FUNGAL AND TERMITE RESISTANCE OF WOOD REACTED WITH PERIODIC ACID OR SODIUM PERIODATE

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ABSTRACT

Wood reacted with either periodic acid or sodium periodate is resistant to attack by brown- and white-rot fungi and subterranean termites in laboratory tests. Both periodic acid and sodium periodate react with wood in 2 to 4 h in aqueous solutions at room temperature. After reaction, the chemicals are leach-resistant. Periodic acid-reacted wood, after leaching, has a threshold retention of 0.26% for *Gloeophyllum trabeum* and 0.11% for *Coriolus versicolor*. Higher threshold retentions are required for sodium periodate.

Keywords: Periodic acid, sodium periodate, fungi, *Gloeophyllum trabeum, Coriolus versicolor,* wood, termite resistance.

INTRODUCTION

Protecting wood against attack by fungi and termites by methods based on modification of the cell-wall polymers has been investigated at the Forest Products Laboratory for several years (Rowell 1975, 1982, 1983). Most of this research has dealt with the bonding of reactive organic monomers to the hydroxyl groups on lignin, hemicelluloses, and cellulose (Rowell 1984a, b). More recently we have investigated chemicals that form stable complexes with cell-wall hydroxyl groups and are resistant to water-leaching.

Two chemicals that form stable complexes with wood are periodic acid and sodium periodate. Periodic acid is known to react with diols in carbohydrates, with cleavage and oxidation taking place between the two diols (Guthrie 1961). This method has been used for many years to determine carbohydrate structure (Bobbitt 1956). Even though these chemicals have been reacted with isolated carbohydrate polymers and monomers, their reactions with whole wood have not been reported.

In preliminary investigations, we found that both periodic acid and sodium periodate reacted with wood to form leach-resistant complexes. Little oxidation of the cell-wall polymers took place, as evidenced by infrared spectroscopy.

The purpose of this research was: (1) to determine the resistance of reacted wood to brown- and white-rot fungi and subterranean termites in standard laboratory tests, and (2) to study the reactions of periodic acid and sodium periodate with wood.

MATERIALS AND METHODS

Fungal evaluations

Loblolly pine or sweetgum sapwood blocks 1.9 × 1.9 × 1.9 cm (radial × tangential × longitudinal) in size were selected according to the American Society

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for Testing and Materials (ASTM 1976) standards, with three to four annual rings per centimeter. Blocks were reacted with aqueous solutions of either periodic acid or sodium periodate at six concentration levels: 1%, 0.5%, 0.25%, 0.1%, 0.05%, and 0.01% (w/w).

For each test, wood blocks were placed in a vacuum chamber for 1 h at 16 to 22 mm Hg. They were then impregnated with one of the six aqueous solutions. Blocks treated with periodic acid were soaked for 2 h, those treated with sodium periodate for 4 h. After soaking, seven blocks per treatment were dried under a hood for 1 day and then conditioned at 27 C and 30% relative humidity (RH) for 3 weeks. Another seven blocks per treatment were leached in 350 ml of distilled water daily for 2 weeks. After leaching, the leached blocks were also conditioned at 27 C and 30% RH for 3 weeks.

Soil-block fungal decay tests were run according to the ASTM standard (ASTM 1976). *Gloeophyllum trabeum,* a brown-rot fungus, was used with loblolly pine blocks, and *Coriolus versicolor,* a white-rot fungus, was used with sweetgum blocks. Five replicate blocks from each treatment and five control blocks were tested for decay resistance over a period of 12 weeks. The extent of fungal attack was determined by weight loss. Solution retention concentration that resulted in weight loss by decay of less than 2% was generally considered as the threshold retention.

Termite evaluations

Loblolly pine sapwood blocks 0.4 × 2.5 × 2.5 cm (tangential × radial × longitudinal) in size were selected according to the ASTM standards (ASTM 1974), with four to six annual rings. Blocks were reacted with aqueous solutions of either periodic acid or sodium periodate at five concentration levels: 5%, 1%, 0.5%, 0.25%, and 0.1% (w/w); in addition, 10% concentration was included for the periodic acid solution.

For each test, eight blocks were placed in a vacuum chamber for 20 min at 16 to 20 mm Hg. They were then impregnated with one of the six aqueous periodic acid or five sodium periodate solutions and soaked in the treating solution for 24 h. After soaking, four blocks per treatment were dried under a hood for 1 day and then conditioned at 27 C and 30% RH for 3 weeks. Another four blocks per treatment were leached in 200 ml of distilled water daily for 2 weeks. After leaching, the leached blocks were also conditioned at 27 C and 30% RH for 3 weeks.

Reticulitermes flavipes for this study were freshly collected at Janesville, WI. Each treated and control block was exposed to 1.0 g of termites (natural caste mixture averaging 270 undifferentiated functional workers, 1 soldier, and 0.3 nymph). Termite resistance of the treated wood was evaluated (Esenther 1977) for a period of 4 weeks. The extent of termite attack and mortality were determined by weight loss of the blocks and final live weight of the termites. Threshold retentions based on weight loss and termite mortality were determined.

Reaction time and chemical analysis

Fourteen loblolly pine blocks (1.9 × 1.9 × 1.9 cm) were placed in a vacuum chamber for 1 h at 16 to 22 mm Hg. They were then impregnated with 0.1% periodic acid solution and soaked at room temperature for 2, 8, and 24 h. After soaking, seven blocks per treatment were dried under a hood for 1 day and then

TABLE 1. *Weight loss of periodic acid- and sodium periodate-reacted wood blocks resulting from attack by two fungi.*

Treatment	Solution concentration (%)	Retention (%)[1] Loblolly pine	Retention (%)[1] Sweetgum	Weight loss (%)[2] *G. trabeum* Unleached	*G. trabeum* Leached	*C. versicolor* Unleached	*C. versicolor* Leached
Periodic acid	1.0	1.20	1.16	1.3	0.5	1.1	0.2
	0.5	0.60	0.60	0.8	0.0	0.1	0.1
	0.25	0.26	0.30	1.4	0.3	0.2	0.0
	0.1	0.12	0.11	20.4	32.1	0.2	0.1
	0.05	0.06	0.06	43.2	58.3	1.4	4.3
	0.01	0.01	0.01	61.7	56.5	23.9	27.8
Sodium periodate	1.0	1.08	1.09	1.2	0.3	0.9	0.2
	0.5	0.53	0.54	0.7	3.6	1.1	0.1
	0.25	0.26	0.29	1.9	12.3	1.1	0.6
	0.1	0.11	0.11	24.1	44.5	1.2	1.4
	0.05	0.06	0.06	48.6	57.9	8.7	12.7
	0.01	0.01	0.01	38.1	56.7	25.2	32.7
Control				61.8		35.5	

[1] Weight gain of solution before leaching; mean of 10 replicates including five unleached and five leached blocks.
[2] Mean of five replicates.

conditioned at 27 C and 30% RH for 3 weeks. Another seven blocks per treatment were leached in 350 ml of distilled water daily for 2 weeks. After leaching, the leached blocks were also conditioned at 27 C and 30% RH for 3 weeks. Five replicate blocks from each treatment and five control blocks were tested for fungal decay resistance by *G. trabeum* over a period of 12 weeks. The extent of fungal attack was determined by weight loss.

RESULTS AND DISCUSSION

Decay resistance

For wood reacted with periodic acid, threshold retention with *G. trabeum* was 0.26% in both unleached and leached blocks; with *C. versicolor,* threshold retention was 0.05% in unleached and 0.11% in leached blocks (Table 1). Leaching of periodic acid-reacted blocks did not decrease *G. trabeum* decay resistance but did decrease *C. versicolor* decay resistance.

For wood reacted with sodium periodate, threshold retention with *G. trabeum* was 0.26% for unleached blocks and 1.05% for leached blocks; with *C. versicolor,* threshold retention was 0.11% for both unleached and leached blocks (Table 1). Leaching of sodium periodate-reacted wood caused a fourfold decrease in *G. trabeum* decay resistance but did not decrease *C. versicolor* decay resistance.

For termite tests, threshold retention for periodic acid-reacted wood with *R. flavipes* was 1.4% in unleached blocks and 14% in leached blocks (Table 2). Leaching of periodic acid-treated blocks caused a tenfold decrease in termite resistance. Threshold retention for sodium periodate-reacted wood with *R. flavipes* was 6.8% for unleached blocks and was not determined for leached blocks.

The effect on weight loss of soaking loblolly pine blocks in 0.1% periodic acid solution for various times was investigated for *G. trabeum.* For control blocks, weight loss with *G. trabeum* was 61.8%. By soaking wood blocks in 0.1% periodic acid solution for 2 h, weight loss with *G. trabeum* was reduced to 32.1% (Table 3).

TABLE 2. *Weight loss of wood blocks and mortality of* R. flavipes *exposed to wood treated with periodic acid or sodium periodate.*

Treatment	Solution concentration (%)	Retention[1] (%)	Weight loss (%)[2]		Termite mortality (%)	
			Unleached	Leached	Unleached	Leached
Periodic	10	14.1	0	0	100	100
acid	5	7.05	0	1.9	100	79
	1	1.42	0	3.4	100	76
	0.5	0.71	2.4	6.4	68	64
	0.25	0.36	8.1	11.1	77	72
	0.1	0.14	12.1	6.3	71	84
Sodium	5	6.8	0	6.0	100	94
periodate	1	1.35	5.2	11.9	87	64
	0.5	0.67	10.6	10.7	61	81
	0.25	0.33	12.9	7.1	69	88
	0.1	0.14	7.2	4.9	86	70
Control			19.5		0	

[1] Weight gain of solution before leaching, mean of six replicates.
[2] Mean of three replicates.

Weight loss was further reduced from 14.6% to 5.4% as length of soaking increased from 8 to 24 h, respectively. This means that the fungal decay resistance of periodic acid-reacted wood can be improved substantially by lengthening the reaction time from 2 to 24 h.

Chemical analysis

Chemical analysis of periodic acid-reacted wood showed that periodic acid reacted with wood in the blocks within 2 h and remained in the wood even after 2 weeks of water-leaching. For example, after treatment with 0.1% periodic acid solution, chemical analysis showed 90 mole percent of periodic acid in the wood (Table 4). This means that 90 mole percent of periodic acid reacted with wood to form leach-resistant products. At 1% periodic acid solution, 114 mole percent of periodic acid was found in wood (Table 4). This more than 100% value may indicate that periodic acid is able to react with wood quickly (within 2 h) to form stable complexes with cell-wall polymers of wood. Therefore, the reaction of periodic acid with wood is not merely a deposition of periodic acid in wood. Rather, it involves bond formation between periodic acid and polymers of wood, particularly the more accessible and configurationally more favorable hemicelluloses and diols in lignin polymers. The C-2 and C-3 vicinal diols of mannopyranose-containing hemicelluloses in wood are in *cis* configuration, which is favorable for the bonding of periodic acid to these polysaccharides. At low con-

TABLE 3. *Effect of periodic acid soaking time on weight loss of wood blocks resulting from attack by* G. trabeum.

Treatment	Soaking time (h)	Weight loss from *G. trabeum* attack[1] (%)
Control	0	61.8
0.1% periodic	2	32.1
acid solution	8	14.6
	24	5.4

[1] Mean of five replicates.

TABLE 4. *Periodic acid content in reacted wood before and after water leaching.*

Periodic acid solution concentration (%)	Retention before leaching		Iodine content after leaching[1]		Molar ratio of periodic acid before and after leaching
	Weight (%)	Molar content (m moles/100 g wood)	Weight (%)	Molar content (m moles/100 g wood)	
0.01	0.01	0.044	0.021	0.165	3.75
0.1	0.12	0.527	0.06	0.473	0.90
1.0	1.21	5.308	0.77	6.067	1.14

[1] Chemically analyzed.

centration of periodic acid, there was no change in the infrared spectrum in the carbonyl region. At the 10% concentration level, a slight increase in the carbonyl region was evident. The high percentage of periodic acid found in wood even after leaching could explain why leached periodic acid-reacted blocks were as effective as unleached blocks in preventing attack by brown- and white-rot fungi. The high iodine content (0.021%) in wood being treated with 0.01% periodic acid (Table 4) may be due to a greater error in chemical analysis when the samples have a very low concentration of periodic acid.

CONCLUSIONS

Two potential new wood preservatives, periodic acid and sodium periodate, were evaluated for fungal and termite resistance in wood in laboratory tests. These potential preservatives reacted with wood in 2 to 4 h at room temperature in aqueous solutions, and the resulting periodic acid- or sodium periodate-reacted wood was resistant to water leaching as well as to attacks by brown- and white-rot fungi and to a lesser extent by subterranean termites. Periodic acid was more effective, at equal weight percentage concentration, than sodium periodate in controlling attack by fungi and termites.

Reaction of periodic acid with wood may initially involve bonding of periodate to diols of wood polymers to form stable complexes. These periodate-wood-polymer complexes are resistant to water leaching, which may be responsible for their efficacy in fungal decay resistance.

Field testing on large pine stakes is presently under way.

REFERENCES

ASTM. 1974. Standard method of laboratory evaluation of wood and other cellulosic materials for resistance to termites. D 3345-74. American Society for Testing and Materials, Philadelphia, PA.

ASTM. 1976. Standard method of testing wood preservatives by laboratory soil-block cultures. D 1413-76. American Society for Testing and Materials, Philadelphia, PA.

BOBBITT, J. M. 1956. Periodate oxidation of carbohydrates. Advances in Carbohydrate Chemistry 11:1–41.

ESENTHER, G. R. 1977. Nutritive supplement method to evaluate resistance of natural or preservative-treated wood to subterranean termites. J. Economic Entomol. 70(3):341–346.

GUTHRIE, R. D. 1961. The "dialdehydes" from the periodate oxidation of carbohydrates. Advances in Carbohydrate Chemistry 16:105–158.

ROWELL, R. M. 1975. Chemical modification of wood: Advantages and disadvantages. Proc. Am. Wood-Preservers' Assoc.

———. 1982. Wood preservation and stabilization by chemical modification of the wood substance. Chemical aspects of wood technology. Swedish Forest Products Laboratory, STFI Series A, No. 772, pp. 32–49.

———. 1983. Chemical modification of wood: A review. Vol. 6, No. 12, pp. 363–382. Commonwealth Forestry Bureau, Oxford, England.
———. 1984a. Bonding of toxic chemicals to wood. Applied Biochem. and Biotechnol. 9:447–453.
———. 1984b. Penetration and reactivity of wood cell wall components. ACS Advances in Chemistry Series 207, pp. 175–210.