Termite Resistance Study of Oil Palm Trunk Lumber (OPTL) Impregnated with Oil Palm Shell Meal and Phenol-Formaldehyde Resin

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A phenol-formaldehyde (PF) resin treatment of OPTL with various concentrations of finely ground palm shell, together abbreviated PF-FGPS, has been used to improve termite resistance. Termite resistance was evaluated in two ways, in a laboratory test and in a field test that lasted 3 months. A feeding arena sample was prepared for the first experiment so that the responses of the subterranean termite (*Coptotermes curvignathus* (Holmgren)) and the drywood termite (*Cryptotermes cynocephalus* (Light)) to the laboratory test could be observed for 4 weeks and 12 weeks, respectively. In general, the PF-FGPS led to greater termite resistance than did the control (dried OPTL and rubberwood), and the resistance of the samples to the subterranean termite *C. curvignathus* was classified as moderate when the samples were treated with OPS meal. Meanwhile, the resistance of the samples to the drywood termite *C. cynocephalus* was classified as moderate when samples were treated with OPS meal concentrations of 0, 1, and 3%. The samples treated with 5% OPS meal were classified as resistant. In the field test, samples impregnated with OPS meal at levels of 3%, 5%, and 10% were classified as resistant, while those impregnated with OPS meal at levels of 0 and 1% were classified as moderately resistant to attack by the subterranean termite.

Keywords: Impregnation; Finely ground biomass; Termite; Termite resistance; Oil palm trunk; Oil palm shell

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INTRODUCTION

The increasing world population has led to an increase in demand for wood material for construction purposes as well as for furniture. One way to overcome the shortage in wood supply is to use non-woods such as oil palm trunks (OPT). Oil palm trunk lumber (OPTL) is a very familiar material that has been used for centuries in low-cost and medium- to low-performance markets. As the economic life span of the oil palm tree is 25 to 30 years (Abdul Khalil *et al*. 2010), it is estimated that more than 70,000 ha will have to be replanted every year, requiring the felling of about 9 million palms in Malaysia alone (Mokhtar *et al.* 2008). Many researchers (Abdullah *et al.* 2012; Abdul Khalil *et al*. 2012, 2010; Jawaid *et al.* 2011; Hayawin *et al.* 2011; Bhat and Abdul Khalil

2011; Ul Haq Bhat *et al.* 2010) are working toward transforming this OPT biomass waste into an alternative wood lumber material. The OPT, oil palm shell (OPS), oil palm empty fruit bunch (EFB), and pressed fruit fiber (PFF) have a number of potential uses: lumber, pulp and paper, reconstituted boards, bio-composites, animal feed, fuel, *etc*. Moreover, this biomass will become an environmental problem if no effort is made to use it. Ensuring the utilization of this biomass will solve the disposal problems and create value-added products by converting waste to wealth. OPT, if economically converted into value-added products, could spur the economic activities and increase the income of the nation. It also indirectly impacts the reduction of fossil fuel usage, reduces pressure on tropical timber from forests, and increases economic activities of the nation. Besides, it would help to adopt new technology for utilizing the biomass materials waste into value added products for green energy technology (Abdul Khalil *et al*. 2010)

Decay and insect attack can limit the performance of OPTL, and this is one of the major concerns. It is also expected that the loss will increase if the OPTL is not treated properly for use in furniture and building materials. However, various modification treatments can extend the service life of OPTL. Among the existing modification methods, impregnation is the most popular (Dungani *et al.* 2013) and effective (Furuno *et al.* 2004). Based on recent literature, it has been found that impregnation by phenol-formaldehyde resin (PF) or non-resin chemicals can improve the quality of the OPT. This treatment significantly improves the properties and appearance of the OPT and can thus be used to produce high-grade furniture and housing materials (Bakar *et al*. 2005, 2007), if protection against biodeterioration can be achieved (Islam *et al*. 2007, 2011).

One of the most important groups of organisms responsible for destroying wood and/or panel products made from bio-based materials and used in buildings or other construction are termites. The subterranean termite (*Coptotermes curvignathus* Holmgren) is the most voracious species. This species attacks structural timbers and other cellulosic materials (panel products) as well as living trees. Several studies (Ahmed *et al.* 2004; Aparna 2013) have shown that these termites also attack wood-based panel products. The drywood termite (*Cryptotermes cynocephalus* Light) ranks second for destroying wood or wood-based panels (Tarumingkeng 2001). Both species feed on cellulosic material, including wood, books, dried plants, and furniture, as well as structural wood. While subterranean termites burrow underground, drywood termites do not need soil. As the drywood termite lives entirely within sound dry wood, this pest is easily transported to different areas by means of various human activities.

The objective of this study was to investigate the performance of OPS meal-impregnated OPTL (PF-FGPS) against both the subterranean and dry wood termite. The study focused on two methods, a simple no-choice-feeding test in the laboratory and a choice-feeding test in the field. The intent was that together, the laboratory studies and the field studies would provide a more comprehensive assessment of the performance of OPS fine-ground palm shell-impregnated OPTL (PF-FGPS) in reducing the impact of termites.

EXPERIMENTAL

Preparation of OPTL and Finely Ground Meal from OPS

The commercially-available OPT was sawn into pieces of square lumber with sides of 150 mm and then dried in a kiln at a moisture content of 13% to 15%. The dried square lumber was then cut into 50 mm x 50 mm x 500 mm segments for use in the experiments.

OPS powder samples having total evaporable moisture contents of 1.5% were further ground using a grinder/refiner followed by high-energy ball milling. The milling was done for 30 h at 170 rev min^{-1} with a ratio of 10:1 of balls to powder. The milling chamber was made of tungsten carbide, and the balls were stainless steel, having a diameter of 10 mm. Toluene was used to avoid agglomeration, as reported by Paul *et al.* (2007). The particle size was analyzed by Transmission Electron Microscope (TEM) (Phillips CM 12).

Impregnation of PF-FGPS into Samples

The PF resin was prepared at high molecular weight and at a concentration of 15% w/w. Finely ground OPS meal of exactly 1, 3, 5, and 10% w/w was added to the PF resin to achieve different concentrations of PF-FGPS. The mixtures (PF resin and OPS meal) were compounded using a twin-screw extruder (Haake Model Rheodrive 500). The mixture was perfectly incorporated into the chamber to begin the process of impregnation. The PF-FGPS was impregnated into the OPTL by a vacuum-pressure method. An initial vacuum was created for 15 min at 3 bar, followed by pressure at 7 bar for 60 min, and then a final vacuum at 3 bar for 10 min.

Resistance to Subterranean Termite in Laboratory Test

The laboratory test for termite resistance was conducted according to the ASTM D 3345-74 method. The sample size was 20 x 20 x 10 mm. All samples were oven dried at 35 °C for 3 days and then weighed. Several rectangular glass jars (150 x 45 mm^2), which were used as containers, were evenly filled with moistened water-washed sand (30 g sand of mesh size 40 and 10 mL of water). One sample was placed into each jar. A total of 275 termites (250 workers and 25 soldiers) were added to each screw-cap glass jar. The containers were placed in a dark location for 28 days. There were five replications for this experiment. Upon termination of the termite test, samples were removed from the jars, carefully cleaned by brushing off any adhering debris, and again oven dried (35 °C) for 3 days before being weighed. Percentage mass losses of the samples, visual rating of termite attacks on the test samples according to the standard, and percentage of termite mortality in each jar were measured.

Resistance to Subterranean Termite in Field Test

Samples sized 200 x 20 x 10 mm were air dried for 3 weeks and were numbered with metal labels. Five samples from each category were buried 150 mm into the ground and 100 cm apart during the wet months of March to May, 2012. Test site were located in the arboretums where the dominant subterranean termite were *Coptotermes* spp., *Macrotermes* spp., *Microtermes* spp., and *Nasutitermes* spp. (Nandika *et al*. 2003). After 12 weeks, the samples were removed from the ground, thoroughly cleaned, and weighed to determine their oven-dry weights. The weight loss percentages were calculated from the dried PF-FGPS samples. The condition (protection level) of each test specimen with respect to termite attack was determined using the scoring system described by Garcia *et al*. (2012).

Resistance to Drywood Termite

The laboratory test for resistance to the drywood termite was conducted according to the procedure of Hadjib and Muslich (2011), with one modification in that a PVC tube (30 mm in height and 18 mm in diameter) was used instead of a glass tube. The size of the test specimen was 50 x 25 x 20 mm. One specimen was used for every tube. The experiment was repeated five times. Specimens were placed horizontally under the vertically installed tube, so that the larger surface of the sample came into contact with the lower mouth (hole) of the glass tube. Fifty worker drywood termites were added to the tube. After 12 weeks, samples were removed from the tube, cleaned thoroughly, and weighed to determine their oven-dry weights. The weight loss percentages were calculated, and the condition (protection level) of each test specimen with respect to termite attack was determined according to ASTM D3345-74.

Morphology of OPS Meal-Impregnated Samples after Termite Attack

The samples were prepared for observation with a scanning electron microscope (SEM) before and after the termite attack. The samples were carefully and securely crosscut using a microtome. The smoothness and flatness of the end surface of the crosscut was examined by a light microscope. Gold coating was performed with a sputter coater (Fison SC 515) before the samples were observed in a Leica Cambridge S-360 SEM under conventional secondary electron imaging conditions and with an acceleration voltage of 5 kV. SEM micrographs were taken from the surface of the specimen in the case of termite-damaged samples. SEM, TEM, and X-ray diffraction (XRD) were used to determine the morphology, particle size, and crystallographic structure, respectively, of the OPS meal.

Data Analysis

A one-way analysis of variance (ANOVA) and Duncan's multiple range test were used to analyze the data. All statistical tests were performed using SAS at a 95% confidence level.

RESULTS

Properties of OPS Meal-Impregnated OPTL

A TEM micrograph showed that the particle size ranged from 50 to 100 nm (Fig. 1), with an average particle size close to 50.75 nm. This reduction of particle size from micro to nano was due to the length of time in the ball milling process, leading to the larger surface area of the particles (Fig. 2). A morphological study of the nano-structured OPS meal is presented in Fig. 2. Typically, nano-structured OPA meal consists of irregular and crushed shapes. XRD analysis indicated that the crystalline area of the OPS was eroded during ball milling, thus causing the amorphous area to increase in the very small particles after the ball milling process. Paul *et al*. (2007) also reported similar features for nano-structured materials derived from fly ash. They found that the size reduction was the result of high-energy ball milling, while the total surface free energy increased after 60 h of ball milling. According to Park *et al*. (2010), the index of crystallinity has a significant influence on the hardness, density, transparency, and diffusion. XRD diffraction analysis indicated that the crystallinity of the OPS nanoparticles decreased as the particle size decreased.

Weight Percent Gain (WPG) with Impregnation

The weight percent gained (WPG) by PF-FGPS-impregnated OPTL for various concentrations of OPS meal is shown in Table 1. It was seen that the highest WPG was for OPTL having 5% OPS meal impregnation (35.31% w/w). Levels of OPS meal of more than 5% reduced WPG, which might be because of the inhibition of resin by the OPS meal into wood cells during the impregnation. SEM analysis confirmed the presence of PF resin and OPS meal in the vessels and parenchymatous cells of the OPTL (Fig. 3).

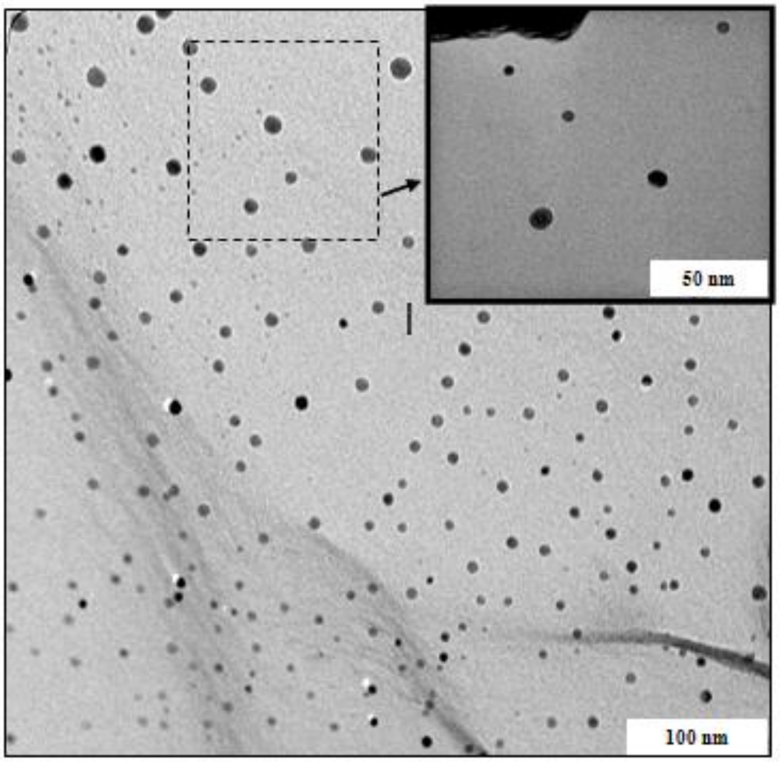


Fig. 1. TEM micrograph showing the distribution of nanoparticles in the OPTL

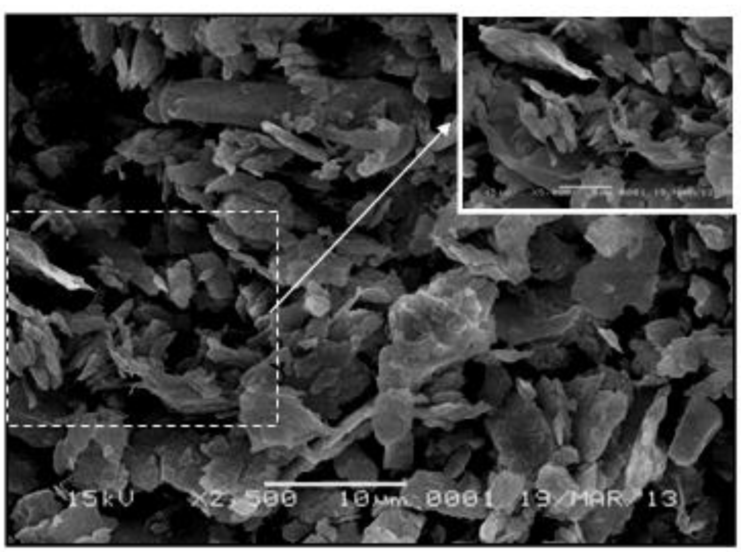


Fig. 2. SEM micrograph showing the macro-texture of the surface and shapes of the finely ground OPS meal

Table 1. WPG Variation with OPS the Level of OPS Meal

OPS meal (%)	Weight percent gain (%)
0	32.48 (0.43)*
1	33.89 (0.30)
3	34.02 (0.29)
5	35.31 (0.46)
10	34.80 (0.31)

* Values in parentheses are standard deviations

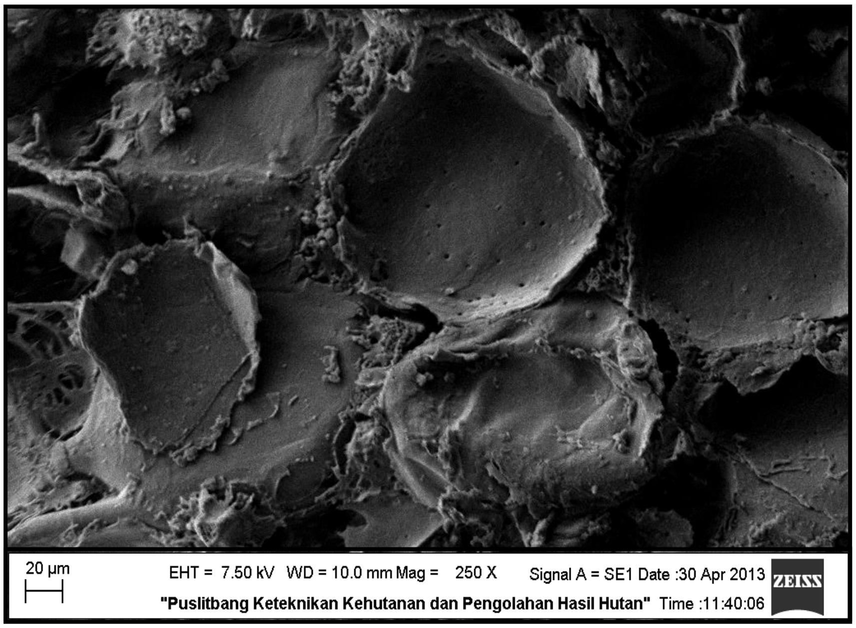


Fig. 3. SEM micrograph showing the presence of PF resin and OPS meal in the OPTL

Resistance to Subterranean Termite of PF-FGPS-Impregnated OPTL in Laboratory Test

Table 2 shows the average weight loss (%), mortality, and visual rating of the PF-FGPS-impregnated OPTL when exposed to the subterranean termite. It was found that the addition of palm shell meal reduced the weight loss, and the lowest weight loss was found when the palm shell meal content was 10%. Statistical analysis indicated that PF-FGPS impregnation significantly reduced the weight loss (F = 17.65, df = 4, P < 0.05) of the specimens after attack by the subterranean termite. There were also significant differences in weight loss between samples with different percentages of PF-FGPS impregnation. In the laboratory test, the termite mortality was around 65% for any percentage of OPS meal addition; however, the mortality rate was very low for dried OPTL (6.5%) and rubberwood (5.3%) after the 4-week test period. Termite mortality also varied significantly between the treated and untreated samples (F = 457.29, df = 4, P < 0.05). Significant variation was also found between samples of different PF-FGPS concentrations. Because of the no-choice test and the conditions of limited food sources, it was found that the termites often behaved like cannibals or non-productive members of their colony, as was also reported by Nandika (1998).

The visual observations supplemented the results of the weight loss measurements. The OPS meal-treated samples received ratings of 7, while the untreated samples (dried OPTL and rubber wood) received ratings of 4. It is important to mention that the termites began feeding from the soft section and then progressed toward the hard section of the impregnated OPTL samples. In general, the addition of OPS meal produced high termite resistance (classified as moderate resistance). The untreated specimens, dried OPTL and rubberwood, belonged to the resistance classes of very poor and poor, respectively, and must be preserved if their service life is to be prolonged. The PF resin may have toxic effects upon inhalation (Ryu *et al*. 1991; Sukartana *et al*. 2000; Sucipto *et al*. 2010); however, lignocellulosic composites with PF resin were not completely resistant against the subterranean termite attack under laboratory conditions.

Table 2. Average Weight Loss, Mortality, Visual Rating, and Resistance Class of PF-FGPS, Dried OPTL, and Rubberwood Exposed to *C. curvignathus* Holmgren

Impregnated OPTL	Weight loss (%)	Termite mortality	Average visual rating	Resistance class
PF without OPS meal	10.73 (0.57)*	55.50	7	Moderately resistant
PF with 1% OPS meal	9.86 (0.59)	67.50	7	Moderately resistant
PF with 3% OPS meal	9.35 (0.46)	64.35	7	Moderately resistant
PF with 5% OPS meal	8.87 (0.39)	68.43	7	Moderately resistant
PF with 10% OPS meal	8.78 (0.84)	64.50	7	Moderately resistant
Dried OPTL	26.29 (0.90)	6.50	0	Very poor
Rubberwood	24.23 (0.76)	5.30	4	Poor

* Values in parentheses are standard deviations.

Field Test

According to the data presented in Table 3, PF-FGPS significantly ($F = 27.48$, $df = 4$, $P < 0.05$) increased the resistance against subterranean termite attack during the field test, which was indicated by the lower weight loss in comparison to the control samples. There were also significant differences in weight loss between samples with different percentages of PF-FGPS impregnation. The lowest weight loss (16%) was found when the PF-FGPS impregnation was 5%. The percentage weight losses for dried OPTL and rubberwood were 47.52% and 50.79%, respectively. The termite damage was lowest (25%) when the PF-FGPS was also 5%, and this was classified as resistant. Significant variation ($F = 120.32$, $df = 4$, $P < 0.05$) was found between treated and untreated samples with respect to termite damage. The variation with regard to termite damage was also significant due to the corresponding variation in concentration of PF-FGPS. The results indicated that PF-FGPS was not an acceptable food for termites, and thus encouraged them to leave the board without causing any remarkable damage. The dried OPTL and rubberwood control samples exhibited damage of 83 and 89%, respectively, which indicated they were not resistant. The PF-FGPS impregnation having the OPS meal concentration of 0, 1, 3, and 10% ranged in termite damage from 28 to 41%, indicating moderate resistance, while 5% PF-FGPS impregnation was classified as resistant because the damage was only 25%. The higher density of 5% concentration of PF-FGPS might be the cause of this higher resistance against termites compared to other samples. Similar results were also reported by Arango *et al.* (2006), where the author mentioned that higher density of the board resulted in more resistance against termite attack. The natural durability of OPTL might have had some additional impact on the relatively higher termite-resistance properties. Garcia *et al*. (2012) reported similar findings in a study testing wood wool cement board from *Gmelina arborea* Roxb. under similar field conditions. The authors mentioned that the natural durability of *G. arborea* and the cement acted as a protective shield for the wood and provided resistance against the termites. The subterranean termite utilizes wood, and primarily the cellulose, as a shelter and food source (Bowyer *et al*. 2003). The greater the amount of OPS meal that was in the test sample, the lower the weight loss of the samples. This was because termite feeding activity decreased with the increase in PF-FGPS. Furuno *et al*. (2004) reported that resin plays a very important role in the decay resistance of wood by forming a wall of polymer inside the cell walls.

Table 3. Average Weight Loss, Mortality, Visual Rating, and Resistance Class of PF-FGPS, Dried OPTL, and Rubberwood during the Three Month-Field Test

Impregnated OPTL	Weight loss (%)	Termite damage (%)	Resistance class
PF without OPS meal	24.85 (1.08)*	41	Moderately resistant
PF with 1% OPS meal	23.60 (1.98)	32	Moderately resistant
PF with 3% OPS meal	20.60 (1.69)	28	Moderately resistant
PF with 5% OPS meal	16.00 (1.20)	25	Resistant
PF with 10% OPS meal	18.44 (1.63)	30	Moderately resistant
Dried OPTL	47.52 (1.45)	83	Not resistant
Rubberwood	50.79 (1.58)	89	Not resistant

* Values in parentheses are standard deviations.

The results showed that termites continually attacked the untreated specimens as their choice of food. Among the treated samples, the termites attacked only the PF resin-treated samples. In the choice test, the feeding activity of the termites depended on several external factors, namely the type of food and its availability. The variation in the chemical components of wood and in the taste threshold of the termites contributed to the difference in feeding preference. Hence, the physical and chemical properties of the wood influenced the level of damage in the wood during the termite attack (Supriana 1983). Furukawa and Kobayashi (2006) reported that the mechanical properties of wood also influence the degree of damage.

PF-FGPS-Impregnated OPTL Resistance to Drywood Termite

In the laboratory test, the resistance of PF-FGPS specimens against drywood termites was assessed in relation to various concentrations of OPS meal. The results of the resistance test are presented in Table 4. The average mass loss percentage of PF-FGPS-impregnated OPTL ranged from 2.54% to 4.92%. The lowest mass loss percentage (2.54%) was found when the sample was impregnated with 5% OPS meal, and the highest mass loss percentage (4.92%) was found when the sample was impregnated with 1% OPS meal. The results also showed that the average mass loss percentage was 6.68% when there was no OPS meal impregnation. According to Table 4, the average mass loss percentages were 16.91 and 23.66% for dried OPTL and rubberwood, respectively. It was found that the difference in weight loss between the treated and untreated samples was significant ($F = 12.33$, $df = 4$, $P < 0.05$). It was also found that there were significant differences in weight loss between samples with different percentages of PF-FGPS impregnation (Table 5). The termite mortality increased with the increase in OPS meal up to 5%. However, the termite mortality was very low for dried OPTL (7.85%) and rubberwood (5.68%). This variation was significant (F = 884.64, df = 4, P < 0.05) between the treated and untreated samples. 0 and 1% OPS meal-impregnated samples were placed in resistance class III (moderately resistant); however, others were placed in resistance class II (resistant). The dried OPTL and rubberwood were placed in resistance class V (poor). This may have been because of the relatively higher hardness of these samples due to the impregnation of PF-FGPS, which is not an environment suitable for drywood termites. The findings of this study are supported by studies conducted by Arango *et al*. (2006), Bakar (2008), and Hadi *et al*. (2010). Bakar (2008) suggested that PF resin might not be toxic to the termites at contact; however, termites died due to the undigested impregnated samples. Thus, it is unrealistic to assume that resin-treated wood will be resistant to termite attack without having limited feeding damage, even though some feeding will kill the termite (Williams *et al*. 1990).

Table 4. Average Weight Loss, Termite Mortality, Visual Rating and Resistance Class of PF-FGPS, Dried OPTL, and Rubberwood during the Drywood Termite *C. cynocephalus* (Light) Assay

Impregnated OPTL	Laboratory test			
	Weight loss (%)	Termite mortality (%)	Average visual rating	Resistance class
PF without palm meal	6.68 (1.38)*	28.33	7	Moderately resistant
PF with 1% palm meal	4.92 (1.53)	27.67	7	Moderately resistant
PF with 3% palm meal	2.60 (0.87)	38.27	9	Resistant
PF with 5% palm meal	2.54 (0.92)	42.12	9	Resistant
PF with 10% palm meal	2.80 (1.00)	26.97	9	Resistant
Dried OPTL	16.91 (1.80)	7.85	4	Poor
Rubberwood	23.66 (1.74)	5.68	4	Poor

* Values in parentheses are standard deviations.

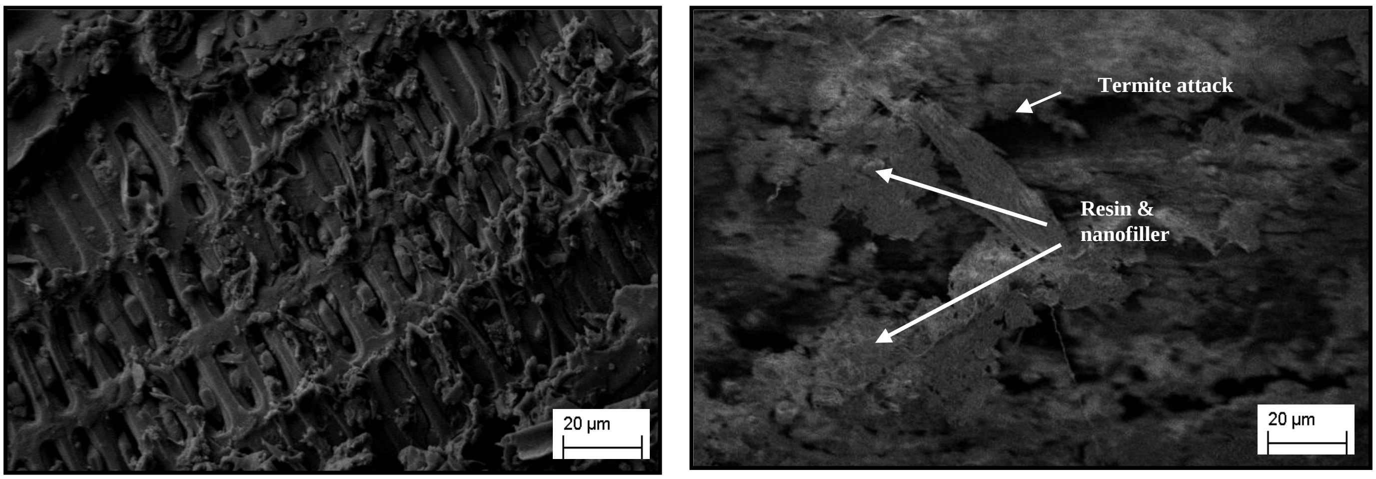
Table 5. Duncan Multiple Range Test (DMRT) for Differential Analysis of PF-FGPS-Impregnated OPTL

	Concentration of PF-FGPS (%)				
Testing	0	1	3	5	10
	Analysis of weight loss (%)				
Laboratory test (%)	10.73a	9.86b	9.35cd	8.87dc	8.78eb
Field test (%)	24.85ab	23.60ba	20.60c	16.00d	18.44e
Drywood termite test (%)	6.68a	4.92b	2.60c	2.54dce	2.80ecd
	Analysis of mortality (%)				
C. curvignathus (Holmgren)	55.50a	67.50b	64.35c	68.43d	64.50ce
C. cynocephalus (Light)	28.33a	27.67ab	38.27c	42.12d	26.97be
	Analysis of termite damage (%)				
Subterranean termite	41a	32b	28c	25d	30e

Note: Values in the same column followed by the same letter are not significantly different.

Properties of PF-FGPS-Impregnated OPTL after Termite Attack

A scanning electron microscope (SEM) observation showed that the termites began by attacking the samples from the middle and then progressed to attacking the OPS meal, which was the PF-FGPS. Termites attacked the center of the board by making a hole, thereby penetrating inside of the board. This behavior is a manifestation of termites characteristic of cryptobiotic, in which the termites tend to hide themselves and avoid the light. The center of the sample was found to have a lower density than the surface of the sample, which was why the termites preferred to begin the attack from there (Fig. 4). Termites attacked PF-FGPS as well as the PF-impregnated OPTL samples. Termites attack wood to consume cellulose (Bowyer *et al.* 2003); however, the percentage of cellulose was reduced as a result of treatment. According to Abdul Khalil *et al*. (2008), the amount of cellulose in OPT ranges from 41.0 to 45.4%, while the cellulose content in the OPS meal treated-OPTL is approximately 29.7% (Arami-Niya *et al*. 2010). Among other physical factors, the PF-FGPS density influenced the ability of the termites to fragment the PF-FGPS mechanically with their mandibles.



Before termite attack After termite attack

Fig. 4. Scanning electron micrograph showing subterranean termite attack on PF-FGPS

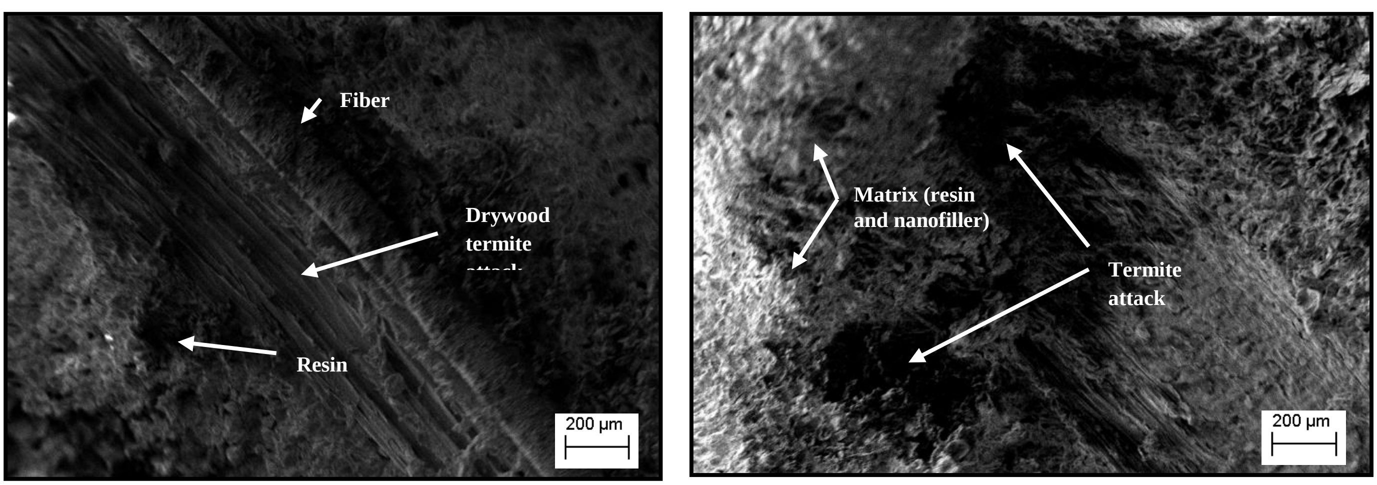


Fig. 5. Scanning electron micrograph showing drywood termite attack on PF-FGPS

Figure 5 shows the drywood termite attack on PF-FGPS-impregnated OPTL. The drywood termites showed patterns of attack similar to those of subterranean termites. However, the drywood termite attack was less severe than the subterranean termite attack under the same treatment conditions. The drywood termites tended to cut wood across the grain by destroying both the softer springwood and the harder summerwood. They made small holes on the wood surface wherever they infested. The details of the mechanism of termite attack were described by Furukawa and Kobayashi (2006). They mentioned that the attack begins with the earlywood tracheids, which are easily bitten away and broken into a small piece by the mandible; accordingly, numerous V-shaped bite marks were left in the degraded earlywood following the attack.

CONCLUSIONS

1. Impregnation of phenol-formaldehyde resin that had been mixed with finely ground oil palm shell meal (PF-FGPS) into the oil palm trunk lumber (OPTL) improved the resistance against subterranean and drywood termite attacks by filling the cell lumens and increasing the density.
2. In laboratory conditions, the treated OPTL was categorized as moderately resistant against subterranean termites for any percentage of PF-FGPS impregnation. It was also moderately resistant against subterranean termites after a 12-week field test for any percentage of PF-FGPS impregnation except for 5%, which was categorized as resistant under the same field conditions.
3. For the drywood termite test, PF-FGPS impregnations equal to or above 3% were categorized as resistant, while the remaining impregnations were categorized as moderately resistant.
4. The advanced materials applications of finely ground meal from OPS would reduce the present environmental problems coming from this biomass, and would ensure the sustainable use of this renewable biomass resource for the future.

ACKNOWLEDGEMENTS

The author would like to thank Universiti Sains Malaysia (USM), Penang, Malaysia, for providing Research Grant no. 1001/PTEKIND/814133 for this study. The author is also thankful to Prof. Pingkan Aditiawati, School of Life Sciences and Technology, Institut Teknologi Bandung, West Java-Indonesia and Prof. Y. S. Hadi, Department of Forest Product, Faculty of Forestry, Bogor Agricultural University, West Java, Indonesia, for providing the necessary facilities for preparing the part of the research during the sabbatical leave for the period of December 1, 2011 to August 31, 2012.

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Article submitted: June 24, 2013; Peer review completed: July 31, 2013; Revised version received and accepted: August 5, 2013; Published: August 9, 2013.