# Evaluation of the termite resistance of wood pressure treated with copper naphthenate

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**Abstract**

Southern pine wafers pressure-treated with copper naphthenate in American Wood-Preservers' Association P9 Type A oil or in toluene were evaluated for resistance to attack by the Formosan subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Wood samples were pressure treated to target copper retentions of 0.040, 0.075, 0.095, or 0.150 pcf, conditioned to simulate field exposure, and exposed to termites in 4-week no-choice and two-choice laboratory tests. Copper retentions were assayed by x-ray fluorescence after treatment, after leaching, and again after exposure to the termites. An approximate 20 percent loss of copper after weathering and termite exposure was noted in samples treated to target retentions of 0.095 and 0.150 pcf Cu. With or without a heavy oil carrier, copper naphthenate showed some toxicity to termites and deterred termites from feeding on the treated wood. At the highest target retentions of 0.095 and 0.150 pcf Cu, southern pine weight losses from termite feeding did not exceed 4 percent in no-choice tests nor 1 percent in two-choice tests. Similar results were observed in no-choice tests with Douglas-fir blocks treated with copper naphthenate in oil or toluene. Field data are needed, but these results indicate that copper naphthenate pressure treatments are of value in protecting wood from attack by the Formosan subterranean termite.

The Formosan subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae) is the major cause of wood deterioration in the Hawaiian islands (22,23). Every year, a large number of utility pole failures are directly attributable to Formosan subterranean termite damage. In fact, in Hawaii and other Pacific regions, termites frequently surpass decay fungi as a threat to poles in service (9).

Copper naphthenate is of interest as a treatment for utility poles in Hawaii because of its favorable environmental characteristics (8,16,17), its history of successful performance as a fungicide (7,15), and its low conductivity (6). However, field performance has been found to vary among geographic locations (10), and there is only limited information available on the termite resistance of wood pressure impregnated with copper naphthenate (15).

This study was initiated to determine the potential of copper naphthenate for use as a pressure treatment to protect wood from attack by Formosan subterranean termites. The target copper retentions included those specified by the American Wood-Preservers' Association (AWPA) (3) for treatment of Pacific Coast Douglas-fir poles: 0.075, 0.095, and 0.150 pcf.

Douglas-fir is the principal wood imported to Hawaii for use as poles and structural lumber (25). However, pine sapwood is as acceptable to termites as Douglas-fir (13), and it is more uniform in permeability and thus more useful for evaluating the general char-

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TABLE 1. —*Formosan subterranean termite mortality and weight loss of southern pine wafers treated with copper naphthenate in AWPA P9 Type A oil, in a 4-week no-choice laboratory test.*

| Initial copper retention | | | Post-leaching copper retention | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Target | Calculated[a] | Assayed[b] | Overall[b] | Inner[c] | Outer[c] | Post-test Cu retention[b] | Wood weight loss[d] | | Termite mortality[d] |
| (pcf) | | | | | | | (g) | (%) | |
| 0.150 | 0.130 | 0.134 | 0.107 | 0.070 | 0.098 | 0.103 | 0.06 ± 0.07 AB | 2.60 ± 3.42 | 73.05 ± 10.70 A |
| 0.095 | 0.084 | 0.079 | 0.063 | 0.050 | 0.070 | 0.064 | 0.04 ± 0.01 A | 1.76 ± 0.53 | 79.85 ± 7.44 A |
| 0.075 | 0.069 | 0.073 | 0.058 | 0.046 | 0.070 | 0.046 | 0.07 ± 0.02 AB | 3.20 ± 1.17 | 72.90 ± 15.71 A |
| 0.040 | 0.036 | 0.043 | 0.034 | 0.030 | 0.034 | 0.026 | 0.12 ± 0.04 B | 5.41 ± 1.56 | 67.35 ± 4.69 A |
| Solvent control | | -- | -- | -- | -- | -- | 1.07 ± 0.06 C | 47.91 ± 4.20 | 11.50 ± 1.08 B |
| Untreated control | | -- | -- | -- | -- | -- | 1.02 ± 0.07 C | 44.32 ± 4.44 | 20.60 ± 2.01 B |

[a] Mean copper retention (pcf) calculated from weight change due to treating solution uptake ($n$ = 16).
[b] Mean copper retention (pcf) determined by x-ray fluorescence ($n$ = 3).
[c] Mean copper retention (pcf) in outer or inner 2 mm of wafer, determined by x-ray fluorescence ($n$ = 3).
[d] Mean ± standard deviation. Means followed by different capital letters are significantly different (ANOVA, Duncan's Multiple-Range Test, $\alpha$ = 0.05).

acteristics of the preservative system. For this reason, we used southern pine sapwood wafers in this study. To test the applicability of our results to Douglas-fir lumber, which is principally heartwood, Douglas-fir heartwood cubes were also treated to the same target retentions, then split in half to expose the least-treated inner wood and evaluated for termite resistance.

## Experimental procedure

### Wood treatment

Flatsawn southern pine (*Pinus* spp.) sapwood wafers (25 by 25 by 6 mm, or approximately 1 by 1 by 0.25 inch) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) heartwood cubes (25 mm, or approximately 1 in. on each side) were pressure treated with solutions of copper naphthenate (Mooney Chemical, Inc., OM Group, Inc.) dissolved in either 30 percent AWPA P9 Type A oil (No. 2 fuel oil) / 70 percent toluene, or in toluene alone (5). The treatment schedule was 1) 30 minutes of vacuum (25 in. Hg); 2) 60 minutes of pressure (100 psi); and 3) 4 hours of soaking (ambient conditions).

Southern pine was the standard reference species in our study, since the permeability and uniform characteristics of this wood allow reliable comparisons with results obtained elsewhere with this same species. Douglas-fir heartwood blocks were included in the evaluation principally to test the effects of preservative penetration on treatment efficacy in this less permeable and less uniform species. For this reason, Douglas-fir blocks, rather than the standard thin wafers, were treated. These treated blocks were split in half before termite exposure to allow the insects access to the inner wood without having to pass the high preservative gradient in the surface wood.

The pine wafers were treated to target retentions of 0.040, 0.075, 0.095, or 0.150 pcf (calculated as copper only) in each of the two solvent systems, while the Douglas-fir blocks were treated to the three higher target retentions. Solvent-treated controls and untreated controls were also included in the experimental design, and subjected to the same weathering regime as the wood treated with copper naphthenate. After treatment, the samples were blotted dry, weighed to determine solution uptake, wrapped in aluminum foil, and kept in a fume hood for 7 days to allow slow evaporation of the solvent. The samples were then unwrapped and allowed to air-dry further until the weights stabilized.

### Weathering

The treated wood samples were exposed to a two-stage weathering regime. First, the samples were leached by being submerged in distilled water for 2 hours, then dried in a forced-air oven at 49°C for 22 hours each day for 14 days (18). This cycle was used by Duncan (11) to simulate 60 days of outdoor summer exposure in Wisconsin. After the 14-day weathering cycle, the samples were exposed to evaporative aging in a forced-air oven at 40°C for 4 weeks. This 6-week weathering regime was intended to remove a substantial amount of solvent carrier from the treated wood, and to simulate a brief period of exterior exposure to tropical conditions.

### Measurement of preservative retentions

Copper retentions in the treated wood were calculated before weathering by the weight change of the samples due to treatment solution uptake. Before and after the 6-week weathering sequence, subsamples of the pine wafers and Douglas-fir blocks were assayed for copper content using an ASOMA x-ray fluorescence spectrometer (2). The concentration gradients in three pine wafers per treatment were evaluated by assaying the copper contents of the outer 2-mm shell and the inner 2-mm core of each wafer. To determine penetration of the preservative in Douglas-fir, three Douglas-fir blocks per treatment were sliced and assayed in 5-cm layers (outer, middle, and inner) from the surface of the cube. Following the termite tests, subsamples of the termite-exposed pine wafers were also analyzed for copper content. This method was adopted in order to measure loss of the preservative due to leaching, and to determine the actual copper naphthenate concentrations to which the insects were exposed. The spectrometer had been calibrated for CCA analysis. This may have resulted in some error in the assayed copper retentions reported (S.L. Grove, personal communication). However, the agreement between the initial calculated and assayed copper retentions was quite good, considering that different block subsets were analyzed at each stage (Tables 1-3).

## No-choice termite test

Formosan subterranean termite workers (pseudergates, or undifferentiated individuals older than the third instar) and soldiers were collected from an active field colony on the Manoa campus of the University of Hawaii (20). Termites were collected immediately before their use in laboratory assays.

The no-choice termite bioassay was similar to AWPA and American Society for Testing and Materials (ASTM) standard methods (1,4), except that termite mortality was recorded and the ovendry weight loss in the test wafers was used to measure damage, rather than visual estimation. The test containers were 8 cm in diameter by 10 cm high screw-top plastic jars, each containing 150 g of washed and ovendried crushed coral sand (sieved to pass a U.S. 14-mesh screen) and 30 ml of distilled water. One test sample was placed on the surface of the damp sand and 400 termites (360 workers and 40 soldiers) were added to each jar. Five replicates of each formulation at each retention (2 formulations × 4 retentions; plus oil, toluene, and untreated controls) were included in the tests with southern pine sapwood. Jar lids were loosely replaced and the jars were incubated in an unlit temperature-controlled cabinet (29°C ± 0.5°) for 4 weeks (28 days), then dismantled, and termite mortality and ovendry wood weights were recorded.

The Douglas-fir cubes were evaluated in a similar fashion, except that each block was first split in half to allow termite access to the interior of the block, and the half-block was then placed on the surface of the sand with the cut (interior) face down. Termite mortality (percentage mortality transformed by the arcsine of the squareroot) and wood weight loss data were subjected to analysis of variance (ANOVA) and means were separated by Duncan's Multiple-Range Test, $\alpha$ = 0.05 (19).

## Two-choice termite test

Two-choice termite feeding assays, in which termite workers were presented simultaneously with both a copper naphthenate-treated and solvent-treated (control) pine wafer, were performed to determine the degree of repellency or feeding deterrence associated with copper naphthenate treatment. This test more closely approximates field conditions, in which termites presumably have a choice of materials on which to feed. The two-choice test was limited to the oil formulation. The experimental setup was otherwise identical to the no-choice test, except that two wafers were placed on the surface of the damp sand, on opposite sides of the jar. Five replicates of each of the four copper retentions were paired with oil-treated control wafers.

Termite mortality (percentage mortality transformed by the arcsine of the square root) and wood weight loss data from the treated and control wafers were subjected to analysis of variance (ANOVA) and

TABLE 2. — *Formosan subterranean termite mortality and weight loss of southern pine wafers treated with copper naphthenate in toluene, in a 4-week no-choice laboratory test.*

| Initial copper retention | | | Post-leaching copper retention | | | Post-test | | | Termite |
|---|---|---|---|---|---|---|---|---|---|
| Target | Calculated[a] | Assayed[b] | Overall[b] | Inner[c] | Outer[c] | Cu retention[b] | Wood weight loss[d] | | mortality[d] |
| (pcf) | | | | | | | (g) | (%) | (%) |
| 0.150 | 0.138 | 0.129 | 0.103 | 0.083 | 0.109 | 0.114 | 0.04 ± 0.01 A | 1.89 ± 0.52 | 69.20 ± 17.46 A |
| 0.095 | 0.077 | 0.086 | 0.069 | 0.045 | 0.063 | 0.077 | 0.08 ± 0.03 A | 3.59 ± 1.21 | 67.90 ± 19.67 A |
| 0.075 | 0.070 | 0.077 | 0.062 | 0.046 | 0.058 | 0.058 | 0.09 ± 0.04 A | 4.16 ± 1.58 | 65.20 ± 4.11 A |
| 0.040 | 0.036 | 0.047 | 0.038 | 0.030 | 0.041 | 0.026 | 0.20 ± 0.07 B | 9.02 ± 2.80 | 51.50 ± 15.90 A |
| Solvent control | | -- | -- | -- | -- | -- | 1.01 ± 0.08 C | 46.15 ± 3.96 | 15.75 ± 5.10 B |
| Untreated control | | -- | -- | -- | -- | -- | 0.94 ± 0.05 D | 41.61 ± 3.43 | 17.20 ± 1.54 B |

[a] Mean copper retention (pcf) calculated from weight change due to treating solution uptake ($n$ = 16).
[b] Mean copper retention (pcf) determined by x-ray fluorescence ($n$ = 3).
[c] Mean copper retention (pcf) in outer or inner 2 mm of wafer, determined by x-ray fluorescence ($n$ = 3).
[d] Mean ± standard deviation. Means followed by different capital letters are significantly different (ANOVA, Duncan's Multiple-Range Test, $\alpha$ = 0.05).

TABLE 3. — *Formosan subterranean termite mortality and weight loss of split Douglas-fir blocks treated with copper naphthenate in AWPA P9 Type A oil or toluene, in a 4-week no-choice laboratory test.*

| Treatment | Cu retention | | Post-leaching Cu distribution[b] | | | | | Termite |
|---|---|---|---|---|---|---|---|---|
| | Target | Calculated[a] | Inner | Middle | Outer | Wood weight loss[c] | | mortality[c] |
| | (pcf) | | | | | (g) | (%) | (%) |
| CuNaph/oil | 0.150 | 0.155 | 0.118 | 0.132 | 0.168 | 0.16 ± 0.04 A | 3.29 ± 0.82 | 57.65 ± 5.11 A |
| | 0.095 | 0.101 | 0.074 | 0.081 | 0.118 | 0.14 ± 0.01 A | 3.01 ± 0.23 | 53.50 ± 2.68 A |
| | 0.075 | 0.074 | 0.047 | 0.057 | 0.090 | 0.17 ± 0.05 A | 3.72 ± 1.18 | 60.60 ± 13.56 A |
| CuNaph/toluene | 0.150 | 0.139 | 0.078 | 0.110 | 0.152 | 0.13 ± 0.04 A | 2.68 ± 0.84 | 59.85 ± 7.60 A |
| | 0.095 | 0.093 | 0.063 | 0.081 | 0.111 | 0.18 ± 0.04 A | 3.74 ± 1.14 | 57.05 ± 2.83 A |
| | 0.075 | 0.069 | 0.054 | 0.050 | 0.092 | 0.26 ± 0.11 A | 5.82 ± 2.45 | 55.50 ± 9.06 A |
| Untreated control | -- | -- | -- | -- | -- | 1.29 ± 0.28 B | 28.29 ± 4.76 | 32.60 ± 10.68 B |

[a] Mean copper retention (pcf) calculated from weight change of blocks (25 mm on each side) due to treating solution uptake ($n$ = 8).
[b] Mean post-leaching copper retentions (pcf) of successive 5-mm layers determined by x-ray fluorescence ($n$ = 3 blocks).
[c] Mean ± standard deviation. Means followed by different capital letters are significantly different (ANOVA, Duncan's Multiple-Range Test, $\alpha$ = 0.05).

TABLE 4. — *Formosan subterranean termite mortality and weight loss of southern pine wafers treated with copper naphthenate (in AWPA P9 Type A oil) and control pine wafers, in a 4-week two-choice laboratory test.*

| Target Cu retention[a] | Wood weight loss[b] CuNaph treated | Solvent control | Termite mortality[b] |
|---|---|---|---|
| (pcf) | (%) | | |
| 0.150 | 0.78 ± 0.35 A | 49.10 ± 2.50 C | 20.20 ± 6.30 A |
| 0.095 | 0.49 ± 0.13 A | 51.97 ± 4.92 C | 20.20 ± 5.41 A |
| 0.075 | 0.68 ± 0.28 A | 50.61 ± 4.98 C | 18.85 ± 3.90 A |
| 0.040 | 1.77 ± 1.10 B | 46.90 ± 2.28 C | 20.55 ± 3.67 A |

[a] Wafers used were part of the same group used in the no-choice tests. Assayed copper retentions reported in Table 1 also apply to these results.
[b] Mean ± standard deviation. Means followed by different capital letters are significantly different (ANOVA, Duncan's Multiple-Range Test, $\alpha$ = 0.05).

means separated by Duncan's Multiple-Range Test, $\alpha$ = 0.05 (19).

## Results and discussion

In general, there was close agreement between the initial calculated and assayed copper retentions in the wafers and blocks. Copper naphthenate was not readily leached out of the wood under the rigorous weathering sequence used to prepare samples for these tests, or during the termite assays (Tables 1 and 2). With either solvent system at the two highest target preservative retentions, weathering and termite exposure resulted in a maximum reduction of approximately 20 percent in copper retention. These results suggest that at the highest target copper retention evaluated of 0.150 pcf, greater than 0.100 pcf Cu can be expected to remain in pressure-treated wood even under rigorous exposure conditions.

In the no-choice termite exposure tests, termites fed less, and sustained higher mortality, on wood treated with any amount of copper naphthenate than on the solvent or untreated controls (Tables 1 and 2). A heavy oil carrier was not required for preservative efficacy. The mean weight loss due to termite feeding on pine wafers treated to the three highest retentions did not exceed 5 percent of their initial weight. This was also true of the Douglas-fir blocks treated to target retentions of 0.095 and 0.150 pcf Cu (Table 4). Chemical analyses of the outer, middle, and inner layers of wood in these blocks indicated that the Douglas-fir heartwood was more permeable than we had expected, with the corewood having 51 to 70 percent of the copper concentration in the outer layer (Table 4).

Although there was 52 to 80 percent mortality in groups of termites forced to feed on copper naphthenate-treated wood (Tables 1-3), mortality in the 28-day interval was not retention-dependent at the dosages tested. When termites were given the choice of feeding on treated wood or solvent controls, they fed almost exclusively on the controls (Table 4). In these two-choice tests, wood weight losses from termite feeding fell to less than 2 percent at the 0.040 pcf Cu target retention, and less than 1 percent at the three higher copper retentions, even though no significant termite mortality occurred.

These results indicate that these copper naphthenate treatments had insecticidal activity, but that their antifeedant properties were more important in protecting samples from termite attack during the 4-week exposure. As was observed in similar laboratory evaluations of chlorothalonil (12) and disodium octaborate tetrahydrate (14), a very minor amount of termite feeding occurred even with high preservative retentions. In contrast, termites exposed in similar tests to Douglas-fir treated with the arsenical preservative ACZA (21) or radiata pine treated with CCA (13) died within 2 weeks without any measurable feeding on the treated wood. However, electrical conductivity, effects on wood texture, and disposal requirements are also of concern to users of preserved wood (6,8), and different preservative systems may be more appropriate than others for different end uses.

Weathered pine or Douglas-fir samples treated with copper naphthenate (with or without an oil carrier) to target retentions of 0.095 or 0.150 pcf Cu sustained less than 4 percent weight losses from termite feeding in our 4-week no-choice tests, and less than 1 percent weight losses in the two-choice tests. These results indicate that copper naphthenate pressure treatments are of value in protecting wood from attack by the Formosan subterranean termite. Field evaluations have been initiated to test the applicability of these laboratory results, and to determine whether still greater protection may be obtained with higher preservative retentions.

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