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by

J. Kenneth Grace[1], Peter E. Laks[2], and Robin T. Yamamoto[1]

[1]Department of Entomology
University of Hawaii
Honolulu, Hawaii 96822-2271
USA

[2]Institute of Wood Research
Michigan Technological University
Houghton, Michigan 49931
USA

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Sweden

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J. Kenneth Grace[2], Peter E. Laks[3], and Robin T. Yamamoto[2]

[2]Department of Entomology, University of Hawaii, Honolulu, HI 96822-2271, USA
[3]Institute of Wood Research, Michigan Technological Univ., Houghton, MI 49931, USA

ABSTRACT
The fungicide chlorothalonil was evaluated as a wood preservative to prevent attack by the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Southern yellow pine wafers treated with chlorothalonil (CTL) in P9 oil, CTL + chlorpyrifos in P9 oil, or CTL in xylene were conditioned by evaporative aging at 40° C for 4 weeks and exposed to termite attack in a modified ASTM D3345 4-week laboratory test. Actual CTL retentions were assayed post-test by X-ray fluorescence, and an approximate 50% decrease in CTL concentration found from the pretest nominal CTL retentions. With all three treatments, termite feeding on wood with actual retentions of 0.05-0.10 pcf (corresponding to 0.10-0.21 pcf nominal) did not differ significantly from the respective solvent controls. CTL retentions of 0.13-0.15 pcf (0.41-0.45 pcf nominal) limited wood weight loss from termite feeding to 6-13%, and retentions of 0.26-0.39 pcf (0.81-0.94 pcf nominal) CTL resulted in only 3-4% wood weight loss. Termite mortality was correlated with CTL retention. These results demonstrate that chlorothalonil is toxic to termites, and at the appropriate retention will deter *C. formosanus* from feeding on treated wood.

KEYWORDS: *Coptotermes formosanus*, wood preservative, termite control, Rhinotermitidae, Isoptera

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1 INTRODUCTION

Chlorothalonil (CTL, tetrachloroisophthalonitrile) is a fungicide used extensively in agriculture. In the United States, it is registered for use on turfgrass and over 35 food crops. CTL is also used to control mildew in paints and coatings, and as a marine antifouling agent (Woods and Bell 1990). The fungicidal properties of CTL, relatively low mammalian toxicity (acute oral and dermal $LD_{50} > 10,000$ mg/kg), and favorable environmental characteristics (Woods and Bell 1990) have encouraged its development as a wood preservative.

The most immediate application of CTL in wood preservation may be for protection against mold and sapstain fungi, either alone or in combination with other fungicides (Micales *et al.* 1989; Laks *et al.* 1991). With fungicidal efficacy and solubility similar to pentachlorophenol (Laks 1990), CTL formulations in heavy oil are under development for use in utility poles and pilings.

In Hawaii and other tropical regions, termites are as great a threat to utility poles and other wood in service as decay fungi. Where the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), occurs, it is a more important cause of utility pole failure than fungal decay (DeGroot 1986; Tamashiro *et al.* 1990). The current study was initiated to evaluate the efficacy of CTL

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and CTL in combination with an insecticide (chlorpyrifos) in protecting wood from attack by the Formosan subterranean termite. Three pressure-impregnated formulations were evaluated in a modified ASTM D3345-74 (1986) laboratory test (identical to AWPA E1-72): CTL in P9 Type A oil, CTL (5%) + chlorpyrifos (0.3%, or 1/16 of the CTL concentration) in P9 oil, and CTL in xylene.

2 MATERIALS AND METHODS

The P9 Type A oil formulations of CTL and CTL (5%) + chlorpyrifos (0.3%) (ISK Biotech Corp., Mentor, Ohio) were diluted in toluene to achieve target CTL retentions of 0.1, 0.2, 0.4, or 0.8 pcf (pounds per cubic foot) in southern yellow pine wafers (1 x 1 x 0.25 inches, flat sawn). The pressure treatment schedule was as follows: (a) 30 minutes vacuum (25 inches Hg), (b) 60 minutes pressure (100 psi), (c) 4 hours soak (ambient conditions). Oil solvent control wafers were prepared in similar fashion. In order to evaluate the effects of CTL independent of the oil solvent system, wafers were also impregnated to these same target retentions with an experimental formulation of CTL in paraxylene, followed by rapid evaporation in a forced draft oven set at 100° C. Previous work has shown that this procedure results in a CTL gradient of approximately 2:1 between the exterior and interior equal-volume portions of 0.75 inch pine sapwood cubes (Laks, unpublished data). Xylene solvent control wafers and untreated controls were also included in the test design.

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, using the trapping technique described by Tamashiro *et al.* (1973). Termites were collected immediately before their use in the laboratory assays.

The laboratory bioassay was similar to ASTM D3345-74 (1986), except that termite mortality was recorded and the oven-dry weight loss in the test wafers was used to measure damage, rather than visual estimation. The test containers were 8 cm diameter by 10 ~~inch~~ cm high screw-top plastic jars, each containing 150 g washed and oven-dried crushed coral sand (sieved to pass a 14 US mesh screen) and 30 ml distilled water. One test wafer was placed on the surface on the damp sand, and 400 termites (360 workers and 40 soldiers) added to each jar. Five replicates of each formulation at each retention (3 formulations x 4 retentions; and oil, xylene, and untreated controls) were included. Jar lids were loosely replaced and the jars were incubated in an unlighted temperature-controlled cabinet (29 ± 0.5° C) for 4 weeks (28 days), then dismantled, and termite mortality and oven-dry wood weights recorded.

An unexpected problem was encountered during the test when all termites exposed to the treated wafers (including the oil and xylene solvent controls) died within two weeks, apparently due to toxicity of the residual solvents. At the conclusion of this four week test, no measurable feeding had occurred on any of the treated wafers. An additional weathering procedure was then employed to remove residual solvent from the test wafers, and these same wafers were again exposed to termite feeding in a second four week test. In sum, following the original treatment, the test wafers were exposed to the following weathering sequence:

(1) Evaporation of solvent in a fumehood (ambient conditions) for two weeks; xylene samples were also dried in a vacuum oven (40° C) for five days.

(2) Oven drying (90° C) for one day.

(3) Exposure to damp sand and termites for four weeks (29° C).

(4) Oven drying (90° C) for one day.

(5) Evaporative aging in a forced air draft oven (40° C) for four weeks.

(6) Oven drying (90° C) for three days, before the second four-week exposure to termites.

Following the second (and successful) four-week termite exposure, the wood samples were again oven dried (90° C) for three days, and the CTL retention (cross sectional) of each wafer was assayed by x-ray fluorescence.

Termite mortality and wood weight loss data were subjected to analysis of variance (ANOVA) and means separated by Duncan's multiple range test, $\alpha = 0.05$ (SAS Institute 1987).

3 RESULTS AND DISCUSSION

Our subsequent experience with these solvent systems (unpublished data) suggests that exposure of the test wafers to moist heat during the first unsuccessful termite assay was most important in removing the residual oil and xylene solvents. The rather lengthy weathering sequence to which the test wafers were ultimately exposed led to an approximate 50% reduction in CTL retentions (Table 1). Similar reductions in CTL content have also been noted in soil block tests for decay resistance (Laks, unpublished data), but not in tests with larger wood specimens (T.L. Woods, personal communication), suggesting that the high surface to volume ratio of the small test wafers may facilitate leaching.

Both termite mortality and feeding on the treated wood were correlated with CTL retention (Table 1). With all three CTL formulations, termite feeding on wood with assayed retentions of 0.05-0.10 pcf (corresponding to 0.10-0.21 pcf nominal) did not differ significantly from the solvent controls. CTL retentions of 0.13-0.15 pcf (0.41-0.45 pcf nominal) limited wood weight loss from termite feeding to 6-13%, and retentions of 0.26-0.39 pcf (0.81-0.94 pcf nominal) CTL resulted in only 3-4% wood weight loss. Nominal retentions of 0.31-0.81 pcf have proved effective (average AWPA termite ratings of 9.4 and 10.0) for at least three years in above-ground, termite-specific field trials in Hawaii (Woods and Bell 1990).

P9 oil alone is deterrent to termites and contributed to CTL efficacy, while slightly higher CTL retentions were required with the xylene formulation to prevent termite feeding. In this laboratory evaluation, the addition of chlorpyrifos to the oil formulation resulted in higher termite mortality, but had no significant effect on the amount of damage resulting from termite feeding. This is consistent with the results of laboratory evaluations of CTL and CTL + chlorpyrifos oil formulations against other termite species (T.L. Woods, personal communication).

TABLE 1. - Formosan subterranean termite mortality and weight loss of southern yellow pine wafers in a modified 4-week ASTM D3345-76 (1986) laboratory test. Wafers were pressure treated with chlorothalonil in P9 oil (CTL/P9 Oil), P9 oil + chlorpyrifos (CTL/CPY/P9), or xylene (CTL/Xylene).

Formulation	Retention (pcf)		Termite Mortality[3]	Wood Weight Loss[3]	
	Nominal[1]	Post-test[2]	(Percent)	Milligrams	Percent
CTL/P9 Oil	0.81	0.26	87 ± 7bc	81 ± 10a	3.5 ± 0.2
	0.41	0.14	84 ± 7b	180 ± 13ab	8.0 ± 0.2
	0.20	0.10	32 ± 3d	530 ± 29c	24.6 ± 0.6
	0.10	0.08	21 ± 3d	876 ± 53d	41.7 ± 1.3
CTL/CPY/P9	0.81	0.26	100 ± 0a	65 ± 5a	2.8 ± 0.1
	0.41	0.13	80 ± 8b	133 ± 29a	6.0 ± 0.6
	0.21	0.08	37 ± 2d	520 ± 33c	24.0 ± 0.6
	0.10	0.05	24 ± 4d	929 ± 83d	42.5 ± 1.6
CTL/Xylene	0.94	0.39	97 ± 3ab	103 ± 9a	4.3 ± 0.2
	0.45	0.15	70 ± 13b	299 ± 62b	13.4 ± 1.2
	0.21	0.08	24 ± 2d	865 ± 50d	39.9 ± 0.8
	0.11	0.05	18 ± 2d	1125 ± 31f	52.8 ± 0.7
P9 Oil Control	-	-	33 ± 4d	614 ± 68c	28.0 ± 1.4
Xylene Control	-	-	22 ± 3d	1091 ± 83ef	51.8 ± 1.0
Untreated Control	-	-	18 ± 2d	971 ± 44de	45.5 ± 4.3

[1]Average chlorothalonil retention based on weight increase due to treatment.

[2]Average post-test chlorothalonil retention assayed by x-ray fluorescence.

[3]Mean (± SEM) of five replicates. Means within a column followed by different letters are significantly different at the 0.05 level.

The results of this laboratory evaluation demonstrate that chlorothalonil is toxic to termites, and at the appropriate retention will deter Formosan subterranean termites from feeding on treated wood. Laboratory and field studies are continuing to determine the significance of the decrease in CTL content in laboratory specimens, and to refine the threshold retention required for protection from Formosan subterranean termite attack.

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