100%, respectively. The best properties of the sandwich panel were obtained by the sengon-isocyanate panel with 8% boric acid-borax and 5% alum treatment which has thickness swelling of 2.37%, water absorption of 49.04%, weight loss of 0.0124%, termite mortality of 100%, and attack degree of 0.

KEYWORDS: Impregnation, dimensional stability, oil palm lumber, sengon wood, dry wood-termite durability.

INTRODUCTION

The trend of building a knockdown house has been on the rise lately due to its favorable advantages. The knockdown house has a reasonable building cost and a rapid construction time compared to conventional systems (Widayanti et al. 2020). Malik et al. (2020) explained that lignocellulose-based panels are a promising material for knockdown houses because they are simple to manufacture, lightweight, and possess good characteristics for house components. Moreover, the lignocellulose-based panel is also considered a renewable and eco-friendly material that adheres to the sustainable housing principle (Cahyani and Rarasati 2021).

Many wood and non-wood species evidently have good potential as building materials (Nurdiah 2016 and Santi et al. 2016). Sengon wood and oil palm lumber are especially appealing to be developed as house-building materials in Indonesia. Both materials are widespread plant commodities in Indonesia. In 2015, sengon log production could reach 2.51 million m^3 (Priadi et al. 2019). Hambali and Rivai (2017) estimated that Indonesia could be generated up to 34.13 million tons/year of oil palm trunk waste. This number is predicted to continually increases with the growing cultivation of sengon and oil palm trees in Indonesia. The other advantages of sengon wood and oil palm lumber are that they are lightweight and relatively easy to manufacture into composite products suitable for building components. Naturally, sengon wood and oil palm lumber's mechanical strength are not proper for house component utilization. Sengon wood and oil palm lumber's natural strength are suitable for furniture, packing materials, and light construction (Suhaily et al. 2012, Listyanto 2018). Further processing of both materials into composite products may be needed to increase their mechanical strength. Awaludin et al. (2018) and Srivaro et al. (2019) discovered that composite technology could increase sengon wood and oil palm lumber’s strength, allowing them to be used for house components such as wall and floor systems.

However, sengon wood and oil palm lumber also have some disadvantages that restrict them as future house-building materials. Sengon wood and oil palm lumber have low dimensional stability and low water resistance (Dungani et al. 2013 and Rahayu et al. 2021). Both materials also have poor durability against dry wood termite. Sengon wood and oil palm lumber were classified as non-resistant and susceptible to dry-wood termite attack (Ul Haq Bhat et al. 2010, Arinana et al. 2012). The weaknesses of both materials possibly lead to the short service life of houses built with sengon wood and oil palm lumber. Applying wood preservation technology using boron-based preservatives may be the right solution to encounter this issue. The boron-based preservative is widely recognized as one of the best wood preservatives because it is cheap but effective to enhance wood properties, including durability and dimensional stability (Priadi et al. 2020). Boron preservatives are also considered friendly to the environment and have low toxicity against mammals (Tsunoda 2001).

Despite its advantages, the boron-based preservative is easily leached from treated wood (Thévenon et al. 2010). This disadvantage limits the application of boron-based preservatives to enhance the wood and wood product durability. Some studies have been done to reduce the leaching of boron preservatives. Nguyen et al. (2020) mentioned that adding alum to boron-based preservatives can remarkably reduce leachability. However, reports about its direct effect on treated material properties are considered quite limited. Therefore, this paper will supply new information on the effect of boron-alum preservatives on the treated material properties, precisely the dimensional stability, and dry-wood termite durability.

MATERIAL AND METHODS

Materials

Oil palm lumber (*Elaeis guineensis* Jacq.) taken from a replanting area in Banten Province and sengon (*Falcataria moluccana* (L.) Nielsen) wood cut from a community forest in Sukabumi District, West Java Province were chosen as a core part of the sandwich panel, while its face and back part used gmelina (*Gmelina arborea* Roxb.) wood from Sukabumi District, West Java Province. Two types of adhesives, i.e. isocyanate CU3 adhesive (PT. Konishi, Indonesia) and a self-produced tannin-based bio-adhesive (OPE-R) were used to make sandwich panels for this research. Several materials needed for producing OPE-R adhesive were oil palm trunk liquid extract, resorcinol (Buana Laboratory, Indonesia), tapioca flour, 30% NaOH solution (Central Kimia, Indonesia), and 37% liquid formaldehyde (Central Kimia, Indonesia). Borax (Central Kimia, Indonesia), boric acid (Central Kimia, Indonesia), and alum (Central Kimia, Indonesia) were required to make the preservative solution. All chemical materials used in this research were technical grade materials.

Methods

Sandwich panel manufacturing process

The manufacturing process of the sandwich panel started with the preparation of raw materials. There were three raw materials used in this research, i.e., oil palm lumber, sengon wood and gmelina wood. Oil palm lumber and sengon wood were used as the core part of sandwich panel. Gmelina wood was used as the face and back part of the panel. The illustration of sandwich panel composition is presented in Fig. 1. The oil palm lumber and sengon wood were cut into 400 x 100 x 25 mm dimensions. At the same time, the gmelina wood was peeled into a veneer with a thickness of 21 ± 2 mm. Those veneers were then cut into 400 x 400 mm dimensions. All raw materials were then air-dried until they reached a moisture content of ±12%.

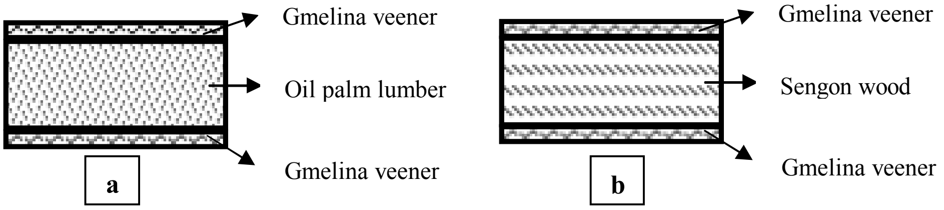

Fig. 1: a) Cross section illustration of oil palm-core sandwich panel; (b) cross section illustration of sengon-core sandwich panel.

In adhesive preparation, each adhesive component was weighed and then mixed. For isocyanate adhesive, the ratio of resin/hardener was 85/15 wt%. After both were weighed according to the ratio, the resin and hardener of isocyanate glue were mixed manually using a glass rod stirrer until they were evenly blended. For tannin-based adhesive, the oil palm trunk extract was weighed and mixed with resorcinol, tapioca flour, 30% NaOH solution, and liquid formaldehyde in the ratio of 2.5 wt%, 2.5 wt%, 5 wt%, and 10 wt% based on oil palm extract weight, respectively.

The following step was forming the sandwich panel. The adhesive was first applied onto the wood surface using a double glue spread (the top and bottom). The glue spread rate for producing sandwich panels using isocyanate was 200 $g{\cdot}m^{-2}$, while the tannin-based adhesive was 170 $g{\cdot}m^{-2}$. The difference in glue spread rate between isocyanate and tannin-based adhesives was caused by the lower viscosity of the tannin-based adhesive. Then, the panel was hot-pressed for 5 min with a temperature of 110°C and pressure of 2 MPa. The sandwich panels were conditioned for about one week before being impregnated with a preservative solution.

Impregnation of borax-borix-alum solution into sandwich panel product

This research used a combination of borax ($Na_2[B_4O_5(OH)_4]{\cdot}8H_2O$), boric acid ($H_3BO_3$) and alum ($K_2SO_4.Al_2[SO_4]_3.24H_2O$) as preservative materials. The content of borax and boric acid were 8%, respectively, while the content of alum was 5%, 10% and 15%. Firstly, borax (BX), boric acid (BA), and alum (A) were dissolved in aquadest, which had been warmed to the temperature of ± 60°C, to form a preservative solution. The preservative solution was then impregnated into the sandwich panel by immersion technique. The immersion duration applied was 24 hours. All panels were then air-dried until they reached a moisture content of ± 12%.

Dimensional stability and water resistance testing

Dimensional stability testing of the sandwich panel was evaluated using a water-soaking test following the method in SNI 03-2105 (2006). The application of the method was slightly modified in the sample size part. A dimensional stability test was performed by immersing a 50 x 25 x 25 mm sandwich panel sample in room temperature water (25°C) for 24 hours. Before the testing, the thickness and weight of each sample were measured. Both sample thickness and weight were also measured after being soaked in water. The experiment was conducted three times for each treatment. The thickness swelling and water absorption value of the panel were calculated using Eqs. 1 and 2:

$$TS = \frac{ta - tb}{tb} \times 100 \quad (\%) \qquad (1)$$

$$WA = \frac{wa - wb}{wb} \times 100 \quad (\%) \qquad (2)$$

where: *TS* - thickness swelling (%), *ta* - sample thickness after being immersed in water (mm), *tb* - sample thickness before being immersed in water (mm), *WA* - water absorption (%), *wa* - sample weight after being immersed in water (mm), and *tb* - sample weight before being immersed in water (mm).

Dry-wood termite durability testing

The sandwich panel's dry wood termite durability was also tested in addition to dimensional stability. The test was carried out according to SNI 01-7207 (SNI 2014) with five replications of each treatment. The termite species used was *Cryptotermes cynocephalus* Light. The evaluation of dry-wood termite durability was performed by placing a glass tube (diameter of 18 mm, height of 30 mm) vertically on the wide side of each sandwich panel sample sized 50 x 25 x 25 mm. Fifty healthy and active worker termites were put on inside the tube, and the top part of the tube was covered by cotton. All the samples were stored in a dark room for 12 weeks. After 12 weeks, the samples were washed and dried using the oven with a temperature of 60 ± 2°C for 48 hours. After that, each sample was weighed, and the number of dead termites after feeding was counted to calculate their weight loss and mortality rate. The calculation of weight loss and mortality rate were done based on Eqs. 3 and 4:

$$WL = \frac{wa - wb}{wb} \text{ x } 100 \quad (\%) \qquad (3)$$

$$M = \frac{nb}{na} \text{ x } 100 \quad (\%) \qquad (4)$$

where: *WL* - weight loss (%), *wa* - sample weight after feeding test (g), and *wb* - sample weight before feeding test, *M* - termite mortality rate (%), *na* - the number of alive termites used in the feeding test, *nb* - the number of death termite after feeding test.

Besides weight loss and mortality rate, the specimen's attack degree and resistance class were also measured. The attack degree was measured by visual observation of the sample. This measurement is referred to SNI 01-7207 (BSN 2014), which can be seen in Tab. 1. The determination of resistance class was rated according to the weight loss, as presented in Tab. 2. The data collected from the evaluation of sandwich panel properties were later statistically analyzed using a three-way analysis of variance at a 95% confidence level, continued by Tukey's honestly significant difference (HSD).

Tab. 1: Dry wood termite attack degree classification (SNI 2014).

Damage category	Specimen condition	Percentage of damaged area (%)	Attack degree
No damage to the surface area	Intact specimen or there is only minor damage detected in the surface area	0 - 5	0
Slightly attacked	Feeding marks in the form of bite marks are present	5 - 15	40
Moderately attacked	Feeding marks in the form of slightly deep and slightly wide tunnels are present	16 - 35	70
Heavily attacked	Feeding marks in the form of deep and wide tunnels are present	36 - 50	90
Very heavily attacked	Destroyed specimen, approximately 50% of the specimen has been eaten by termites	> 50	100

Tab. 2: Resistance classes of wood to dry wood termite (SNI 2014).

Resistance class	Weight loss (%)	Resistance degree
I	< 2	Very resistant
II	2 – 4.4	Resistant
III	4.45 – 8.2	Moderately resistant
IV	8.3 – 28.1	Non-resistant
V	> 28.1	Susceptible

FTIR (Fourier transform infrared) analysis

The samples for FTIR analysis were powdered using a mill machine. The samples were then dried at 40°C overnight to reduce the moisture. A FTIR analysis of those samples was conducted with a FTIR spectrophotometer (Bruker FTIR Tensor 37, Indonesia) using KBr disk method. It was recorded through an average of 32 scans at a resolution of 4 cm^{-1}.

RESULTS AND DISCUSSION

Dimensional stability and water resistance of the sandwich panel

The sandwich panel's thickness swelling (TS) and water absorption (WA) values in this research are presented in Fig. 2 and Fig. 3.

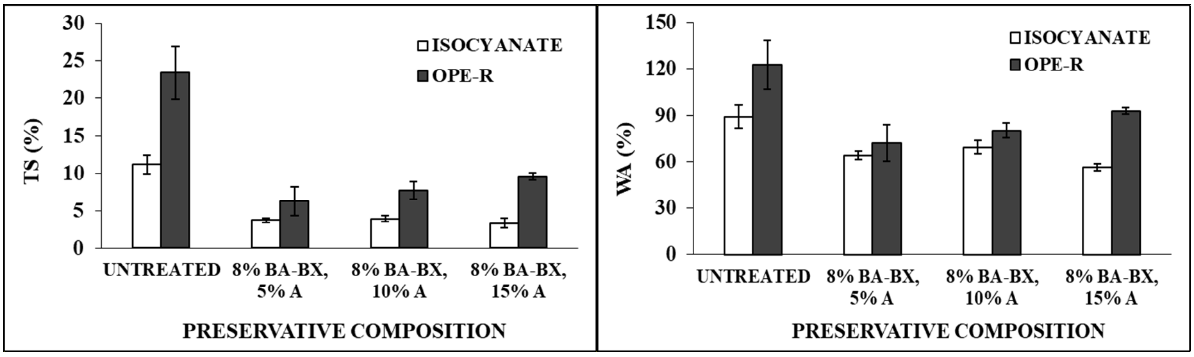

Fig. 2: The effect of alum content in preservative solution towards thickness swelling (TS) and water absorption (WA) properties of sandwich panel with oil palm lumber core. Vertical lines through the bars represent the standard deviation from the mean.

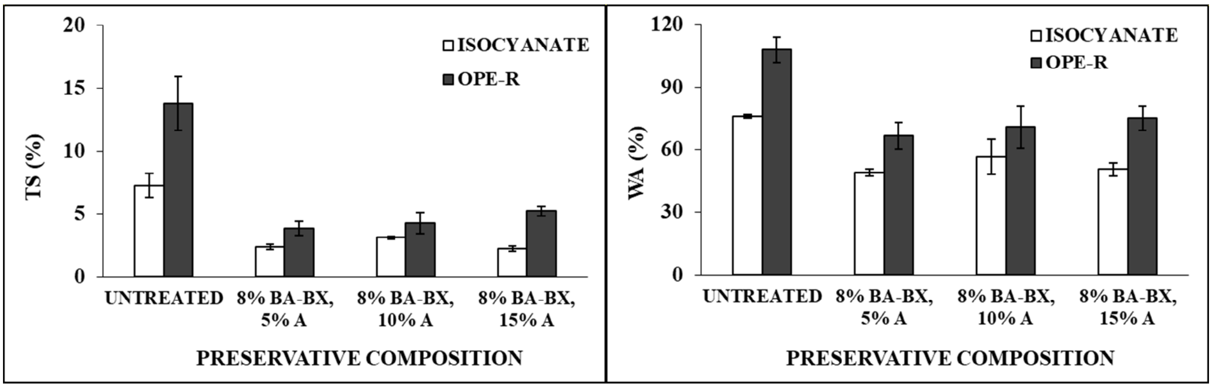

Fig. 3: The effect of alum content in preservative solution towards thickness swelling (TS) and water absorption (WA) properties of sandwich panel with sengon wood core. Vertical lines through the bars represent the standard deviation from the mean.

The TS and WA values for the sandwich panel ranged from 3.33% to 23.43% and 56% to 123%, respectively, in oil palm sandwich panel. In sengon sandwich panel, the TS and WA values were about 2.23% to 13.79% and 49% to 108%. Isocyanate-sengon sandwich panel treated with 8% boric acid-Borax (BA-BX) and 5% alum (A) was found to have the lowest TS and WA values. The highest TS and WA values it was obtained from the untreated OPE-R-oil palm sandwich panel. Based on the analysis of variance result in Tab. 3, the factor of the core material significantly affected the TS and WA properties. In this research, the TS value of the oil palm core panel was about 25−84% higher than the sengon core panel, while its WA value was 7-31% higher. High thickness swelling and water absorption values pointed to wood or wood products' poor dimensional stability and water resistance. Different lignocellulosic materials may show different swelling and water absorbing characteristics which can be attributed to the difference in anatomical structure and chemical composition (Hernández 2007 and Srivaro et al. 2018).

The higher TS and WA values in oil palm panels were likely resulted from the presence of parenchyma tissue in oil palm lumber. Parenchyma tissue had relatively high starch content accumulated at about 17.71% (Lamaming et al. 2015). Starch had a rich presence of OH groups, making it easier to form hydrogen bonding with water molecules (Mishra and Naik 1998) and thus made parenchyma tissue has a very hygroscopic characteristic (Abdul Khalil et al. 2012). In addition, oil palm lumber fibers also had a porous structure, which prompted large initial water uptake (Abdullah et al. 2012). It also could lead to a higher TS and WA value of the oil palm lumber composite.

The adhesive type was also proven significantly affect both thickness swelling and water absorption properties of the sandwich panel (Tab. 3). In this research, OPE-R bonded panel's TS value was 36-188% higher than isocyanate panels, while its WA value was 11-48% larger. The finding indicated that the OPE-R panel had inferior dimensional stability and water resistance properties to the isocyanate panel. The higher TS and WA values of the OPE-R panel might be attributed to the poor water resistance ability of the OPE-R adhesive. Poor water resistance of OPE-R adhesive negatively affected the bonding strength of OPE-R bonded panels in wet conditions. Previous research by Santoso et al. (2020) found that the wet bonding strength of bamboo and wood composite products bonded with OPE-R adhesive was 24–83% lower than its dry bonding strength.

Tab. 3: Analysis of variance of thickness swelling (TS) and water absorption (WA) properties.

	Factors	**TS**	**WA**
Significance (p-value)	Core material	7.56×10^{-10} *	2.48×10^{-6} *
	Adhesive type	2.75×10^{-11} *	3.28×10^{-12} *
	Preservative composition	4.34×10^{-17} *	1.64×10^{-13} *
	Core material x Adhesive type	6.49×10^{-3} *	9.79×10^{-1} $^{\mathrm{ns}}$
	Core material x Preservative composition	2.07×10^{-3} *	9.22×10^{-1} $^{\mathrm{ns}}$
	Adhesive type x Preservative composition	8.00×10^{-7} *	7.48×10^{-4} *
	Core material x Adhesive type x Preservative composition	1.96×10^{-1} $^{\mathrm{ns}}$	6.90×10^{-1} $^{\mathrm{ns}}$
Note: * - significant at $p < 0.05$, $^{\mathrm{ns}}$ - not significant at $p > 0.05$.			

Chemical bonds formed by adhesive have a major impact on wood panel properties, such as its mechanical properties and dimensional stability (Magalhães et al. 2021). A study by Hashim et al. (2011) and Sulastiningsih et al. (1995) about the properties of oil palm laminated veneer lumber and sengon wood blockboard exhibited a result that supported the previous statement, in which the panel with the best bonding strength relatively also produced the lowest value of thickness swelling. High bonding strength in lignocellulose-based composite products could represent the high number of resin or bonding agents reacted with OH groups in lignocellulosic material (Widyorini et al. 2016). The formation of the bond between OH-groups from raw material and resin or binding agent potentially reduced the number of OH-groups that can form a hydrogen bond with water. Hence, the panel with higher bonding strength rather had lower TS and WA values.

According to the analysis of variance result (Tab. 3), the preservative composition factor significantly influenced both the TS and WA value of the sandwich panel produced in this study. Impregnating the sandwich panel with borax-boric acid-alum preservatives caused a considerable increase in dimensional stability and water resistance properties. This statement was proven by the decreased value of TS and WA after impregnation with the combination of boron-alum solution. Panel sandwich treatment with the boron-alum solution could sequentially reduce the TS and WA values to 57-73% and 25-41%. However, further analysis with Tukey's HSD found that the amount of alum added to the boron preservative did not significantly affect the TS and WA values. The enhancement of panel dimensional stability and water resistance after treatment with boron alum solution was probably due to the hygroscopic boron compounds being bound in the lignocellulosic raw material, which overall would increase the raw material hydrophobicity (Kartal et al. 2007).

The TS and WA value of the boron-alum-impregnated panel were considerably lower than the boron-only-impregnated composite board in other research. Based on Terzi et al. (2017), TS and WA values of hardwood-softwood composite board impregnated with a 10% borax -boric acid mixture at equal composition were around 12% and 108%. The boron-alum-impregnated composite panel's average TS and WA values were 62% and 38% smaller than the boron-impregnated one. Hence, the addition of alum could enhance the ability of the boron-based solution to improve dimensional stability and water resistance. This result might be because alum could facilitate the formation of stronger boron compound fixation in wood. Alum, as an electrolyte, is capable of forming a huge amount of positively charged ions that can help negatively charged boron ions to be more firmly bound in wood by assisting the creation of an isoelectric state in the bounding system (Nguyen et al. 2020).

Dry wood termite durability of sandwich panel

Tabs. 4 and 5 show the result of dry wood termite durability testing of oil palm and sengon sandwich panels. The number of weight loss, mortality and attack degree of each panel was in a range of 0.52 x 10^{-2} % to 1.41%, 39.33% to 100%, 0% to 70% in oil palm panel, and 0.78 x 10^{-2} % to 1.65%, 38.67% to 100%, 0% to 70% in sengon panel. The highest weight loss values, and attack degree were generally recorded on all untreated panels. For mortality, its highest value came from all panels with preservation treatment. On the other hand, the lowest value of weight loss and attack degree have resulted from all treated panels, while mortality has resulted from all untreated panels. Mortality has a linear relation with termite durability. The high mortality rate reflected better termite durability. On the contrary, the high weight loss and attack degree represented poor termite durability. The rate of termite durability on wood and other lignocellulosic material was commonly called resistance class. The parameter to determine resistance class was different between each standard of termite durability testing that existed. In the SNI standard, the determination of the resistance class solely used the weight loss parameter. Following the SNI standard, all panels in this research were categorized with class resistance I or very resistant because their weight loss number was less than 2%.

Tab. 4: Dry wood termite durability of sandwich panel with oil palm lumber core.

Adhesive	Preservative composition	Weight loss (%)	Mortality (%)	Attack degree (%)
Isocyanate	Untreated	1.41 ± 0.15	39.33	70
	8% BA-BX, 5% A	1.35 x10^{-2} ± 0.07 x 10^{-2}	100	0
	8% BA-BX, 10% A	0.52 x 10^{-2} ± 0.12 x 10^{-2}	100	0
	8% BA-BX, 15% A	1.09 x 10^{-2} ± 0.16 x 10^{-2}	100	0
OPE-R	Untreated	1.25 ± 0.07	38.67	70
	8% BA-BX, 5% A	1.41 x 10^{-2} ± 0.75 x 10^{-3}	100	0
	8% BA-BX, 10% A	1.37 x 10^{-2} ± 1.03 x 10^{-3}	100	0
	8% BA-BX, 15% A	0.80 x 10^{-2} ± 2.17 x 10^{-3}	100	0

Tab. 5: Dry wood termite durability of sandwich panel with sengon wood core.

Adhesive	Preservative composition	Weight loss (%)	Mortality (%)	Attack degree (%)
Isocyanate	Untreated	1.10 ± 0.24 x 10^{-2}	40	70
	8% BA-BX, 5% A	1.24 x 10^{-2} ± 0.26 x 10^{-2}	100	0
	8% BA-BX, 10% A	0.81 x 10^{-2} ± 0.07 x 10^{-2}	100	0
	8% BA-BX, 15% A	0.78 x 10^{-2} ± 0.07 x 10^{-2}	100	0
OPE-R	Untreated	1.65 ± 0.17	38.67	70
	8% BA-BX, 5% A	2.33 x 10^{-2} ± 0.44 x 10^{-2}	100	0
	8% BA-BX, 10% A	1.57 x 10^{-2} ± 0.99 x 10^{-3}	100	0
	8% BA-BX, 15% A	2.07 x 10^{-2} ± 0.49 x 10^{-2}	100	0

Some research results done by other researchers suggested that the assessment of durability class is based not only on its weight loss but also on the termite foraging pattern on the wood. Batista et al. (2016) and Fauzziyah et al. (2019) found that apart from weight loss strength downgrade of wood after the termite attack was also affected by the number of the attacked area. If termites attacked a large area of the wood sample, it likely resulted in notably weakened wood strength on a large area. Hence, in this research, we also did resistance class evaluation according to the IPT standard (1980), which included the visual appearance of termite foraging patterns to rate the termite durability class of wood. Based on the IPT standard (1980), all untreated sandwich panels in this study with feeding marks in the form of tunnels were classified as moderately attacked (class resistance II). All treated sandwich panels with feeding marks in the form of minor bite marks on the surface area were considered superficially attacked (class resistance I) by the same standard.

Based on the analysis of variance in Tab. 6, the core material factor was not significantly affecting any of the termite durability parameters. The preservative composition significantly affected both termite durability parameters, such as weight loss (WL) and mortality (M). While while the adhesive type factor only significantly influenced the weight loss parameter. For interaction between two factors, the interaction between the core material and preservative composition did not significantly affect either weight loss or mortality. Interaction between core material-adhesive type and adhesive type-preservative composition significantly impacted weight loss, but neither significantly influenced mortality. Interaction between three factors was found only significantly influenced weight loss.

Tab. 6: Analysis of variance of weight loss (WL) and mortality (M) properties.

	Factors	WL	M
Significance (p-value)	Core material	$4.02 \text{ x } 10^{-1\ \text{ns}}$	$8.74 \text{ x } 10^{-1\ \text{ns}}$
	Adhesive type	$3.72 \text{ x } 10^{-3}$ *	$6.34 \text{ x } 10^{-1\ \text{ns}}$
	Preservative composition	$2.03 \text{ x } 10^{-34}$ *	$3.58 \text{ x } 10^{-40}$ *
	Core material x Adhesive type	$7.11 \text{ x } 10^{-6}$ *	$8.74 \text{ x } 10^{-1\ \text{ns}}$
	Core material x Preservative composition	$7.48 \text{ x } 10^{-1\ \text{ns}}$	$9.94 \text{ x } 10^{-1\ \text{ns}}$
	Adhesive type x Preservative composition	$4.97 \text{ x } 10^{-4}$ *	$8.74 \text{ x } 10^{-1\ \text{ns}}$
	Core material x Adhesive type x Preservative composition	$1.01 \text{ x } 10^{-8}$ *	$9.94 \text{ x } 10^{-1\ \text{ns}}$
Note: * - significant at $p < 0.05$, $^{\text{ns}}$ - not significant at $p > 0.05$.			

As mentioned previously, there was a significant difference in weight loss and mortality rate between the isocyanate panel and the OPE-R panel. There was no notable difference in the attack degree on the panel found between those adhesives. OPE-R adhesive tended to have a larger weight loss than isocyanate adhesive. The difference in weight loss between the two types of adhesive was about 4% to 160%. The difference in mortality rate value between isocyanate and OPE-R adhesive was only 2-3%, with the isocyanate panel having the larger mortality rate. Overall, isocyanate was able to give better termite durability compared to OPE-R. It was probably caused by some chemical substance in isocyanate that prompted termite reluctance to feed on the sandwich panel (Syamani et al. 2011).

The effect of boron-alum impregnation treatment seemed to have more influence on termite durability. Treating sandwich panels with boron-alum prompted better performance in weight loss, mortality, and attack degree parameters. Boron-alum treatment on the sandwich panel could reduce its weight loss and attack degree by up to 100% while increasing its mortality rate by about 150-159%. The value of the boron-alum treated panel weight loss was found to be far less than boron-only alum treated. The value of sengon boron-treated and oil palm trunk boron-treated on Darmono et al. (2013) and Harsono et al. (2016) was 5.22% and 19.36%, respectively, which were more or less 100% higher than the weight loss of boron-alum treated panel on this research. This positive effect of alum addition in further increasing the termite durability might be caused by the better fixation of boron in wood facilitated by alum, as described before in the TS and WA value discussion. Boron compounds were reported to have high toxicity against wood destroyer agents such as termites and fungi but low toxicity against vertebrates and mammals, making them suitable for enhancing wood durability (Gentz and Grace 2006).

FTIR analysis

Fig. 3 shows an FTIR analysis result of the isocyanate-bonded sengon wood sandwich panel with different impregnation treatments. As mentioned in Feng et al. (2011) and Xia et al. (1995), the esterification of boron compounds in wood could be verified by the formation of a new band at 1380, 1340, 1280, 940, and 810 cm^{-1}, which potentially showed characteristic bands of tri-coordinated and tetrahedra boron. The wavenumbers at 1380, 1340, 1280, 940, and 810 cm^{-1}

were each associated with the stretching vibrations of the boric acid hydroxyl groups, B-O-B stretching vibrations, B-O-C stretching vibrations, stretching vibrations of the B\\O bonds of 'boroxol rings', BOH in-plane bending vibration, and stretching and bending vibrations of B\\O in BO^{4-} tetrahedra (Boulos et al. 1971). The valence vibration bands of B-O-B and B-O-C at 1600, 1500, and 1450 cm^{-1}, which respectively indicated the existence of benzene rings, also could be an indicator of boron compounds polymerization in wood (Zhang et al. 2020).

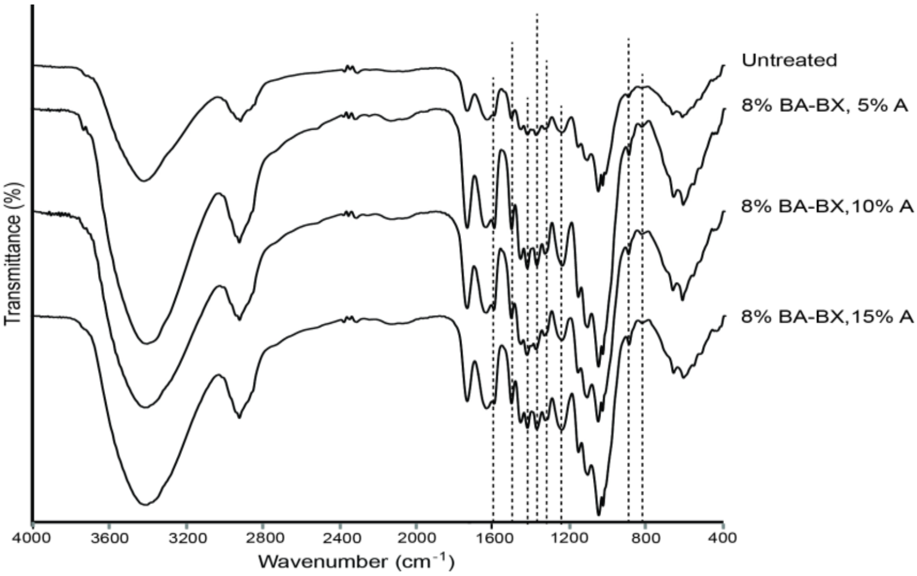

Fig. 4: FTIR spectra of sengon wood sandwich panel bonded with isocyanate before and after impregnation with the borax-boric acid-alum solution at different composition.

All of those boron-wood reaction bands were found to exist on sandwich panel FTIR analysis result in this experiment, which is marked by the dotted line in Fig. 4. However, the wavenumbers recorded were not precisely like the wavenumber listed in Zhang et al. (2020) research. The wavenumbers recorded in this research were around 1598, 1507, 1425, 1380, 1336, 1247, 899, and 810 cm^{-1}. The different wavenumber of the same band recorded was not uncommon in FTIR analysis. This phenomenon could happen due to the difference in analysis conditions, such as the tested material, analysis method, or analysis instrument.

Based on the FTIR analysis result, it might be interpreted that the linkage of boron compounds-raw material occurred with the sandwich panel with boron-alum treatment. This linkage made some properties of the panel being evaluated in this study, such as dimensional stability, water resistance, and termite durability from the boron-alum treated panels, remarkably better than the untreated panels. From the FTIR result, we could see that the addition of alum did not influence the reaction peak notably. This outcome was in line with Tukey's HSD analysis result of preservative composition factor in thickness swelling, water absorption, and termite durability. It can be concluded that the addition of 15% alum generally achieved the same number of boron-raw material bonds that were formed with 5% and 10% alum addition. The 5% alum might be considered the optimum amount of alum addition in the boron-based preservative solution used in this study.

CONCLUSIONS

(1) The core material, adhesive type, and preservative composition factors significantly affected the stability, water resistance, and durability of sandwich panels in this research. *(2)* Oil palm and OPE-R panels had inferior dimensional stability, water resistance, and termite durability compared to sengon and isocyanate panels. *(3)* Boric acid-borax-alum treatment hugely increased dimensional stability, water resistance, and termite durability of both sengon panel and oil palm bonded with isocyanate and OPE-R adhesives in this research. *(4)* Addition of alum to boron-based preservatives in this research increased the effectiveness of boron-based preservatives. It might be due to the higher level fixation of the preservative solution on the panel, which was prompted by alum addition. *(5)* Stability, water resistance, and durability of panels after treatment with alum ratios of 5%, 10%, and 15% were not drastically different. Hence, the optimum alum ratio in this research was concluded at 5%. *(6)* The sengon-isocyanate panel with 8% boric acid-borax and 5% alum treatment has the best stability and durability properties, i.e., thickness swelling of 2.37%, water absorption of 49.04%, weight loss of 1.24 x 10-2 %, termite mortality of 100% and attack degree of 0.

ACKNOWLEDGMENTS

The authors are grateful for the support of funding from the LPDP (The Indonesia Endowment Fund for Education) and Pustarhut BSI (The Center for Standardization of the Sustainable Forest Management Instruments of the Ministry of Environment and Forestry) for the research facilities.

REFERENCES

1. Abdul Khalil, H.P.S., Amouzgar, P., Jawaid, M., Hassan, A., Ahmad, F., Hadiyana, A., Dungani, R., 2012: New approach to oil palm trunk core lumber material properties enhancement via resin impregnation. Journal of Biobased Materials and Bioenergy 6(3): 1-10.
2. Abdullah, C.K., Jawaid, M., Abdul Khalil, H.P.S., Zaidon, A., Hadiyane, A., 2012: Oil palm trunk polymer composite: morphology, water absorption, and thickness swelling behaviours. Bioresources 7(3): 2948-2959.
3. Arinana, A., Tsunoda, K., Herliyana, E.N., Hadi, Y.S., 2012: Termite-susceptible species of wood for inclusion as a reference in Indonesian standardized laboratory testing. Insects 3(2): 396-401.
4. Awaludin, A., Shahidan, S., Basuki, A., Zuki, S.S.M., Nazri, F.M., 2018: Laminated veneer lumber (LVL) sengon: an innovative sustainable building material in Indonesia. International Journal of Integrated Engineering 10(1): 17-22.
5. Batista, D.C., Nisgoski, S., da Silva Oliveira, J.T., de Muñiz, G.I.B., Paes, J.B., 2016: Resistance of thermally modified *Eucalyptus grandis* W. Hill ex Maiden wood to deterioration by dry-wood termites (*Cryptotermes* sp.). Ciência Florestal 26(2): 671-678.

6. Boulos, E.N., Kreidl, N.J., 2006: Structure and properties of silver borate glasses. Journal of the American Ceramic Society 54(8): 368-375.
7. Cahyani, D.R., Rarasati, A.D., 2021: Sustainability and affordability analysis for one million housing program a case in Cileungsi District Bogor Regency West Java. IOP Conf. Series: Earth and Environmental Science 79(1): 012022.
8. Darmono, D., Atun, S., Prasetyo, S., 2013: Application of borax and boric acid mixture as preservative material for termite attack. (In Indonesian). Inotek 17(1): 82-99.
9. Dungani, R., Jawaid, M., Abdul Khalil, H.P.S., Jasni, J., Aprilia, S., Hakeem, K.R., Hartati, S., Islam, M.N., 2013: A review on quality enhancement of oil palm trunk waste by resin impregnation: future materials. Bioresources 8(2): 3136-3156.
10. Fauzziyah, S., Karlinasari, L., Nandika, D., 2019: Penetration depth evaluation approach for termite-infested *Shorea* spp. Lumber. Bioresources 14(3): 7080-7094.
11. Feng, N., Zheng, A., Wang, Q., Ren, P., Gao, X., Liu, S.B., Shen, Z., Chen, T., Deng, F., 2011: Boron environments in B-doped and (B, N)-codoped TiO_2 photocatalysts: a combined solid-state NMR and theoretical calculation study. The Journal of Physical Chemistry C 115(6): 2709-2719.
12. Gentz, M.C. and Grace, J.K., 2006: A review of boron toxicity in insects with an emphasis on termites. Journal of Agricultural and Urban Entomology 23(4): 201-207.
13. Hambali, E., Rivai, M., 2017: The potential of palm oil waste biomass in Indonesia in 2020 and 2030. IOP Conf. Series: Earth and Environmental Science 65(1): 012050.
14. Harsono, D., 2016: The effectivity of borax and boric acid preservatives to against termites (*Coptotermes curvignathus* Holmgren) attack on oil palm trunk (*Elaeis guinensis* Jacq.). (In Indonesian). Jurnal Riset Industri Hasil Hutan 8(2): 87-98.
15. Hashim, R., Sarmin, S.N., Sulaiman, O., Yusof, L.H.M., 2011: Effects of cold setting adhesives on properties of laminated veneer lumber from oil palm trunks in comparison with rubberwood. European Journal of Wood and Wood Products 69: 53-61.
16. Hernández, R.E., 2007: Swelling properties of hardwood as affected by their extraneous substances, wood density, and interlocked grain. Wood and Fiber Science 29(1): 148-156.
17. IPT 1157, 1980: Methods of testing and analysis in wood preservation: Accelerated laboratory test of natural resistance or wood preserved to the attack of termites of the genus *Cryptotermes* (Fam. *Kalotermitidae*).
18. Kartal, S.N., Hwang, W.J., Imamura, Y., 2007: Water absorption of boron-treated and heat-modified wood," Journal of Wood Science 53(5): 454-457.
19. Lamaming, J., Hashim, R., Peng Leh, C., Sulaiman, O., Sugimoto, T., 2015: Chemical, crystallinity and morphological properties of oil palm trunk parenchyma and vascular bundle. International Journal of Environmental Engineering 2(1): 66-70.
20. Listyanto, T., 2018: Wood quality of *Paraserianthes falcataria* L. Nielsen syn wood from three year rotation of harvesting for construction application. Wood Research 63(3): 497-504.
21. Magalhães, R., Nogueira, B., Costa, S., Paiva, N., Ferra, J.M., Magalhães, F.D., Martins, J., Carvalho, L.H., 2021: Effect of panel moisture content on internal bond strength and thickness swelling of medium density fiberboard. Polymers 13: 114.

22. Malik, J., Trisatya, D. R., Abdurachman, A., 2020: Potential use of fully wood based sandwich panel for house component in Indonesia for disaster mitigation and rapid built: A review. IOP Conf. Series: Materials Science and Engineering 935(1): 012022.
23. Mishra, S., Naik, J. B. 1998: Absorption of water at ambient temperature and steam in wood–polymer composites prepared from agrowaste and polystyrene. Journal of Applied Polymer Science 68: 681-686.
24. Nguyen, T.T.H., Tran, V.C., Li, S., Li, J., 2020: Effects of rosin-alumunium sulfate treatment on the leachability, color stability and decay resistance of wood treated with a boron-based preservative. Bioresources 15(1): 172-186.
25. Nurdiah, E.A., 2016: The potential of bamboo as building material in organic shaped buildings. Procedia - Social and Behavioral Sciences 216: 30-38.
26. Priadi, T., Sholihah, M., Karlinasari, L., 2019. Water absorption and dimensional stability of heat-treated fast-growing hardwoods. Journal of the Korean Wood Science and Technology 47 (5): 567–578.
27. Priadi, T., Orfian, G., Cahyono, T.D., Iswanto, A.H., 2020: Dimensional stability, color change, and durability of boron-mma treated red jabon (*Antochephalus macrophyllus*) wood. Journal of the Korean Wood Science and Technology 48(3): 315-325.
28. Rahayu, I., Dirna, F.C., Maddu, A., Darmawan, W., Nandika, D., and Prihatini, E., 2021: Dimensional stability of treated sengon wood by nano-silica of betung bamboo leaves. Forests 12(11): 1581-1590.
29. Santi, S., Pierobon, F., Corradini, G., Cavalli, R., Zanetti, M., 2016: Massive wood material for sustainable building design: the Massiv–Holz–Mauer wall system. Journal of Wood Science 62: 416–428.
30. Santoso, A., Basri, E., Balfas, J., 2020: The quality of laminated wood - bonded with tannin adhesive made from extracted mahogany wood bark. (In Indonesian) Jurnal Penelitian Hasil Hutan 38(3): 151-160.
31. Srivaro, S., Rattanarat, J., Noothong, P., 2018: Comparison of the anatomical characteristics and physical and mechanical properties of oil palm and bamboo trunks. Journal of Wood Science 64: 186–192.
32. Srivaro, S., Matan, N., Lam, F., 2019: Performance of cross laminated timber made of oil palm trunk waste for building construction: a pilot study. European Journal of Wood and Wood Products 77(3): 353-365.
33. SNI 03-2105, 2005. Papan partikel (Particleboards).
34. SNI 01-7207, 2014: Uji ketahanan kayu terhadap organisme perusak kayu (Test resistance of wood against wood destroying organisms).
35. Suhaily, S.S., Jawaid, M., Abdul Khalil, H.P.S., Mohamed, A.R., Ibrahim, F. 2012: A review of oil palm biocomposites for furniture design and applications: potential and challenges. Bioresources 7(3): 4400-4423.
36. Sulastiningsih, I.M., Sutigno, P., Iskandar, M.I. 1995: The effect of strip dimension on some properties of sengon (*Paraserianthes falcataria*) blockboard. (In Indonesian) Journal Penelitian Hasil Hutan 13(5): 186-195.

37. Syamani, F.A., Subiyanto, B., Massijaya, M.Y., 2011: Termite resistant properties of sisal fiberboards. Insects 2(4): 462-468.
38. Terzi, E., Kartal, S.N., Geradine, P., Ibanez, C. M., Yoshimura, T., 2017: Biological performance of particleboard incorporated with boron minerals. Journal of Forestry Research 28(1): 195-203.
39. Thévenon, M.F., Tondi, G., Pizzi, A., 2010: Environmentally friendly wood preservative system based on polymerized tannin resin-boric acid for outdoor applications. Maderas: Ciencia y Tecnología 12(3): 253-257.
40. Tsunoda, K., 2001: Preservative properties of vapor-boron-treated wood and wood-based composites. Journal of Wood Science 47(2): 149-153.
41. Ul Haq Bhat, I., Abdullah, C.K., Abdul Khalil, H.P.S., Ibrahim, M.H., Fazita, M.R.N., 2010: Properties enhancement of resin impregnated agro waste: oil palm trunk lumber. Journal of Reinforced Plastics and Composites 29(22): 3301–3308.
42. Widayanti, B.H., Yuniarman, A., Lestari, S.A.P., Yunianti, S.R., 2020: The level of satisfaction in construction of post-earthquake houses in Tanjung Sub-district, North Lombok Regency. IOP Conference Series: Earth and Environmental Science 447: 012028.
43. Widyorini, R., Umemura, K., Isnan, R., Putra, D.R., Awaludin, A., Prayitno, T.A., 2016: Manufacture and properties of citric acid-bonded particleboard made from bamboo materials. European Journal of Wood and Wood Products 74(1): 57-65.
44. Xia, S., Gao, S., Li, J., Li, W., 1995: IR-spectra of borate. Journal of Salt Lake Science 3(3): 49-53.
45. Zhang, J., Koubaa, A., Xing, D., Liu, W., Wang, Q., Wang., X., Wang, H., 2020: Improving lignocellulose thermal stability by chemical modification with boric acid for incorporating into polyamide. Materials and Design 191: 108589.

JAMALUDIN MALIK*, ERLINA NURUL AINI, DEAZY RACHMI TRISATYA,
SONA SUHARTANA
NATIONAL RESEARCH AND INNOVATION AGENCY (BRIN)
RESEARCH CENTER FOR BIOMASS AND BIOPRODUCTS
BOGOR 16911, INDONESIA
*Corresponding author: jamaludin.malik@brin.go.id

IMAM WAHYUDI, SARAH AUGUSTINA
IPB UNIVERSITY
FACULTY OF FORESTRY AND ENVIRONMENT
DEPARTMENT OF FOREST PRODUCTS
JALAN ULIN KAMPUS DARMAGA
BOGOR 16680, INDONESIA