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Natural durability of tropical and native woods against termite damage by *Reticulitermes flavipes* (Kollar)☆

Rachel A. Arango, Frederick Green III*, Kristina Hintz, Patricia K. Lebow, Regis B. Miller

USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398, USA

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Abstract

Environmental pressure has resulted in voluntary removal of chromated copper arsenate (CCA) from wood preservatives in residential applications in the United States. A new generation of copper organic preservatives was formulated as replacements, but these preservatives may not provide a permanent solution to all related problems. Some of these issues include concern over copper in aquatic environments and corrosion of fasteners. Copper preservatives in general are also poor inhibitors of mould. Therefore, we still need to evaluate alternative solutions in order to address current inadequacies of copper organic wood preservatives. In this study, six hardwoods and six softwoods were evaluated for their ability to resist termite damage by *Reticulitermes flavipes*. Mass loss versus specific gravity showed an inverse correlation in tropical hardwood species, but a slightly positive correlation in native softwood species. Also, southern yellow pine and Douglas-fir wood blocks were evaluated after treatment with 0.1% copper borate, water-borne (WB) copper naphthanate, and *N'N*-naphthaloylhydroxylamine (NHA). Erisma, juniper, ipe, and white-cedar were highly resistant. The NHA-protected Douglas-fir and southern pine resisted attack as effectively as copper borate or WB copper naphthanate treatment. These results indicate that selected naturally durable wood species, both tropical and native, inhibit *R. flavipes* damage as effectively as preservative treatment.

Keywords: NHA; Borate; Termite damage; Specific gravity

1. Introduction

Many types of wood have their own natural defences against insects and other pest species. This is especially true in tropical environments because there is no frost season to keep pest populations down (Beal et al., 1974). While evolving, plants and trees have developed the property of producing their own line of chemical defences (extractives) that keep invaders out. One goal of the wood preservation industry should be to exploit the natural defence mechanisms of durable wood species or simply use the naturally resistant wood itself. By using a compound already found in nature, the environmental impact would be minimal, yet still toxic to the insects.

One objective of this study was to supply background information on the natural resistance of different types of native and tropical woods to termite feeding, and to investigate whether observed resistance correlates with the specific gravity or density of the wood. Natural resistance of wood to termite attack seems to be correlated with wood species that have a higher specific gravity (Esenther, 1977). A study carried out by Peralta et al. (2004), which focused on wood consumption rates of different forest species by termites under field conditions, did not find a strong correlation between wood density and termite resistance. The authors did, however, acknowledge the importance of wood hardness as a deterrent to termite damage, concluding that wood density alone cannot be considered the single most important factor in determining termite resistance. A second objective of the experiment reported here was to

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*Corresponding author.
E-mail address: fgreen@fs.fed.us (F. Green III).

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compare termite resistance of treated domestic wood species with that of untreated domestic wood species. The similar termite study by Esenther (1977) serves as a reference for comparison, not only between specific species but also between tropical and non-tropical species as a group.

The third objective was to evaluate whether ageing in Alaska yellow-cedar affects termite resistance. Sections of Alaska yellow-cedar heartwood were used from different sources. Blocks from one group were less than 5 years old, and those from another group more than 20 years old. The hypothesis was based on the study by Rudman (1966), which proposed that along with the ageing of the tree, the extractives aged as well. The natural resistance of Alaska yellow-cedar wood is mostly caused by the nootkatone oil that it produces, and the presence of allelochemicals, such as terpenoids, quinones and phenolics (Cornelius et al., 2004). The oil, which is a known biocide, creates a distinct aroma in heartwood (Harris, 1984). The presumption is that as the tree gets older, the oil will dry up or evaporate, making the tree more susceptible to attack. DeGroot et al. (2000) tested the natural decay resistance of heartwood from both living and dead Alaska yellow-cedar trees, and found that the heartwood of living trees and those that had been dead less than 80 years was adequate for use in above-ground applications or moderately resistant as classified by Highley (1995).

2. Materials and methods

2.1. Wood species and termite test

Glass bottles ($55 \times 55 \times 135 mm^3$; Owens-Brockway, Owens, Ohio) were filled with approx. 120 g soil and 15 mL distilled water and then autoclaved for 45 min. Soil bottles were used to better replicate the environment in which the termites were found and to deter death by starvation (Green et al., 1997). *Reticulitermes flavipes* (Kollar) was collected from the same forest colony at Janesville, Wisconsin, during June, July, and August of 2003 using cardboard traps cultured with the brown-rot fungus *Gloeophyllum trabeum*. Termites were then maintained in humidity- and temperature-controlled incubators until the tests were started. After the termites were removed from the cardboard traps, 1 g (approx. 275 termites) was added to each of the soil bottles after they had cooled.

Wood specimens were cut to approx. 4–10mm in thickness, 40 mm in length, and 27 mm wide. All such test blocks were conditioned at 27°C and 70% relative humidity (RH) to 12.9% equilibrium moisture content (Forest Products Laboratory, 1999; Tables 3 and 4), and were weighed before they were added to the termite bottles. The grain inmost test blocks ran longitudinally where specimens permitted. Testing procedures followed the American Wood Preservers' Association standard for testing wood preservatives using soil-block cultures (AWPA, 2003), while the American Society for Testing and Materials standard for evaluating cellulosic materials for resistance to termites was used to interpret the results (ASTM, 1998). A total of 12 different tree species were used and multiple trees (3–5) were tested in: Southern yellow pine sapwood (*Pinus* spp.); Douglas-fir heartwood (*Pseudotsuga menziesii*); poulsenia heartwood (*Poulsenia armata*); balsa which has no appreciable distinction between heartwood and sapwood (*Ochroma pyramidale*); western hemlock heartwood (*Tsuga heterophylla*), ceiba heartwood (*Ceiba pentandra*), Alaska yellow-cedar heartwood (*Chamaecyparis nootkatensis*); Atlantic white-cedar heartwood (*Chamaecyparis thyoides*); grignon or qualea heartwood (*Qualea* spp.); juniper heartwood (*Juniperus* spp.); cambara or erisma heartwood (*Erisma* spp.); and ipe heartwood (*Tabebuia* spp., lapacho group) (Flynn and Holder, 2001). Alaska yellow-cedar heartwood blocks were classified as either class I, live trees, or class III, trees that had been dead for more than 20 years.

2.2. Preservative treatments

Southern yellow pine sapwood blocks were vacuum-treated with three different preservatives: 0.1% WB copper naphthanate (WB CuNapth); 0.1% copper borate (CuBor); and 0.1% N'N-naphthaloylhydroxamine (NHA) as shown in Table 1 (Chen et al., 1986; Green et al., 1997; Nzokou et al., 2002). Douglas-fir heartwood blocks were also vacuum-treated in the same manner as southern yellow pine blocks (Douglas-fir sapwood is nearly absent and is therefore not used in construction). The average retention of preservatives is given in Table 2. These blocks were then died and conditioned to 70% RH and 12.9% equilibrium moisture content before being added to the termite bottles. The bottles were held in the incubator at 27°C and 95% RH for 28 days, and general observations made. If all termites appeared dead, the bottle was taken out and the number of days until 100% mortality recorded.

2.3. Mass loss analysis

At the end of the 4-week period, the blocks were removed, died overnight, and conditioned once again at 70% RH. Mass loss of these blocks was determined after their moisture levels were equilibrated. For each of the bottles, the remaining live termites were weighed and recorded. Statistical associations of naturally durable woods considered three factors: viz. termite mortality, specific gravity, and percentage mass loss, and were based on the non-parametic Spearman's rank correlation coefficient (Hollander and Wolfe, 1999). This statistic is the usual Pearson's correlation coefficient based on the relative rankings of each of the factors, and has a value between -1 and 1, with the value -1 indicating perfect disagreement in the rankings, and a value of 1 indicating perfect agreement. Calculations were based on the means of groups. Treated groups of wood were compared by non-parametic analysis of variance (ANOVA) based on medians.

3. Results and discussion

3.1. Termite test

The termite resistance tests showed that untreated southern yellow pine blocks suffered the highest mean mass loss (1.04g) (Table 1). Except for Atlantic white-cedar, which did not experience any mass loss, ipe, a tropical timber found widely dispersed throughout South and Central America had the lowest amount of termite damage (Flynn and Holder, 2001). The native softwood data did not show a positive correlation between mass loss, termite mortality, and specific gravity (Fig. 1). There was an apparent inverse relationship between specific gravity and termite mortality in native species. The hypothesis that woods with a higher specific gravity have a greater natural resistance to degradation by *R. flavipes* appears positively associated with the termite mortality data of the tropical hardwood species and negatively associated with percentage mass loss (Fig. 2). It appeared that there was a higher percentage of termite deaths in bottles with woods of a higher specific gravity. However, these graphs were based solely upon the wood species chosen for the experiment.

Table 1
Results of the natural resistance of 12 species of native and exotic woods exposed to *R. flavipes*

Wood blocks			Mean termite mortality (%)[b]	Specific gravity (ovendry wt/green volume)[c]
Wood"	Mean mass loss (g)[b]	Mean mass loss (%)[b]		
Untreated wood blocks				
Southern yellow pine (s)	1.04 (0.4)	41.32 (15.3)	22.65 (19.1)	0.67
Douglas-fir (s)	0.79 (0.2)	23.08 (5.8)	45.44 (18.2)	0.45–0.46
Poulsenia (h)	0.74 (0.1)	20.27 (1.9)	79.40 (8.5)	0.33
Balsa (h)	0.69 (0.2)	68.97 (25.7)	52.70 (17.6)	0.10–0.17
Hemlock (s)	0.69 (0.3)	21.14 (13.1)	71.80 (25.8)	0.38
Ceiba (h)	0.52 (0.1)	37.47 (5.2)	87.15 (18.1)	0.25
80IS Alaska yellow-cedar (s)	0.48 (0.0)	16.52 (1.1)	51.43 (5.0)	0.42
Qualea (h)	0.47 (0.1)	10.54 (1.2)	86.24 (4.5)	0.49–0.60
28IS Alaska yellow-cedar (s)	0.46 (0.2)	15.21 (7.0)	54.27 (3.5)	0.42
81IS Alaska yellow-cedar (s)	0.42 (0.1)	12.05 (2.5)	61.43 (15.3)	0.42
22IS Alaska yellow-cedar (s)	0.33 (0.0)	13.91 (0.4)	60.23 (2.4)	0.42
Juniper (s)	0.32 (0.0)	8.40 (1.0)	94.93 (2.7)	0.44
Erisma (h)	0.23 (0.0)	8.50 (0.7)	80.15 (12.4)	0.46
Ipe (h)	0.16 (0.1)	3.00 (0.5)	90.38 (7.1)	0.85–0.97
Atlantic white-cedar (heartwood) (s)	0	0	100	0.35
Treated wood blocks				
CuBor Douglas-fir	0.94 (0.3)	27.36 (7.4)	27.62 (26.9)	NA
CuBor southern yellow pine	0.60 (0.2)	22.80 (6.7)	66.30 (16.5)	NA
NHA Douglas-fir	0.58 (0.2)	16.58 (6.1)	63.90 (24.0)	NA
WB CuNapth Douglas-fir	0.48 (0.2)	13.48 (5.0)	66.92 (31.2)	NA
WB CuNapth southern yellow pine	0.44 (0.1)	18.05 (2.3)	60.62 (11.3)	NA
NHA southern yellow pine	0.36 (0.1)	14.91 (2.0)	80.32 (6.2)	NA

[a] h, hardwood; s, softwood.
[b] Mean (standard deviation).
[c] Specific gravity data taken from Chudnoff (1984)

Table 2
Average retention of preservative treated samples

Treatment	Primary actives (kgm^{-3})[a]	CoBiocide	Total actives
0.1% WB Cu Napth SYP/ Doug fir	(as Cu)[b]	N/A	
	0.114 (0.108)		0.114
	0.317 (0.020)		0.317
0.1% Cu Bor SYP Doug fir	(as CuO)[b]	(as B_2O_3)[b]	
	0.013 (0.005)	0.024 (0.008)	0.037
	0.012 (0.003)	0.016 (0.005)	0.028
0.1% NHA SYP Doug fir	(as Na)[b]		
	0.510 (0.055)	N/A	0.510
	0.380 (0.052)		0.380

[a] ICP, inductively coupled plasma spectrometry (AWPA, 2003)
[b] Mean (SD).

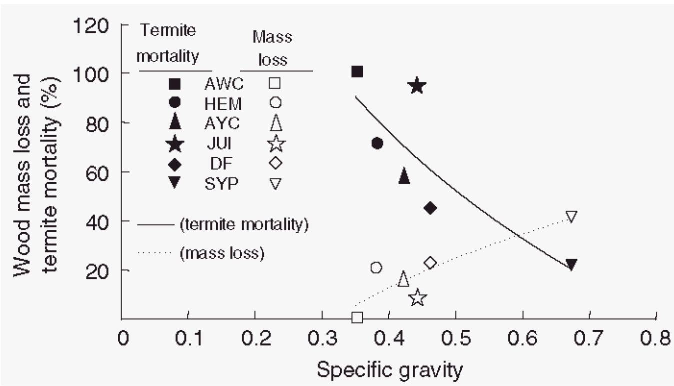

Fig. 1. Relationship of specific gravity of softwoods to termite mortality and mass loss (AWC, Atlantic white-cedar; AYC, Alaska yellow-cedar; JUI, juniper; DF, Douglas-fir; HEM, hemlock; SYP, southern yellow pine).

Esenther's termite test (Esenther, 1977) of the natural resistance of 21 native and exotic woods also showed a positive correlation between specific gravity and resistance. Of the species tested, Esenther found seven exotic woods teak, iroko, mahogany, Australian cypress-pine, niove, greenheart, and holywood lignumvitae to be most resistant, along with several native wood species (two types of oak, black locust, Osage-orange, and redwood) (Esenther, 1977).

3.2. Natural resistance analysis

The age of the Alaska yellow-cedar blocks tested did not appear to affect termite resistance in earlier studies by Grace and Yamamoto (1994). Comparisons of the mean percentage mass loss and mean percentage termite mortality were made to confirm this, and no statistically significant differences between the sets of blocks were revealed. If the Alaska yellow-cedar extractives are the termite deterrent, then this conclusion reduces the possibility that the extractives age rapidly in the dead wood, making it more susceptible to degradation. Two of the Alaska yellow-cedar blocks were less than 5 years old at the time of the test, and two were more than 20 years old. Alaska yellow-cedar is listed as being between resistant and very resistant to decay according to the *Wood Handbook* (Forest Products Laboratory, 1999). When DeGroot et al. (2000) looked at the potential for utilizing dying and dead Alaska yellow-cedar heartwood, they compared their durability to that of trees still alive and those that had been dead for many years. In testing them against decay fungi such as *G. trabeum*, they concluded that heartwood from living trees and those that were dead less than 80 years are adequate to have practical application for above-ground use (DeGroot et al., 2000). The Alaska yellow-cedar blocks used in the study reported here coincided with the classifications found in the *Wood Handbook* (Forest Products Laboratory, 1999), showing moderate to high resistance against damage by termites, although Alaska yellow-cedar stakes have not been shown to perform well inground at Gulfport, Mississippi (personal communication with Stan Lebow, FPL December 2005).

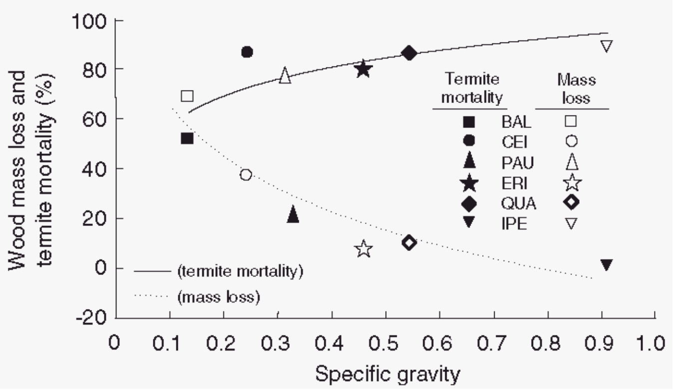

Fig. 2. Relationship of specific gravity of hardwoods to termite mortality and mass loss (BAL, balsa; CEI, ceiba; PAU, poulsenia; ERI, erisma; QUA, qualea; IPE, ipe).

3.3. Durability of treated blocks

Even at low retention, CuBor-treated southern yellow pine blocks showed half the percentage mass loss (from termite damage) of that shown by the untreated southern yellow pine. The WB CuNapth- and NHA-treated southern yellow pine blocks also performed well. Treated southern yellow pine blocks had significantly less mean percentage mass loss than untreated southern yellow pine blocks, but in the study many native and tropical wood species with a high natural durability performed well. All treated blocks were recorded as resistant except for CuBor-treated Douglas-fir, which was classified as moderately resistant. This is most probably related to the higher density of Douglas-fir not allowing it to absorb treatments well (Flynn and Holder, 2001). The NHA and Cu-Napth treatments appeared to improve the resistance of Douglas-fir to termite attack, although this was not statistically significant. This shows the potential of NHA to protect woods that are more resistant to treatment (Kartal et al., 2003). The results also show the potential of a new formulation of water-based preservative such as WB Cu-Napth (Nzokou et al., 2002).

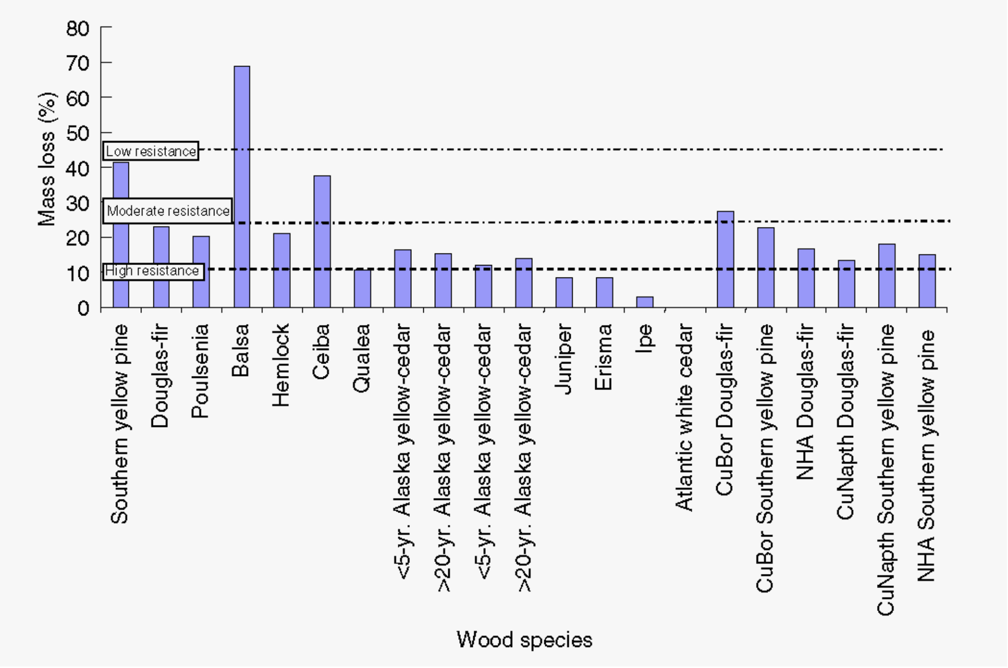

Fig. 3. Percentage mass loss of native and exotic, as well as treated, wood species

3.4. Resistance ratings

According to the standard soil-block test, the untreated woods like juniper, erisma, ipe, and Atlantic white-cedar had a high natural resistance (AWPA, 2003). Douglas-fir, poulsenia, hemlock, Alaska yellow-cedar, and qualea fell into the moderately resistant category. Southern yellow pine and ceiba were found to have low resistance, while balsa showed slight to no resistance (Fig. 3).

3.5. Evaluation of termite test

Timing of the termite testing may have played some role in the lack of measurable mass loss in Atlantic white-cedar, which was carried out in the winter as opposed to the higher activity of summer feeding. The mortality observed was higher than expected in termite tests done in winter, and wood blocks showed less mass loss. According to the ASTM standard, if the termites survive 1 week, they are considered robust enough to have a valid test, even late in the season (ASTM, 1998).

Statistical analysis examined the relationship between termite mortality, mass loss, and specific gravity/density ratio using the Spearman rank correlation coefficient. According to this test, percentage mass loss and percentage termite mortality of softwoods appear inversely associated ($R = -0.94$, p value = 0.0048). Percentage termite mortality and specific gravity are also inversely related ($R = -0.83$, p value = 0.0416), while percentage mass loss has a marginal positive association with specific gravity ($R = 0.77$, p value = 0.0724). The Spearman correlation coefficients based on the six hardwood species indicate a significant inverse association between percentage mass loss and specific gravity ($R = -0.94$, p value = 0.0048).

4. Conclusion

Evaluation of natural termite resistance in native and tropical species is becoming increasingly important in the wood preservation industry, because there has been a greater focus in reducing the potential leaching of chemical treatments out of the wood and into the environment. In using these more naturally durable woods in building projects, the amount of preservative needed to protect the wood is decreased and the longevity of the wood is increased (Tsunoda, 1990). These results indicate that certain native and tropical wood species are resistant to termite attack by *R. flavipes*, and could be effective substitutes for pressure-treated lumber.

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