

Original Article

Termite (Subterranean *Macrotermes carbonarius*) attack Rating of Thermally Treated Teak (*Tectona grandis* L.f.) Plywood

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ABSTRACT

Thermal treatment of teak veneer has been known to improve the biological properties of teak-plywood products and a viable protection method from termite attacks. The objective of this study was to investigate the rating of teak plywood attacked by termite at various temperature levels and time durations. The temperatures of 180, 200, 220, 240°C and control temperature were applied for three different time durations, i.e., 4, 8, and 12 minutes on teak veneer sheets. The plywoods were produced using two types of adhesives, namely Phenol Formaldehyde (PF) and Urea Formaldehyde (UF), with both samples placed on the ground (50 cm deep, 50 cm wide and 5 m long in direct contact with termite nests). The results showed that the termite attacks at 220 and 240 °C exposed for a duration of 4, 8, and 12 minutes were significantly different it is increased as per the temperature in both plywood products. It is concluded that thermally treated veneer at 220 and 240 °C can withstand termite attacks on such teak plywood products.

Keywords: Plywood thermal treatment; Termite rating; Termite attack

INTRODUCTION

Teak (*Tectona grandis* L.f.) is recognized as one of the most valuable premium woods in the world (Lwin *et al.*, 2003), which is a hard wood known for its strength, durability, and natural beauty. Teak is native to India, Myanmar, Laos, and Thailand and is most commonly found in the moist and dry deciduous forests at elevations below 1,000 m above sea level, growing best in locations experiencing an annual rainfall between 1,250 to 3,750 mm, minimum temperature between 13° to 17°C and maximum temperature between 39° to 43°C (Pacific Agribusiness Research and Development Initiative, 2007). Lwin *et al.* (2003) confirmed that based on various the general characteristic ages, sapwood and heartwood make up around 65.02 % and 34.98 % of teak, respectively.

Normally, the chemical composition of teak wood consists of cellulose, hemicellulose, and lignin. The cellulose content varies from sapwood (49.28%), outer heartwood (46.74%), middle heartwood (44.84%), and the inner heartwood (47.01%). Similarly, hemicellulose content varies between 22.96% and 29.67%, while lignin content varies between 30-31% (Lukmandaru, 2015). Li *et al.* (2012) and Arinana *et al.* (2016) reported that termites destroy the wood as well as the cellulose material used in building and construction. For example, the most commonly occurring subterranean termites are potentially the most destructive pests in any building. Termites consumed the cellulose in the cell wall of wood.

Based the observations of Su and Scheffrahn (2000), Rust and Su (2012) and Isanapong (2016) around 2,600 termite species have been identified around the world. These termites belong to one of seven families, out of which six families are lower termites (Mastotermitidae, Hodotermitidae, Kalotermitidae, Rhinotermitidae, Serritermitidae and Termopsidae) and one family is of higher termites (Termitidae). According to Thipsantia (2011), who studied the biodiversity of termites and their relationship with dry dipterocarp and dry evergreen ecosystems at the Sakaerat Environmental Research Station, Nakhon Ratchasima province, Thailand, underground

termites can classified into nine genera, namely *Schedorhinoterme*, *Coptotermes*, *Odontotermes*, *Hypotermes*, *Microtermes*, *Ancistrotermes*, *Mirocapritermes*, *Pericapritermes*, and *Termes*. Miyagawa *et al.* (2011) confirmed that the first recorded termite in Laos had 11 species in the soil mounds including *Macrotermes gilvus*, *Odontotermes feae*, *Odontotermes sp*, *Microtermes obesi*, *Microtermes sp*, *Microcerotermes crassus*, *Globitermes sulphureus*, *Hospitalitermes ataramensis*, *Pericapritermes latignathus*, and *Termes propinquus*. This could imply that Laos and Thailand have similar number of termite species as both countries are located at tropical latitudes. Within the reported termites, 183 species are known to damage building wood materials, while 83 species can cause significant wood damage. Termites are an integral part of a forest ecology; both in creation and destruction of the ecosystem. The dangers of termites are related to them needing cellulose for food which is an important component of wood and fiber (Vongkaluang and Charoenkrung, 2008).

The concerns of wood companies generally arise from such termite damage to wood products. Insects need food from wood, such as cellulose, hemicellulose, lignin, and other elements. Termites were known as the most dangerous that damage wood called termites underground (subterranean termites).

Urea Formaldehyde or UF resins are thermosetting resins and consist of linear or branched oligomers and polymers admixed with monomers. The presence of some unreacted urea is often helpful to achieve specific effects, with the presence of free formaldehyde having both positive and negative effects (Dunky, 2003). Because of irreversible curing reaction, thermosets are rigid and three-dimensionally crosslinked plastics. The soluble and fusible starting material may integrate numerous fillers such as glass, minerals, fibers, and glass mate. As a result of such three-dimensional crosslinked structures, thermosets do not flow evenly when heated. The main types of thermoset resins are epoxy, urea, melamine, unsaturated polyester, phenolic, and polyurethane resins (Kausar, 2017). According to Nuryawan *et al.* (2017) UF resins are synthesized by the reaction of

formaldehyde with urea. Usually, technical grade urea granules (99%) and formalin (37%) are used as raw materials and an aqueous solution of both formic acid (20%wt) and sodium hydroxide (20%wt) are used to adjust the pH level during and after the reaction.

Phenolic resin or phenol formaldehyde (PF) is resistant to hydrolysis of the C-C bond between the automatic nucleus and the methylene bridge and is used in water and weather resistant glue lines and boards including water and weather proofed particle boards, Medium Density Fiberboard (MDF) and plywood for use under exterior weather conditions. PF resins provide high strength and are extremely resistant to moisture (Moubarik *et al.*, 2009). According to Wang *et al.* (2012) and Bekhta *et al.* (2016), the UF resin is widely used in the manufacturing of plywoods, particleboards, fiber boards, and other interior decoration materials because of its advantages. These include availability of raw materials, low cost, high bonding strength, curing at a low temperature, water solubility, and lack of color of the cured resin. However, the chemical action of formaldehyde can cause disorders of the nervous and immune systems in humans. Formaldehyde can cause cancer in humans, while ammonium chloride is a toxic substance, the formaldehyde emission level, as well as toxicity of a hardener is an area of concern. The basic characteristics of UF resin can be explained through it is high reactivity, water solubility and reversibility of the aminomethylen link (Dunky, 1998). In conclusion, the properties of UF and PF make them conducive for use in different weather conditions. The reversibility of amino methylene bridge in UF can also explain the low resistance these resins to water and moisture attack, especially at higher temperatures. This is also one of the reasons for its hydrolysis leading to subsequent emission of formaldehyde. But PF is water resistant and can withstand various weather conditions. This indicates that both the adhesives' products have positive and negative impacts.

A Subterranean termite species belonging to the group of Macrotermes has been reported in the subfamily Macrotermitinae, Genus is Macrotermes, and species *Macrotermes*

carbonarius (Miyagawa *et al.*, 2011). It has also been reported that in Thailand, the attack by *M. gilvus* on wooden products is moderate (3 hits) (Sornnuwat *et al.*, 2003). However, in Laos, no such reporting of *M. carbonarius* attacking wood has been reported, but the Faculty of Forest Science in National University of Laos, located in Vientiane, Lao PDR, found evidence of wood and building damage by *M. gilvus*. This study is the first recorded occurrence of *M. carbonarius* in the area of the Faculty of Forest Science. As the *Macrotermes carbonarius* is the most dangerous species that can damage wood buildings in the study area, the objective of this study was to test the termite attack on thermally treated plywood specimens through the termite nests (subterranean) method.

MATERIALS AND METHODS

Materials

Teak veneer was peeled from the sapwood towards the inner wood using splindleless lathe rotary at the Faculty of Forest Science, National University of Laos, Vientiane, Laos P.D.R. The termite testing was located at 18°02'29.85" N and 102°37'51.74" E. Apparatus used in this study included a small wood hot press machine (model STK No. 44-275, DAKE, Grand Haven, MI, USA), Cole pressure machine (model No BY 814*4/2B, Production code 7265, Made in China), a hot pressure machine (model, No BY 214*4/2A-1, Production code 7276 Mad in China), a circular saw cutter (model, No BJ 6116-4B, Production code 180401), dial thickness gauge digital calipers (code 34-506, Measumax, Melbourne, Australia), and a horizontal flow oven (Model WOF-050, serial No WOF050071018002, Made by Daihan Scientific Co., Ltd).

As mentioned previously, two types of adhesives to be applied on the teak veneer (*Tectona grandis* .L.F) for teak plywood products were PF 402 (TOA-Dovechem Industries Co.Ltd, No dated) and UF Diabond No 283 class E 2 (Thai Commercial Corporation Ltd, No dated). Both adhesives used were prepared based on the Australian/New Zealand Standard (2012).

Veneer samples were used to produce plywood samples of size 40 cm x 40 cm, which

were machined to an approximate dimension of 10 mm x 50 mm x 100 and 30 samples were keeping as an archive (long term storage).

Methods

The plywood product consists of five layers, with the veneer layer placed one over the other and perpendicular to the grain. PF glue was spread on the veneer by passing it through a wool roller with the glue transfer spreader set at 150 g/m².

The UF glue was also spread on the veneer through a roller spreader at a rate of about 120-130 g/m². The dimensions of the teak plywood product thus produced was of size 40 cm x 40 cm through a hot press machine. The hot press rate for the plywood products depends on the thickness, and is around 1 mm per minute. As the thermo-teak and teak plywoods have an average thickness of 10 mm, the time for pressing was 10 minutes for 130°C using PF and 120°C using UF, with the press loading of 2.5 MPa/mm² for both adhesives.

As mentioned, thermo- teak plywood (*Tectona grandis*) was used in this experiment

and the reference species known as termite food were solid teak and rubber (*Hevea brasiliensis*). The surfaces of each sample were brushed such that it was free from dirt and other loose material. Each exposed sample was uniquely numbered using a metal tag, which was attached using stainless steel nails. Samples were then randomly placed in plastic baskets and the position in each basket was recorded. The exposed baskets were also uniquely identified and were then covered by plastic on top of the cannel. The cannel design had dimensions of 50 cm x 50 cm x 500 cm (depth, width, and length).

After five months of exposure, the soil and covering were carefully removed to expose the test samples. In accordance with Norton. (2019), the purpose of this trial was to determine if the test species of timber was susceptible to termite attack, the indicators showed in Table 1. The rating of termite attack measurement was based on the method suggested by Norton. (2019).

Table 1 Parameters for termite measuring using Norton (2019).

Rating	Condition	Description
10	Sound	No sign or evidence of termite attack
9.5	Trace-nibbling	Slight surface nibbling
9	Slight attach	Loss of up to 3% of the cross-section area
8	Moderate attach	Loss of 3-10% of the cross-section area
7	Moderate/severe attach	Loss of 10-30% of the cross-section area
6	Severe attach	Loss of 30-50% of the cross-section area
4	Very severe attach	Loss of 50-75% of the cross-section area
0	Failure	Can be broken by hand or a probe can penetrate through the piece

Analysis of variance (ANOVA) was used to compare differences between sample groups based on the effect of temperature levels and duration of pressing time on the rating. A linear regression analysis was also used to determine the relationship between the temperature levels on the termite attack rating of the plywood samples passed through different treatments. In addition, a multiple regression analysis was also used to determine the parameters that might have influenced the termite attack on the treated thermal plywood.

RESULTS AND DISCUSSION

Results

Plywood samples indicated to obvious termite presence in all the baskets and ‘mudded’ over and between exposed samples as indicated in the parameter procedure of table 1. The results (Table 2) indicate that the control samples of teak plywood thermally treated for 4, 8, and 12 minutes have an evidence of moderate destruction rating of 8.03 (Table 1) or 3-10%, while the highest thermal treatment at 240°C had a higher rating which ranged from 9.31 to 9.78 (90-100%).

Table 2 Termite attack rating of teak plywood thermal treatment based on the duration of time and temperature.

Times (minutes)	Temperature (°C)	PF		UF	
		Mean	Std. Deviation	Mean	Std. Deviation
4	control	8.03	1.03	7.80	0.76
	180	9.11	0.44	9.11	0.56
	200	9.31	0.44	9.51	0.49
	220	9.00	1.27	9.33	0.33
	240	9.75	0.31	9.76	0.36
8	control	8.03	1.03	7.80	0.76
	180	8.90	0.78	9.00	0.66
	200	8.61	1.16	9.30	0.48
	220	9.46	0.31	9.21	0.53
	240	9.31	1.01	9.51	0.51
12	control	8.03	1.03	7.80	0.76
	180	9.11	0.56	8.91	0.76
	200	9.36	0.49	8.85	0.55
	220	9.76	0.34	9.30	0.48
	240	9.78	0.44	9.85	0.32

PF multiple regression model analysis (see in Eq. 1) resulted in an $R^2=0.93$, considered as highly significant

$$\text{Termite rating} = 0.0407 \cdot T + 0.0809 \cdot t \quad (\text{Eq. 1})$$

where: T= Temperature (°C)
t= time (minutes)

Table 1 lists the various UF groups, with the control having a lower protection from termite attack (7.80 or 10-30%), while thermal treatment at 240°C (9.76 or 90-100%) resulted in slight surface nibbling, indicating that the temperature levels improved the protection against termites.

UF multiple regression model analysis (see in Eq. 2) resulted in an $R^2=0.93$, considered highly significant.

$$\text{Termite rating} = 0.0427 \cdot T + 0.0320 \cdot t \quad (\text{Eq. 2})$$

where: T= Temperature (°C)
t= time (minutes)

Discussion

High temperature thermal treatment of both plywood adhesives resulted in protection of teak plywood from termite (subterranean) attack. Roszaini *et al.* (2006) studied the rating of termite attack on teak wood for four weeks

in Malaysia and estimated a rating of 9.53. In a previous research, Grace and Yamamoto (1994) reported the rating of untreated teak wood and that treated with Copper Chrome Arsenic (CCA) against attack by *Coptertomes formosanus* termite for 28 days. The author estimated a rating of 10.00 for CCA treated teak, which reduced to 6.80 for the untreated samples. Nakabonge and Matovu (2021) tested two termite species of *M. bellicosus* and *M. subhyalinus* on *Eucalyptus grandis* and concluded that *M. bellicosus* was more destructive as indicated by a mean percentage loss of 51.5% compared to 39.2% for the latter. In this study, we found that the attack rating of *Macrotomes carbonarius* on teak wood varied with temperature. The rating was high for higher temperatures when compared with the control and lower temperatures.

A thermal treatment of eight minutes on teak plywood indicated that the lowest termite resistance for the PF group was for the control (8.03), while the highest resistance was for the thermally treated plywood at 220°C (9.46 or 90-100%), which indicated that a thermal treatment at high temperature improved the protection of teak plywood from termite damage. Similarly, the UF control group had the lowest rating (7.80 or 10-30%), while the highest rating was for the plywood with thermal treatment at 240°C (9.51 or 90-100%), with the

high temperature treatment resulting in a decreased termite attack of the teak plywood product. Hence, we conclude that thermally treated plywood at 240°C for both adhesives resulted in a higher protection rating against termite attack. Additionally, the control samples for both PF and UF teak plywoods thermally treated for 12 minutes had the lowest attack rating (8.03 and 7.80 respectively), while the highest attack rating was obtained at 240°C (9.78 and 9.85 respectively). We conclude that

this duration of time results in an optimum protection of wood against termite attacks.

Table 3 shows significant differences as obtained from multiple comparisons of one-way ANOVA analysis. For both PF and UF plywood, it was confirmed that control rating was significantly different from thermal treatment at different temperature levels based on various time durations $p < 0.05$. The termite attack rating tended to improve with high temperature treatment.

Table 3 The results of one-way ANOVA analysis of thermal treatment of PF and UF teak plywood at different temperature levels.

Time (minutes)	Temperature (I) (°C)	Temperature (J) (°C)	Mean different (I-J)	St. E	P-value	Mean different	St. E	P-value
4	Control	180	-1.08*	0.20	0.00	-1.31*	0.13	0.00
		200	-1.28*	0.20	0.00	-1.71*	0.13	0.00
		220	-0.96*	0.20	0.00	-1.53*	0.13	0.00
		240	-1.72*	0.20	0.00	-1.96*	0.13	0.00
	180	200	-0.20	0.20	0.33	-0.40*	0.13	0.00
		220	0.11	0.20	0.57	-0.21	0.13	0.11
		240	-0.63*	0.20	0.00	-0.65*	0.13	0.00
	200	220	0.31	0.20	0.12	0.18	0.13	0.18
		240	-0.43*	0.20	0.03	-0.25	0.13	0.06
	220	240	-0.75*	0.20	0.00	-0.43*	0.13	0.00
8	Control	180	-0.86*	0.23	0.00	-1.20*	0.15	0.00
		200	-0.58*	0.23	0.01	-1.50*	0.15	0.00
		220	-1.43*	0.23	0.00	-1.41*	0.15	0.00
		240	-1.28*	0.23	0.00	-1.71*	0.15	0.00
	180	200	0.28	0.23	0.23	-0.30	0.15	0.05
		220	-0.56*	0.23	0.01	-0.21	0.15	0.16
		240	-0.41	0.23	0.07	-0.51*	0.15	0.00
	200	220	-0.85*	0.23	0.00	0.18	0.13	0.18
		240	-0.70*	0.23	0.00	-0.25	0.13	0.06
	220	240	0.15	0.23	0.52	-0.30	0.15	0.05
12	Control	180	-1.08*	0.16	0.00	-1.11*	0.15	0.00
		200	-1.33*	0.16	0.00	-1.05*	0.15	0.00
		220	-1.73*	0.16	0.00	-1.50*	0.15	0.00
		240	-1.75*	0.16	0.00	-2.05*	0.15	0.00
	180	200	-0.25	0.16	0.12	0.06	0.15	0.66
		220	-0.65*	0.16	0.00	-0.38*	0.15	0.01
		240	-0.66*	0.16	0.00	-0.93*	0.15	0.00
	200	220	-0.40*	0.16	0.01	-0.45*	0.15	0.00
		240	-0.41*	0.16	0.01	-1.00*	0.15	0.00
	220	240	-0.01	0.16	0.91	-0.55*	0.15	0.00

The Figure 1 is a graph of termite attack rating for both the thermally treated teak plywood products. For both products, it was confirmed that thermal treatment at different levels of temperature resulted in protection of plywood product, with an above moderate significant linear regression analysis for PF ($R^2=0.6789$ and $p<0.05$), and highly significant for UF ($R^2=0.8548$ and $p<0.05$).

The Figure 2 graphs the attack rating against the length of time for which the product was thermally treated, for both PF and UF plywood products. The modelled relationship through the linear regression analysis indicated to a lower significant for both PF and UF ($R^2=0.2198$ and 0.105 and $p>0.05$, respectively). The length of time for thermal treatment was not found to be significant for thermally treated teak plywood products.

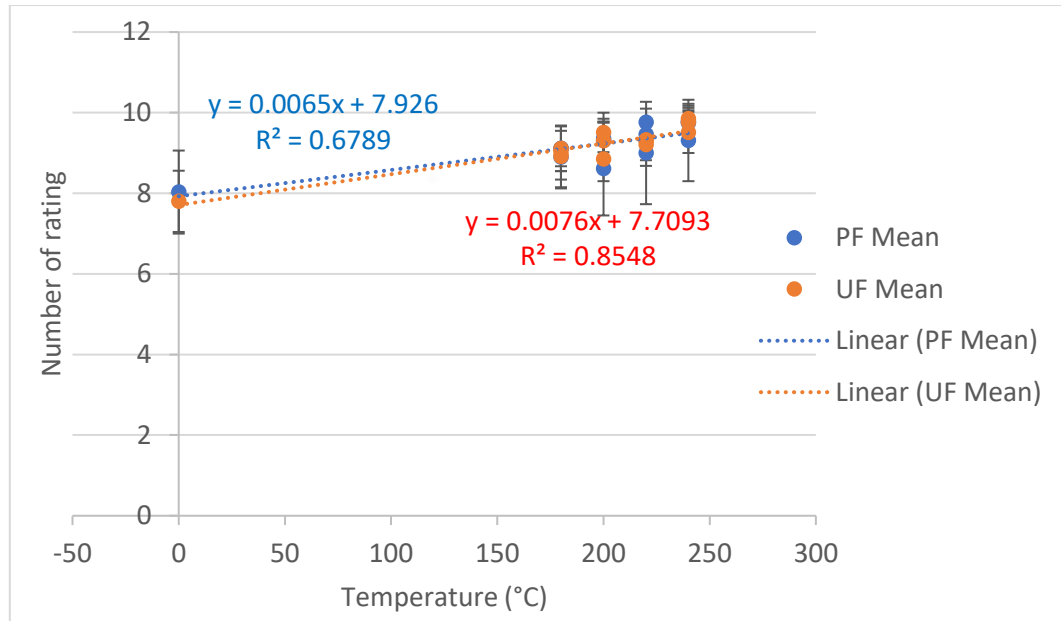


Figure 1 Rating of thermally treated teak plywood products attacked by *Macrotomes carbonarius* termite at different temperature levels.

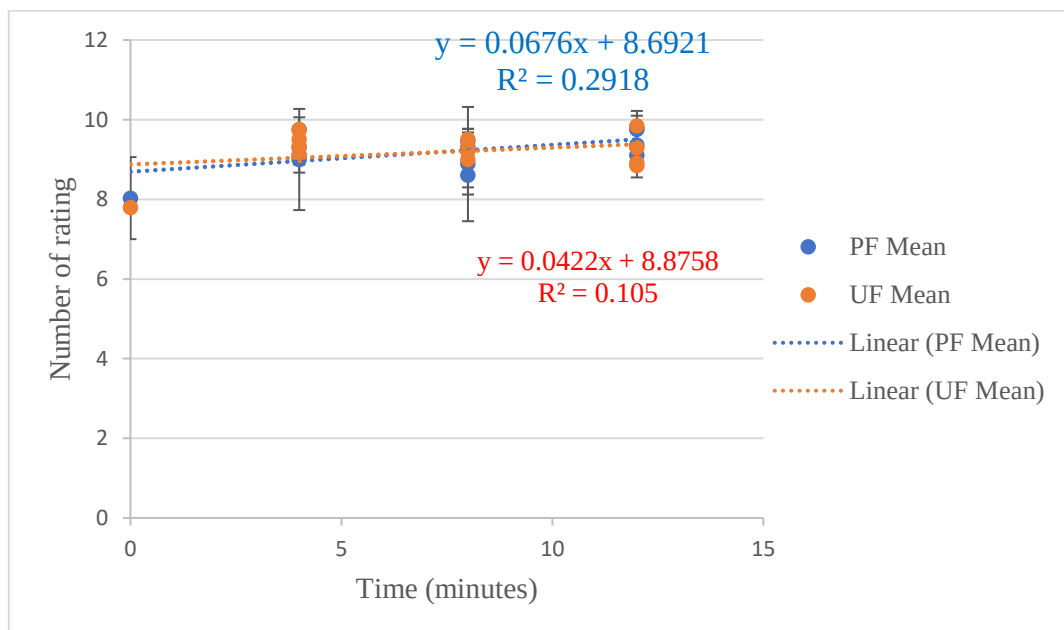


Figure 2 Rating of thermally treated teak plywood products attacked by *Macrotomes carbonarius* termite for various lengths of time.

CONCLUSION

The different levels of temperature at control, (180, 200, 220, and 240°C) based on a thermal treatment of 4, 8, and 12 minutes of for had the lowest termite resistant rating and was significantly different. At 220 and 240°C and based on a thermal treatment duration of 4, 8, and 12 mins, the rating level of termite resistance was higher.

We conclude that a thermal treatment at higher temperatures given a length of time can protect young teak plywood. The minimum recommended temperature for thermal treatment of such products is 220°C for 12 minutes.

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REFERENCES

- Arinana, A., Aldina, R., Nandika, D., Rauf, A., Harahap, I.S., Sumertajaya, I.M., Bahtiar, E.T. 2016. Termite Diversity in Urban Landscape, South Jakarta, Indonesia. **Insects**, 7:20. <https://doi.org/10.3390/insects7020020>
- Australian/New Zealand Standard. 2012. **Plywood-Structural. Part 0: Specifications**. Australia: Council of Standard Australia, Australia.
- Bekhta, P., Sedliacik, J., Saldan, R., Novak, I. 2016. Effect of different hardeners for urea-formaldehyde resin on properties of birch plywood. **Acta Facultatis Xylologiae Zvolen**, 58: 65-72. doi:10.17423/afx.2016.58.2.07
- Dunky, M. 1998. Urea-formaldehyde (UF) adhesive resins for wood. **International Journal of Adhesion and Adhesives**, 18(2), 95-107. doi:10.1016/s0143-7496(97)00054-7
- Dunky, M. 2003. Adhesives in the Wood Industry. In: **Handbook of Adhesive Technology**. CRC Press, Boca Raton, Florida, USA.
- Isanapong, J. 2016. Roles of Verrucomicrobia in lower termite hindgut. **The Journal of Applied Science**, 15(2): 103-119. doi:doi:10.14416/j.appsci.2016.12.001 (in Thai)
- Kausar, A. 2017. Role of thermosetting polymer in structural composite. **American Journal of Polymer Science & Engineering**, 5(1): 1-12.
- Grace, J.K., Yamamoto, R.T. 1994. Natural resistance of Alaska-cedar, redwood, and teak to Formosan subterranean termites. **Forest Products Journal**, 44(3): 41-45.
- Li, H., Lu, J., Mo, J. 2012. Physiochemical lignocellulose modification in the formosan subterranean termite *Coptotermes Formosanus* Shiraki (Isoptera: Rhinotermitidae) and potential uses in the production of biofuels. **Bioresources**, 7(1): 675-685.
- Lukmandaru, G. 2015. Chemical Characteristics of Teak Wood Attacked by *Neotermes tectonae*. **BioResources**, 10(2): 2094-2102. doi:10.15376/biores.10.2.2094-2102
- Lwin, M., Yezin, Tawm N.P. 2003. Study on utilization of plantation teak pre-project CFC/ITTO 73 FT PPD 68/03 Rev.2 (I). In: **Hand Book on Properties of Plantation Teak in Myanmar**. Ministry of Forestry, Forest Department Myanmar: CFC/ITTO 73 FT PPD 68/03 Rev.2 (I), Myanmar.
- Miyagawa, S., Koyama, Y., Kokubo, M., Matsushita, Y., Adachi, Y., Sivilay, S., Kawakubo, N., Oba, S. 2011. Indigenous utilization of termite mounds and their sustainability in a rice growing village of the central plain of Laos. **Journal of Ethnobiology and Ethnomedicine**, 7(1): 24. doi: 10.1186/1746-4269-7-24
- Moubarik, A., Pizzi, A., Allal, A., Charrier, F., Charrier, B. 2009. Cornstarch and tannin in phenol-formaldehyde resins for plywood production. **Industrial Crops and Products**, 30(2): 188-193. doi:10.1016/j.indcrop.2009.03.005

- Nakabonge, G., Matovu, B. 2021. Variation in susceptibility of *Eucalyptus grandis* and selected hybrid clones to two termite species *Macrotermes bellicosus* and *M. subhyalinus* in Uganda. **All Life**, 14(1): 120-126. doi: 10.1080/26895293.2021.1883126
- Norton. 2019. **Durability Workshop. Retrieved from State of Queensland:** <https://creativecommons.org/licenses/by/4.0/>, 18 August 2023.
- Nuryawan, A., Risnasari, I., Sucipto, T., Heri Iswanto, A., Rosmala Dewi, R. 2017. Urea-formaldehyde resins: production, application, and testing. **IOP Conference Series: Materials Science and Engineering**, 223(1): 012053. doi: 10.1088/1757-899X/223/1/012053
- Pacific Agribusiness Research and Development Initiative. 2007. **Teak Value Chain Review**. University of Adilade: Australaine Center for International Agriculture Research, Australia.
- Thipsantia, P. 2011. **Biodiversity of Termites and their Relationship to Dry Dipterocarp and Dry Evergreen Ecosystems at Sakaerat Environmental Research Station, Nakhon Ratchasima Province**. M.S. Thesis, Institute of Science. Suranaree University of Technology, Nakhon Ratchasima, Thailand. (in Thai)
- Roszaini, K., Salmiah, U., Dahlan, J.M. 2006. Natural Resistance of Timbers to Termite Attack: Laboratory Evaluation of the Resistance of Malaysian Wood Against *Coptotermes Curvignathus* (Holmgren). **Journal of the Institute of Wood Science**, 17(3): 178-182. doi: 10.1179/wsc.2006.17.3.178
- Rust, M.K., Su, N.Y. 2012. Managing social insects of urban importance. **Annual Review of Entomology**, 57(1): 355-75. doi:10.1146/annurev-ento-120710-100634
- Sornnuwat, Y., Vongkaluang, C., Chutibhapakorn, S. 2003. Foraging patterns of termite species in the living complex of Bangkanoon forest plantation, Phuket province, southern Thailand. **The International Research Group on Wood Preservation**. Document IRG/WP, 03-10481. Brisbane, Australia.
- Su, N.Y., Scheffrahn, R.H. 2000. Termites as Pests of Buildings. In: Abe, T., Bignell, D.E., Higashi, M. (eds). **Termites: Evolution, Sociality, Symbioses, Ecology**. Springer Netherlands. Dordrecht, pp. 437-453. doi: 10.1007/978-94-017-3223-920
- Thai Commercial Corporation LTD. No dated. **Technical Document of Plywood Class E-2**. In. Thailand. (in Thai)
- TOA-Dovechem Industries Co.Ltd. No dated. **Phenol Formaldehyde**. Samut Prakarn, Thailand.
- Wang, X., Li, J., Zhang, J., Gao, Q. 2012. Technics and Properties of Plywood Manufacture with Modified Urea-Formaldehyde Resin. **Advanced Materials Research**, 602-604: 743-746. doi:10.4028/www.scientific.net/AMR.602-604.743
- Vongkaluang, C., Charoenkrung, K. 2008. Termites: prevention and removal. In: **Termites**. Bangkok: Aksorn Siam. Bangkok, Thailand. (in Thai)