Blended Species Plywood (White Cypress Pine and Hoop Pine): Effect of Veneer Thickness on Susceptibility to Attack by the Subterranean Termite *Coptotermes acinaciformis*

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Blended species plywood blocks comprising of 24 different veneer configurations of naturally durable white cypress pine and non-durable hoop pine were exposed to the subterranean termite *Coptotermes acinaciformis* in a field trial in Australia. Three thicknesses of cypress (1.8, 2.8, and 3.0 mm) and hoop pine (1.0, 1.5, and 3.0 mm) veneer were included. Blocks were assessed for termite damage using a visual damage rating and mass loss measurement. Blocks using all hoop pine veneers received substantial damage; however, blocks that had cypress face and back veneers had improved termite resistance, particularly for the 1.0-mm hoop pine core veneers. When cypress longbands were blended with hoop pine crossbands that created alternating layers, minimal damage was sustained in the hoop pine veneers; however, the damage increased with increasing hoop pine veneer thickness. All cypress veneers received essentially no termite damage, and cypress veneer thickness did not influence the severity of hoop pine veneer damage. The trial indicated that the plywood made with hoop pine core veneers, cypress pine face, and back veneers offered some termite resistance if the hoop pine veneer thickness was kept thin. Alternating cypress and hoop pine further improved the termite resistance.

Keywords: Plywood; Hoop pine; White cypress pine; Subterranean termite; Natural durability; Veneer

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INTRODUCTION

In Australia, the demand for veneer-based engineered wood products (EWPs), including plywood and laminated veneer lumber (LVL), continues to grow for building products for both structural and non-structural applications, and in both interior and weather-exposed situations. Despite the economic downturn, which resulted from the global financial crisis of 2008, there has been little evidence of any slowdown in the global production of either plywood or veneer (Hughes 2015). With ever-improving manufacturing technology and continued advances in building manufacture and design, the use and popularity of EWPs is expected to increase.

Veneer-based EWPs provide an opportunity to improve the utilization of forest resources compared to traditional sawn products. This is coupled with the potential to use currently under-used, small-diameter native forest log resources (with the advent of spindleless rotary veneering technology) to produce useful veneer-based products. McGavin *et al.* (2018) suggested that a suitable pathway for the use of small-diameter native forest resources would be to blend the rotary veneers recovered from peeling operations with existing commercial plantation softwood veneers such as hoop pine (*Araucaria cunninghamii*). Blending resources can provide a number of benefits including efficient resource utilisation, compatibility with modern building design, and enhanced product performance.

One component of enhanced product performance is the ability to resist biological degradation (termites and fungi) through heightened natural durability, *i.e.*, without the requirement for chemical preservation. Enhanced product durability can potentially be achieved by blending durable and non-durable timber species in an EWP such as plywood or LVL.

White cypress pine (*Callitris glaucophylla*) (from here on referred to as CYP) is a softwood that is widely distributed within Australia's inland native forests (McGavin and Leggate 2019). The heartwood of this species is known to be resistant to termite and fungal attack due predominantly to the presence of extractives (natural preservatives) in the heartwood, though this resistance does not extend to the sapwood. These extractives include thujaplicin, nootkatin, dolabrin, thujaplicinol, and pygmaein. The extractives have been investigated as potential natural preservative treatments (as alternatives to chemical preservatives) for other non-durable timbers to prevent termite attack. The extractives can be either toxic or repellent to termites (Evans *et al.* 2000).

Previous studies (Behr and Wittrup 1969; Kamden and Sean 1994; Evans *et al.* 1997; Evans *et al.* 2000; Kartal and Green III 2003) looking at blends of durable (*e.g.*, CYP) and non-durable (*e.g.*, radiata pine, *Pinus radiata*, or hoop pine) in either particleboard or medium-density fibreboard (MDF) have shown enhanced resistance to termite attack when compared to those composed entirely of a non-durable species.

Faraji *et al.* (2009) demonstrated that the greater the ratio of durable to non-durable veneers in a plywood panel, the more enhanced the termite resistance. The improved durability was also found to be influenced by the number of veneers, veneer thickness, and the veneer lay-up strategy (*i.e.*, the veneer positioning within the panel). Similarly, Nzokou *et al.* (2005) reported that LVL made from blending durable black locust (*Robinia pseudoacacia*) and non-durable red maple (*Acer rubrum*) species demonstrated enhanced durability when the face and back veneer and at least one core veneer were from the durable species.

The study reported by Faraji *et al.* (2009) included plywood made from blends of the durable heartwood of cypress pine (*Cupressus sempervirens*) and the non-durable sapwood of Scots pine (*Pinus sylvestris*), beech (*Fagus sylvatica*), and poplar (*Populus* sp.), which were evaluated against the subterranean termite *Reticulitermes santonensis* in laboratory trials. Plywood blocks included both 5-ply and 9-ply configurations and consisted of a mix of 2.6-mm and 1.3-mm-thick veneers for various blends of durable and non-durable species, as well as single species controls. Resistance to termite attack in a blended plywood was only achieved where the face and back veneers were cypress pine heartwood. Of the four panels that were deemed termite resistant, three of them consisted of 60% durable plies with an integration of durable and non-durable plies in the core of the plywood block as well.

The percentage of mass loss in the 5-ply configurations was always higher than for the 9-ply configurations (where all the veneers in both configurations were of non-durable species). The authors suggested this could be related in part to veneer thickness. The 5-ply configurations comprised only 2.6-mm veneers while the 9-ply configurations consisted of eight 1.3-mm veneers and a centre veneer of 2.6 mm. Termites indiscriminately attacked the thicker veneers in both configurations but preferentially only the outermost 1.5-mm veneers in the 9-ply configuration. The remaining six 1.5 mm veneers were not attacked. The test block dimensions were 50 × 25 × 15 mm^3 and were exposed to 250 termite workers in a laboratory trial.

Trials assessing resistance against basidiomycete fungi, in addition to termites, reported by Faraji *et al.* (2008) showed that the ratio of exposed durable surfaces *vs.* non-durable surfaces in plywood is the determiner of resistance rather than the volume of durable *vs.* non-durable veneers.

Nzokou *et al.* (2005) assessed LVL manufactured using veneers from decay-resistant black locust (*Robinia pseudoacacia*) and decay-susceptible red maple (*Acer rubrum*) to determine the durability impact of the LVL manufacturing process, and to test if the blending of decay-resistant and decay-susceptible species can improve resistance against biological degradation. A laboratory soil block test (against fungi) and a field test (against termites – species unknown) were conducted. The study concluded that durability against decay was shown to improve when the two faces and at least one core veneer were from decay-resistant species. However, the blended LVL was vulnerable to termite attack, and it was concluded that the termites were able to selectively colonize the non-durable red maple veneers even if positioned in the core of the LVL.

In this study, a termite exposure trial was established to investigate the effect of veneer thickness (of both durable CYP and non-durable hoop pine) on enhancing subterranean termite resistance in blended-species plywood panels all consisting of a CYP face and back veneer but half with a full hoop pine core and the remainder having a CYP longband integrated with a hoop crossband. The study aimed to determine in what plywood panel lay-up configurations can the durable CYP enhance the protection of the non-durable hoop pine from subterranean termite attack. Subterranaean termites are social insects and cause significant damage to timber-in-service in Australia. Colonies can have up to hundreds of thousands of individuals and can be wholly subterranean (no above-ground mound) or be associated with visible ground mounds, tree or arboreal structures or in dead or dying limbs (Hadlington 1996). *Coptotermes acinaciformis* is a subterranean termite found in all States of Australia (except Tasmania) and is the most widely distributed and most destructive pest termite species within the country (Evans 2010). The capacity to damage wood and other cellulose based materials is higher than for other *Coptotermes* species. *C. acinaciformis* was identified from the exposure site used in this trial.

EXPERIMENTAL

Materials

Veneer source and test sample matrix

The CYP and hoop pine were the two species included in the study. The CYP represents a mid-high density (basic density 580 kg/m^3), durable softwood that is sourced from sustainably managed native forests, while hoop pine (basic density 450 kg/m^3) represents a plantation softwood resource and is non-durable (Bootle 2010; DAF 2018). Both of these species are commercially available to the Australian timber industry.

The CYP veneers were sourced from small-diameter (< 25 cm) native forest logs that were processed using a spindleless rotary veneering system. The hoop pine veneers were recovered from approximately eight logs peeled by a commercial veneer producer during standard commercial operations. There were three dry-veneer thicknesses of CYP (1.8, 2.8, and 3.0 mm) and hoop pine (1.0, 1.5, and 3.0 mm). A previous DAF (Department of Agriculture and Fisheries) trial investigated a blended species plywood (exposed to *C. acinaciformis*) using just one thickness of CYP veneer (3.0 mm) and one thickness of hoop pine veneer (1.5 mm) comprising five plywood combinations. The hoop pine veneers were damaged by *C. acinaciformis* in all instances other than when incorporated with a CYP face and back veneer and a CYP longband veneer. The intention of this trial was to study the effects of additional thicknesses of CYP and hoop pine veneer and also build on the work done by Faraji *et al.* 2009 which looked at varying thicknesses of durable and non-durable veneer but only in a laboratory trial.

Four different groups of 7-ply plywood were manufactured with different thickness variations represented within each group. This resulted in a total of 24 plywood configurations (Table 1).

Table 1. Eighteen Blended Plywood Configurations and Six Same Species Configurations that were Manufactured andTested

Plywood Configuration	CYP Veneer Thickness (mm)				Hoop Veneer Thickness (mm)			No. of Test Blocks
	1.8	2.8	3.0		1.0	1.5	3.0	
1	√				√			8*
2	√					√		8*
3	√						√	16
4		√			√			16
5		√				√		16
6		√					√	16
7			√		√			16
8			√			√		16
9			√				√	16
10	√				√			8*
11	√					√		8*
12	√						√	8*
13		√			√			8*
14		√				√		8*
15		√					√	8*
16			√		√			16
17			√			√		8*
18			√				√	16
19					√			16
20						√		16
21							√	16
22	√							16
23		√						16
24			√					16
								Total - 312

*These configurations had only 8 test blocks due to limited availability of veneers

- 1 to 9 - CYP face / back and hoop core;
- 10 to 18 - CYP face / back / longband and hoop crossband;
- 19 to 21 - Full hoop pine;
- 22 to 24 - Full CYP

Sample Preparation

The CYP and hoop pine veneers were conditioned to 6% moisture content (MC) and then reduced to sheets measuring 300 × 300 mm^2 using a panel saw. The resultant sheets and a phenol formaldehyde adhesive (Jowat Universal Adhesives Australia Pty. Ltd., Ingleburn, NSW, Australia) were used to manufacture the 7-ply plywood panels. This adhesive is moisture and ultraviolet (UV) resistant, and it is an approved adhesive for external, weather exposed, and structural applications in accordance with AS/NZS 2754.1 (2016).

The adhesive was applied to each face of the veneers targeting a total spread rate of 200 gsm (grams per square metre) per glue line. The assembly stage included an open assembly time of approximately 20 min or until the adhesive was tacky. Pre-pressing was undertaken at 1.2 MPa (approx. 174.0 psi) for 15 min followed by a hot press, at the same pressure, for 12 min at 135 °C in a laboratory press (Enerpac Australasia, Regents Park, NSW, Australia). The heat and pressure applied during the hot press enabled the glueline to cure and bonded the assembled veneers and adhesive into a plywood panel. The panels were then stored for at least 24 h before cutting into test blocks.

All plywood combinations consisted of 7-ply plywood in either a blended (CYP face/back and hoop core; CYP face/back/longband and hoop crossband) or same species (full hoop pine or full CYP) configuration (Fig. 1).

Test blocks measuring 135 × 70 mm by the thickness of the plywood panel, which varied from 7 to 22 mm depending on the veneer thicknesses, were cut from the panels. Eight test blocks were cut from each plywood panel providing a total of 312 (a combination of 16 replicates and eight replicates) test blocks across the 24 different plywood configurations. To attract termite activity towards the test blocks, 350 feeder blocks (135 × 70 × 20 mm^3) were cut from low durability softwood (*Pinus* sp.) sawn timber (predominantly sapwood).

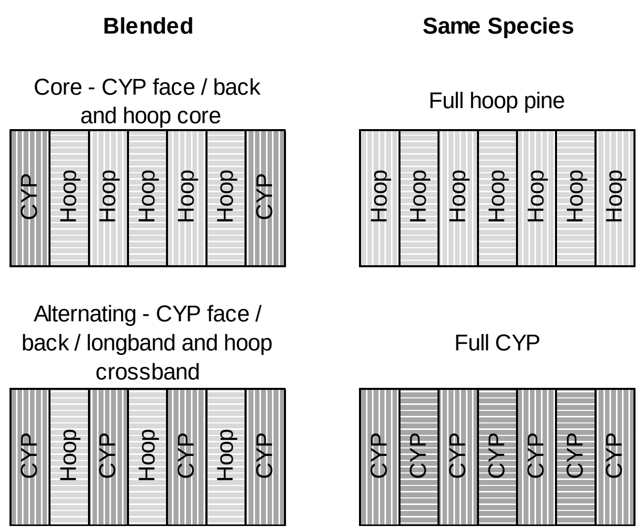

Fig. 1. 7- ply plywood test block configurations (3 CYP thicknesses; 3 hoop thicknesses)

Test Block Arrangement

All test blocks and feeder blocks were weighed to enable mass loss calculations post-exposure to termites. Test block sets were then prepared alternating a feeder block and one test block from each configuration. Corrugated cardboard was used to separate all samples (Fig. 2). The test block sets were then randomly distributed across 24 exposure boxes (opaque plastic boxes).

Fig. 2. Plywood test blocks and pine feeder sapwood blocks positioned in an exposure box

The feeder blocks were included to encourage on-going termite foraging in the exposure box and provide an indicator of termite vigour (based on mass loss of feeder blocks) within each box. The corrugated cardboard was used to provide a series of runways for the termites once they had entered the box and aid the movement of termites throughout the exposure box. Additional feeder blocks and the cardboard were also added to accommodate any free space in the exposure box.

Methods

Field exposure

Several weeks prior to the trial, a dedicated trench was prepared at a field trial site at Esk (27.2333° S, 152.4167° E) in South East Queensland, Australia (Fig. 3). This was in an area where *C. acinaciformis* are known to be very active. The trench was excavated and filled with termite susceptible feeder material (pine off-cuts) to promote further activity. Concrete blocks were laid on top of the trench and pine feeder stakes were driven into the trench through the holes in the concrete blocks ensuring that they were in contact with the timber materials buried in the trench.

Fig. 3. Timber placed atop the aggregation trench was heavily infested with *C. acinaciformis*

At this stage non-durable pine stakes were positioned along the length of the concrete blocks as feeder material to ensure termite activity was present when the exposure boxes were placed in the field. The pine stakes were covered with black plastic secured with soil and additional concrete blocks. The black plastic was 100 µm multi-purpose builders film, which helped protect the exposure boxes from the weather and maintain a dark, humid environment beneath the plastic sheeting.

At trial establishment the black plastic was removed to reveal the pine stakes heavily infested with termites (Fig. 3). The exposure boxes were placed upturned on the concrete blocks before the trench was liberally doused with water and the black plastic re-instated to maintain a dark, humid environment conducive to sustained termite foraging (Fig. 4). The boxes were inspected after one month to ensure that termites were active within all the boxes (as observed through the top of the upturned exposure box) and then left un-disturbed for a further 20 weeks culminating in a 24-week exposure period. The trial ran from November 2018 to May 2019 during the hot summer months when the termites were most active.

Fig. 4. The exposure boxes were placed atop the trench and covered with black plastic

Post exposure assessment

After the 24-week exposure period, the boxes were retrieved from the field and returned to the laboratory for assessment. Each test block set was removed from the boxes, the test blocks were separated from the feeder blocks, and any dirt, debris, and termites were removed. Live *C. acinaciformis* were identified and found in the majority of the 24 exposure boxes at this time (Fig. 5).

Each test and feeder block was visually examined for termite damage. For the test blocks, it was noted whether the face and back veneers and/or the core veneers sustained damage. Each test block was then weighed to determine the mass loss due to termite attack, and subsequently, the percentage of mass loss was calculated to enable further comparison. From the visual assessment and calculated percentage mass loss, each test block was assigned a score based on the following rating system (Table 2) that was adapted from Peters and Creffield (2004).

(a) (b)

Fig. 5. Test block set removed from an exposure box (a) and live termites from inside the box (b)

The rating system was modified to accommodate lateral or end damage to individual core veneers (measured as depth in mm using a pointed metal ruler). Surface damage by termites was only a factor where the face and back veneers were hoop pine, *i.e.*, configurations 19, 20, and 21. A mean termite damage rating was calculated for each plywood configuration as well as the rating range for all test blocks within that configuration.

Table 2. Rating System for Assessment of Termite Damage on Test and Feeder Blocks

Rating	Condition of Test or Feeder Block
1	Sound
2	Superficial damage by termites; nibbling
3	Surface grazing by termites - core veneer damage; < 5 mm in depth
4	Damage (minor) 5 to 25% mass loss - core veneer damage; > 5 mm in depth
5	Damage (moderate) 25 to 50% mass loss - core veneer damage; > 5 mm in depth
6	Damage (severe) 50 to 75% mass loss - core veneer damage; > 5 mm in depth
7	Destroyed; > 75% mass loss

Statistical analysis

Statistical analysis was carried out using GenStat v.19 (VSN, Hemel Hempstead, Unite Kingdom). The CYP controls (plywood configurations 22 to 24) were not analysed because they were not damaged by termites. The average percent feeder mass loss per exposure box was used as a covariate in the analyses to account for variations in termite activity within boxes.

An analysis of variance (ANOVA) was performed on the hoop pine control data with hoop pine thickness as a treatment effect while an unbalanced ANOVA (to account for different replication numbers) was performed on the blended groups with CYP thickness, hoop pine thickness, blended type, and their interaction as treatment effects. Non-significant interactions were subsequently omitted from the model. Means and standard errors (SE) were determined as well as pairwise comparisons using Fishers protected least significant difference (LSD), where means with the same letter were not significantly different.

RESULTS AND DISCUSSIONS

During the exposure period from November 2018 to May 2019 the total rainfall was 284 mm and the average daily temperature was 30 °C (maximum of 40 °C in early December to a minimum of 19.5 °C in late May). The average relative humidity was 43.5% (minimum of 13.5% in late November to a maximum of 80.0% in mid-December). The trial site was exposed to an average solar radiation of 19.5 MJ/m^2 with a maximum of 32 MJ/m^2 in late November to a minimum 4 MJ/m^2 in mid-May (Queensland Government 2020).

The majority of the softwood feeder blocks were either substantially damaged or destroyed by termites, which is indicative of strong termite vigour (Fig. 6). Mean mass losses per exposure box ranged from 29% to 86%, and the mean damage rating for all blocks was 6 (severe) with a range from 1 (sound) to 7 (destroyed). Only 16 blocks out of 350 had a rating of 1. These were spread across eight separate exposure boxes.

Fig. 6. The majority of the softwood feeder blocks were substantially damaged

From the visual assessment and calculated percentage mass loss, each plywood configuration was assigned a mean termite damage rating (Table 3). The test blocks (*i.e.*, 24 plywood configurations) had mean termite damage ratings from 1 (sound) to 5 (moderate damage); however, in some cases the range included blocks with ratings of 6 (severe) and 7 (destroyed).

Table 3. Mean Termite Damage Rating (Core/Crossband)

CYP Veneer Thickness (mm)	Hoop Veneer Thickness (mm)			
	1.0	1.5	3.0	None (CYP Only)
1.8	1* / 1**	3* / 1**	4 */ 2**	1
2.8	1* / 1**	2* / 1**	4* / 3**	1
3.0	1* / 1**	3* / 1**	4* / 1**	1
None (Hoop Only)	4	4	5	

*Core Configuration; ** Crossband/Longband Configuration

The full hoop pine test blocks (1, 1.5, and 3 mm) were all damaged by *C. acinaciformis* and received individual damage ratings between 2 and 7. Individual mass losses per test blocks ranged from 3% to 56% (1.0-mm veneer thickness blocks), 4% to 61% (1.5-mm veneer thickness blocks), and 10% to 82% (3.0-mm veneer thickness blocks) with mean percentage mass losses of 21%, 26%, and 46%, respectively. Statistical analysis of the percent mass loss showed no significant difference between 1.0- and 1.5-mm veneer thickness but a significantly higher loss using 3.0-mm veneer thickness (Table 4).

Table 4. Mean Percent Mass Loss ± SE for Hoop Pine Veneer Thickness in Controls

Hoop Pine Veneer Thickness (mm)	Hoop Control
1	21.00 ± 5.40 **a**
1.5	25.81 ± 5.40 **a**
3.0	45.50 ± 5.40 **b**

Means with the same letter are not significantly different

This result was not unexpected, as hoop pine was a non-durable species with respect to termite attack (DAF 2018) and at a 3.0-mm veneer thickness there is simply more of the non-durable veneer between each glueline for the termites to feed. Conversely, none of the full CYP test blocks were damaged with all blocks receiving a damage rating of 1 (sound) (Fig. 7). This was also not unexpected as CYP heartwood is known to be resistant to termite and fungal attack (Evans *et al*. 1997).

(a) **(b)**

Fig. 7. Hoop pine control blocks (a) were damaged by *C. acinaciformis* while CYP controls (b) did not receive any damage

Statistical analysis of percent mass loss showed that CYP thickness had no significant effect ($p = 0.854$). There was a significant interaction between type (either core or crossband) and hoop pine veneer thickness ($p < 0.001$) with the full hoop core blocks (configurations 1 to 9) showing a percentage mass loss increase as the hoop veneer thickness increased. However, the alternating CYP longband/hoop crossband blocks (configurations 10 to 18) had minimal mass loss regardless of hoop veneer thickness (Table 5).

Table 5. Mean Percent Mass Loss ± SE for Hoop Pine Veneer Thickness and Type

Hoop Pine Veneer Thickness (mm)	Type: Core	Type: Crossband
1	0.478 ± 1.646 **a**	0.086 ± 1.872 **a**
1.5	10.202 ± 1.645 **b**	0.132 ± 2.122 **a**
3.0	22.843 ± 1.503 **c**	2.273 ± 1.840 **a**

Where means with the same letter are not significantly different

Of the test blocks that had CYP face and back veneers, and a hoop pine core (constituting nine separate plywood configurations), only those with a 1-mm hoop veneer thickness were able to resist substantial termite damage irrespective of the thickness of the CYP face and back veneer (Fig. 8). Of the 40 test blocks manufactured using the 1-mm hoop pine veneer in the core and CYP faces, only nine had evidence of termite damage on the edge of a hoop pine veneer only resulting in a damage score ≤ 3 (only two blocks had a rating of 3, the remainder had either 2 or 1). The mean percentage mass loss across the three test block groups that used 1-mm hoop pine core veneers with either 3-mm, 2.8-mm, or 1.8-mm-thick CYP face and back veneers was 0.7%, 0.8%, and 0.3%, respectively. The mass loss was due entirely to damage to the hoop core veneer; the CYP face and back veneer were not damaged.

1.8 mm CYP **2.8 mm CYP** **3.0 mm CYP**

Fig. 8. The majority of the 1-mm hoop pine core plywood blocks were undamaged

However, when the hoop pine core veneer thickness was increased to 1.5 mm and to 3.0 mm, substantial termite damage occurred in the hoop pine veneers (Fig. 9 and Table 5). This was irrespective of the thickness of the CYP face and back veneers. The mean percentage mass losses for the test blocks that used 1.5-mm hoop pine core veneers and the three CYP face and back veneer thicknesses (1.8, 2.8, and 3.0 mm) were 16%, 7%, and 11%, respectively. For the test blocks that used 3.0-mm hoop pine core veneers, the mean percentage mass loss was 23% across all three CYP face and back thicknesses. The durable CYP face and back veneers did not aid in the protection of the non-durable hoop pine core veneers at 1.5 mm and 3.0 mm. In some cases, only the CYP face and back veneers essentially remained due to termite feeding.

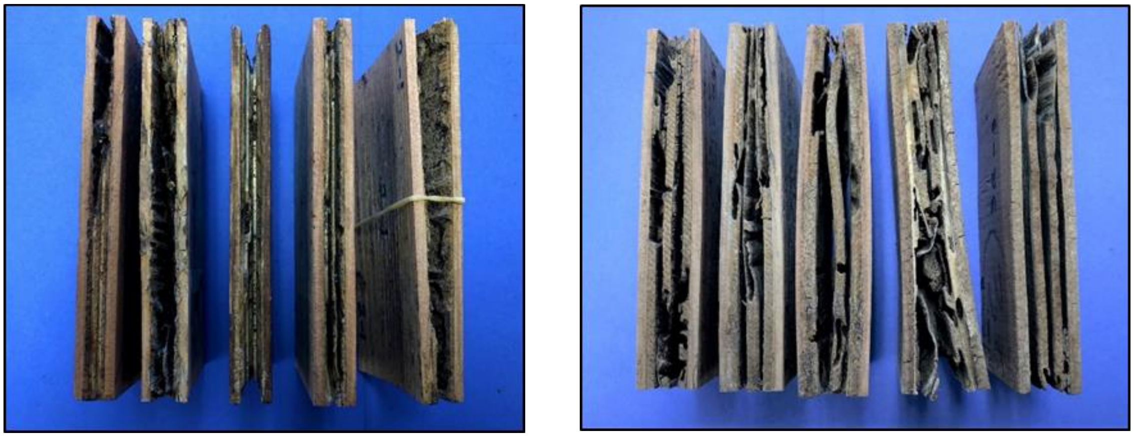

Fig. 9. Extensive termite damage was sustained to the 1.5 and 3.0 mm hoop pine core veneers

Of the plywood configurations 1 to 9 exposed to feeding by *C. acinaciformis*, only configurations with a 1.0-mm hoop pine veneer (configurations 1, 4, and 7) received minimal termite damage (Fig. 10).

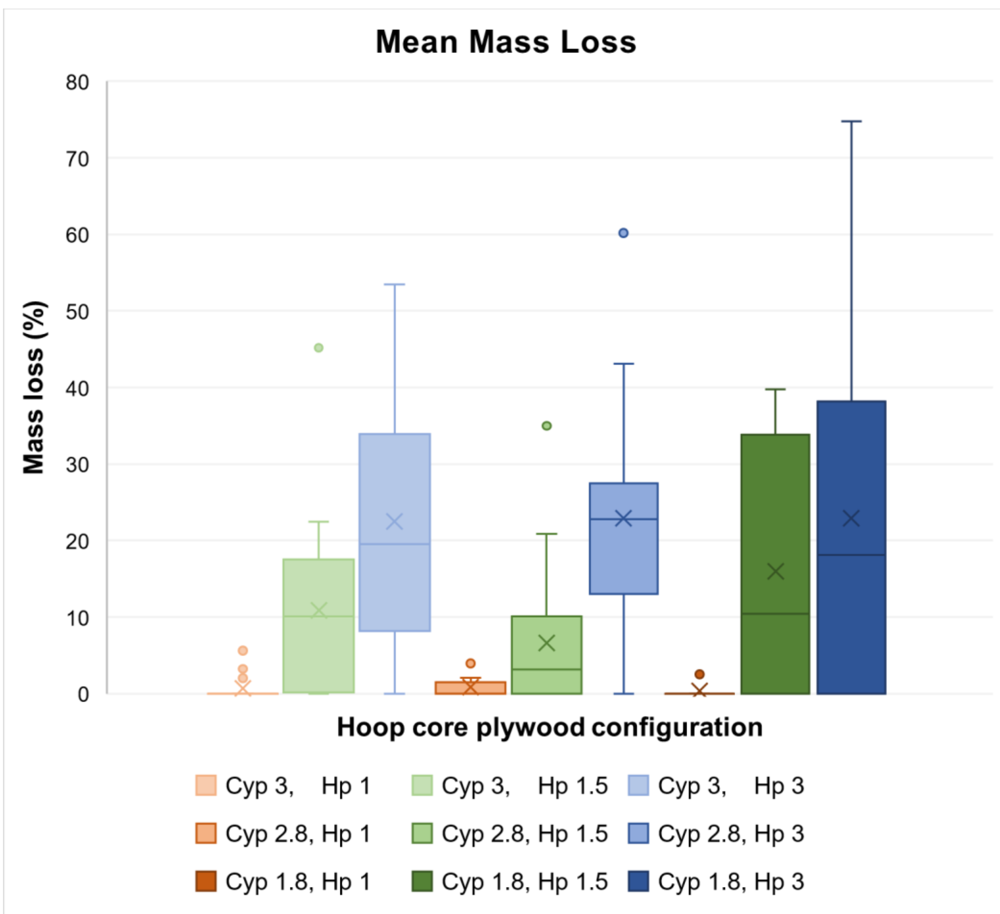

Fig. 10. Mass loss (%) of nine plywood configurations comprising a CYP face, back, and a hoop pine core (cross is the mean; central horizontal bar is the median)

For the plywood test block configurations (10 to 18) that included CYP and hoop pine arranged in an alternating pattern (CYP longbands and hoop pine crossbands), the durability of the hoop pine veneers (resistance to termite attack) was improved compared to limiting the CYP to the face and back veneers. While the CYP veneers were essentially untouched by termites, there were two blocks that had some minor "nibbling" on the CYP longband.

With 1.0-mm hoop pine crossbands, none of the test blocks received termite damage (across all three CYP longband veneer thicknesses) with damage ratings of 1 being recorded (Fig. 11). The encouraging performance of the 1-mm hoop pine veneers was in line with the results observed in the 1-mm hoop core blocks (with CYP face and back veneers), *i.e.*, plywood configurations 1, 4, and 7. One explanation for the resistance to termite attack of the 1.0-mm hoop pine veneers could be the influence of possible migration of CYP heartwood extractives (during the manufacturing process) into the thinner hoop pine veneers to discourage termite attack (Nzokou *et al.* 2005). Additionally the glueline may also have acted as a barrier to termite attack when the veneer thickness was minimal, *e.g.*, 1.0 mm, because the termites could only initiate feeding from the sides and the ends of the blocks due to the presence of durable CYP on the face and back, and with configurations 10, 13, and 16 the CYP longband as well. Shukla and Joshi (1992) previously reported a significant correlation between a reduction in veneer thickness and the resistance to termite attack using a phenol-formaldehyde glueline. They surmised that the penetration of glue (during manufacture) into a thin veneer may impart some degree of resistance to termite attack in combination with extractives migration. In combination with extractives migration is probably the key factor as the glueline was not an effective barrier when all the veneers were hoop pine (even at 1.0 mm), though not having a CYP face or back meant the termites were able attack through the outermost plies and through the gluelines below. This was in contrast to the study by Faraji *et al.* (2009) where only the outer 1.3 mm veneers (in a 9-ply configuration of non-durable veneers) were eaten by termites. Again, it is emphasised that this was a laboratory trial with small block size and a small number of termite (*R. santonensis*) workers.

Fig. 11. Test blocks with a CYP longband and a 1.0-mm hoop pine crossband were undamaged

When the hoop pine crossbands were increased to 1.5-mm-thick veneers, the majority of the test blocks sustained little to no damage. The mean percentage mass loss across the three CYP veneer thicknesses (1.8, 2.8, and 3.0 mm) was ≤ 0.5% with the worst individual test block with a damage rating of only 2.

However, with an increase of the hoop pine veneer thickness to 3.0 mm, there was noticeable increased damage to the hoop pine crossbands in some blocks (and in two blocks, some minor damage to the CYP longbands) (Fig. 12). It could be surmised that once the hoop pine veneer thickness increased to 1.5 or 3.0 mm there was simply more area between the individual gluelines for the termites to exploit the non-durable hoop pine. In addition, there was a greater volume of non-durable veneer for the termites to feed upon. It is well known that termites will aggregate more workers to the site of feeding when there is a larger volume of susceptible material available (Peters *et al.* 2014).

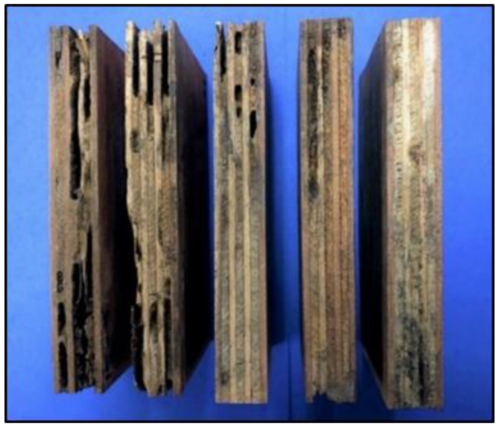

Fig. 12. The 3-mm hoop crossbands were badly damaged in some instances

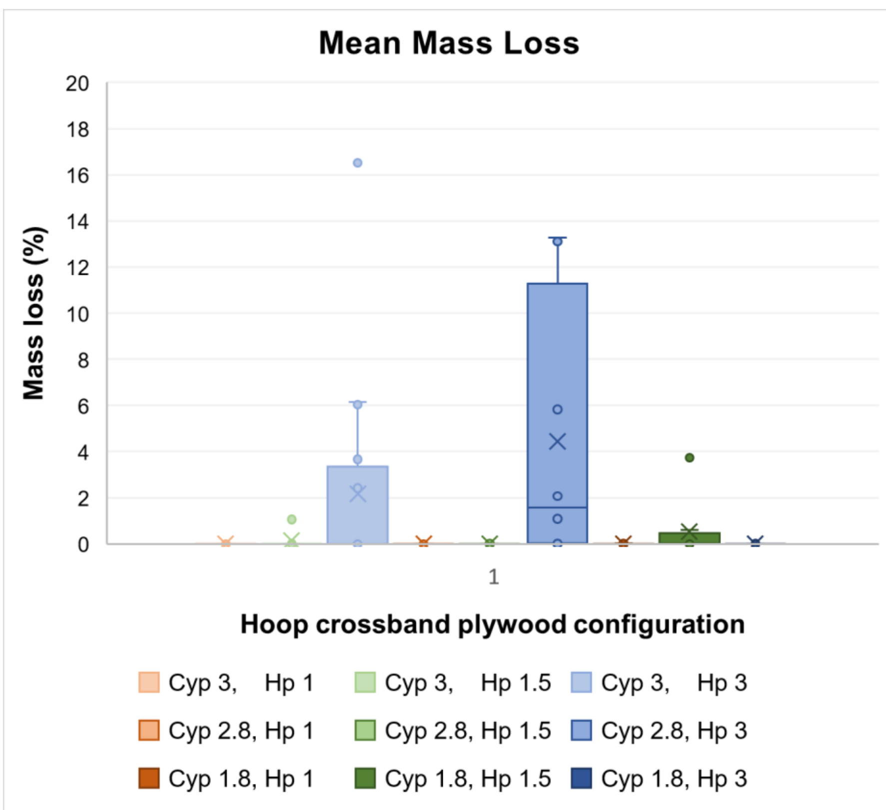

Fig. 13. Mass loss (%) of nine plywood configurations comprising a CYP face, back, longband, and a hoop pine crossband (cross is the mean; central horizontal bar is the median)

To summarise, while there was no significant difference in percent mass loss between hoop pine veneer thickness when in an alternating pattern, there was some evidence of more substantial damage in a limited number of blocks with 3.0-mm veneer thickness (Fig. 13).

The 2.8-mm CYP longband veneers alternating with 3.0-mm hoop pine crossband veneers performed the worst with a mean percentage mass loss of 4.4% . The use of thicker CYP veneers (3.0 mm), produced a mean percentage mass loss of only 2.2%, but one block in particular had a mass loss of 16.5%. It was noteworthy that the test blocks that included 1.8-mm-thick CYP longbands received negligible damage regardless of hoop pine crossband thickness.

CONCLUSIONS

1. The white cypress pine (CYP) rotary veneers that were present as face, back, and/or longband veneers in 21 of the 24 tested plywood configurations were essentially untouched by termites during the field exposure trial. Only two test blocks from 264 blocks that included CYP veneers received some minor ‘nibbling’ on a CYP longband.
2. A blended species 7-ply plywood block comprised of CYP face and back veneers, and hoop pine core veneers was shown to have some resistance to attack by the subterranean termite *C. acinaciformis,* if the core veneer thickness was limited to 1.0 mm. An increase in the thickness of the hoop pine veneers to 1.5 mm resulted in significantly more termite damage to the plywood test block. Increasing again to 3.0-mm veneer thickness produced substantial termite damage significantly higher again than both 1.0 mm and 1.5 mm.
3. A blended species 7-ply plywood block comprised of CYP face, back, and longband veneers, and hoop pine crossband veneers was shown to have some resistance to termite attack if the hoop pine crossband veneers were no greater than 1.5-mm thick. Increasing the thickness of the hoop pine crossband veneers to 3.0 mm was observed to result in termite damage in some blocks, however, this was not statistically significant. While there was no significant difference between CYP thickness, it did appear that at a thickness of 1.8 mm, termite damage was almost non-existant.
4. The improved termite resistance that was observed in the thicker hoop pine veneers used in the plywood configurations that alternated CYP longbands and hoop pine crossbands compared to all hoop pine core veneers (longbands and crossbands) indicates the increased protection is a result of the neighbouring white cypress pine.

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