Effect of Alkaline Treatment on Decay Resistance of Wood

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Abstract

Laboratory tests were undertaken to determine if decay resistance of wood could be improved by alkaline treatment without heat and if a short soaking treatment could be effective. The wood was exposed to different types of wood-degrading fungi under both low- and high-decay-promoting conditions to evaluate performance of the treated wood. Both heated and unheated alkaline-treated woods were very susceptible to white-rot and staining fungi in tests designed to simulate above-ground exposure (low decay). Heated and unheated alkaline-treated wood was equally resistant to brown-rot attack in the low-decay tests, but with ammonia-treated wood higher concentrations of base were required to obtain consistent resistance if the wood was not heated. Alkaline-treated wood was readily attacked by brown-rot fungi when ex-Dosed to a high-decay hazard via the soil-block test.

TREATING WOOD with alkali at elevated temperatures is a specialized method to protect wood used above ground (2, 3, 4). It was thought that the treatment destroyed the thiamine, a constituent in wood that is required by most wood-decaying fungi for growth (2). Above-ground exposure of ammonia-treated pine panels in field tests gave promising results after 8 years of exposure (2). The advantages of using this type of treatment are low cost, clean and paintable wood surfaces, and no hazardous chemicals left in the wood. A disadvantage was indicated by field tests: alkaline-treated wood was not durable if in contact with the soil (2).

In laboratory tests, ammonia- or sodium hydroxide-treated wood exposed to relatively low-decay-promoting conditions (low decay) was decayed by some fungi (3). In the laboratory tests the severe, or high-decay-promoting, conditions (high decay) in the soil-block method (1) for determining wood durability were not used.

Elevated temperatures are considered necessary to destroy thiamine. Recent evidence, however, indicates that the resistance imparted to wood by alkaline treatment may be caused by more than the alteration of the thiamine, and that resistance may be increased without employing heat (3, 4). Thus, if heating were not necessary to increase the decay resistance of wood, treating would be simplified and the potential for practical use greatly enhanced. The treatment might well be used to treat wood for use in exterior millwork or for wood stored above ground in chip piles where an inexpensive, clean treatment is desired to control microbiological degradation.

The objectives here were to determine whether the durability of wood could be improved by alkaline treatment without heat and whether a short soaking treatment could be effective, and to evaluate the performance of alkaline-treated wood exposed to low- and high-decay-promoting conditions and to different types of wood-degrading fungi.

Method

Blocks of wood, 1 by 1/2 by 3/8 inch with the smallest dimension in the grain direction, were air-dried at room temperature. They were then treated with aqueous solutions of ammonia, sodium hydroxide, and a mixture of sodium sulfide (3 percent) and sodium carbonate (8 percent). The Na_2S-Na_2CO_3 mixture was included because of recent interest in using it to control deterioration of wood stored in outdoor chip piles (5).

Two methods for treating were used: Vacuum impregnation, in which blocks were subjected to a vacuum of about 29 inches of mercury for 20 minutes followed by flooding with the treating solution; and soaking, in which blocks were soaked in the treating solution for 5 minutes to 4 hours.

Blocks to be heated after treatment were placed in large test tubes, the open end covered with aluminum foil, and the tubes steamed for 1 hour at 100°C.

After air-drying for at least 24 hours, NaOH- and Na_2S- Na_2CO_3-treated blocks were placed on a shaker and leached to lower the alkalinity of the wood. Before exposure to fungus attack, blocks were conditioned to equilibrium moisture content at 27°C (80°F) and 70 percent relative humidity, weighed, and steam-sterilized at 100°C for 30 minutes. At the end of the test period blocks were dried to equilibrium moisture content, under the same conditions as before exposure to fungus attack, and weighed. The loss in weight of each block indicated the extent of fungus damage.

Two exposure conditions that promote low decay and high decay were used to test the durability of the alkaline-treated wood after exposure to fungus attack.

Low-Decay-Promoting Conditions

The conditions for low decay were used to estimate how wood might perform in above-ground exposures with a minimum of extraneous nutrients. The blocks were moistened by infiltration with distilled water under

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vacuum and placed in 8-ounce French square bottles with 2 percent water-agar (w/v) above the block to maintain a humid atmosphere. The test fungi were grown on Whatman No. 1 filter paper placed over a medium prepared from the following: 15 g Nobles special agar; 10 g glucose; 2 g vitamin-free casein amino acids; 1.5 g KH_2PO_4; 0.5 g $MgSO_4 \cdot 7H_2O$; 0.57 mg H_3BO_4; 0.036 mg $MnCl_2 \cdot 4H_2O$; 0.31 mg $ZnSO_4 \cdot 7H_2O$; 0.039 mg $CuSO_4 \cdot 5H_2O$; 0.018 mg $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$; 0.015 mg $FeSO_4 \cdot 7H_2O$; and 1,000 ml distilled water.

Five-millimeter-square pieces of filter paper with the fungus culture attached were aseptically placed on the sterilized test blocks in the decay-chamber bottles. The weight loss in untreated blocks exposed under these conditions is considerably less than in untreated blocks tested by the soil-block method (3).

Blocks were exposed to fungi that produce brown and white rot.

Wood Exposed to Brown-Rot Fungi, Vaccuum-Impregnailed Blocks. — Sapwood blocks of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*), southern pine (*Pinus* sp.), and sweetgum (*Liquidambar styaciflua* L.) were vacuum impregnated with 0.1, 0.5, 1.0, 5.0, or 10.0 percent aqueous solutions of NH_3 or NaOH, with and without subsequent heating. Southern pine and sweetgum blocks were also impregnated with the aqueous Na_2S-Na_2CO_3 mixture. After treatment the Na_2S-Na_2CO_3-impregnated blocks were not heated. *Poria monticola* (Murr.) (Madison 698) was used to test the effectiveness of the different treatments in retarding brown rot. To determine whether results from alkaline-treated wood exposed to *P. monticola* were typical of brown-rot fungi, pine and Douglas-fir treated with 1 percent NaOH or 1 percent NH3 and heated were exposed to two additional brown-rot fungi, *Lenzites trabea* (Pers.) Fr. (Madison 617) and *Lentinus lepideus* (Fr.) (Madison 534).

Wood Exposed to Brown-Rot-Fungus, Soaked B1ocks. — Southern pine and Douglas-fir sapwood blocks were soaked in aqueous NH_3 (1 or 10 percent), NaOH (1 or 5 percent), and the Na_2S-Na_2CO_3 mixture for 5 minutes, 30 minutes, 1 hour, and 4 hours. Half of the NaOH- and NH_3-soaked blocks were heated after treatment. The Na_2S-Na_2CO_3-soaked blocks were not heated. ***Poria monticola*** was used as the test fungus.

Wood Exposed to White-Rot and Staining Fungi, Vacuum Impregnated. — Sweetgum sapwood blocks were impregnated under vacuum with 0.5, 1, 5, or 10 percent NH_3, 1 percent NaOH, or the Na_2S-Na_2CO_3 mixture. Half of the NH_3- and NaOH-treated blocks were heated after treatment. The Na_2S-Na_2CO_3-treated blocks were not heated. *Polyporus versicolor* (L. ex Fr.) (Madison 697) was used to determine which treatments retarded white rot in sweetgum.

The 1 percent NH_3 solution was also used to treat birch (*Betula* sp.) heartwood and southern pine and Douglas-fir sapwood at elevated temperatures. The durability of these NH_3-treated woods was determined by exposure to *P. versicolor* and the white-pocket rot *Polyporus anceps* (Pk.) (F 784-S). Further durability tests of alkaline-treated pine and sweetgum under low-decay conditions were conducted with five white-rot fungi that require thiamine and two staining fungi that do not require thiamine. These fungi were isolated from outdoor chip piles and are not yet identified. The test blocks were treated with 1 percent NH_3, 1 percent NaOH, and the Na_2S-Na_2CO_3 mixture. The NH_3-treated blocks were heated

TABLE 1. - AVERAGE WEIGHT LOSS OF HEATED AND UNHEATED AMMONIA AND SODIUM HYDROXIDE VACUUM-IMPREGNATED WOOD EXPOSED TO PORIA MONTICOLA UNDER LOW-DECAY-PROMOTING CONDITIONS.[a]

of treating solution	Percent weight loss in:[b]					
	Heated[c]			Not heated		
	Southern pine	Douglas-fir	Sweetgum	Southern pine	Douglas-fir	Sweetgum
%			AMMONIA			
0.1	16	0	0-14[d]	15	19	0-33[d]
.5	0	0	0-29[d]	0-22[d]	0-25[d]	0-7[d]
1.0	0	0	0	0-23[d]	0-27[d]	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
			SODIUM HYDROXIDE			
.1	21	0-19[d]	0-20[d]	17	0-17[d]	0-19[d]
.5	0	0	0-13[d]	0	0	0-15[d]
1.0	0	0	0	0	0	0
5.0	0	0	0	0	0	0
10.0	0	0	0	0	0	0
			CONTROL			
0	–	–	–	17	23	22

[a]Blocks tested with minimal external nutrients.

[b]At least 6 blocks per treatment in 6-week tests.

[c]100°C for 1 hour.

[d]P. monticola unable to become established on some blocks but produced significant decay in others.

Table 2. - AVERAGE WEIGHT LOSS OF WOOD SOAKED IN AMMONIA (UNHEATED) EXPOSED TO PORIA MONTICOLA UNDER LOW-DECAY-PROMOTING CONDITIONS.[a]

Soaking time	Percent weight loss[b] in treated wood[c]			
	Southern pine		Douglas-fir	
	(1 %)	(10 %)	(1 %)	(10%)
0(control)	19		25	
5minutes	17	0	0-26[d]	0
30minutes	15	0	0-12[d]	0
1hour	19	0	0	0
4hours	0	0	0	0

[a]Blocks tested with minimal external nutrients.

[b]At least 6 blocks per treatment in 8-week tests.

[c]Values in parentheses arc NH_3 concentrations.

[d]P. monticola unable to become established in some blocks but produced significant decay in others.

Table 3. - AVERAGE WEIGHT LOSS OF HEATED AND UNHEATED ALKALINE VACUUM-IMPREGNATED SWEETGUM EXPOSED TO POLYPORUS VERSICOLOR UNDER LOW-DECAY-PROMOTING CONDITIONS.[a]

Treating solution	Concentration of solution	Weight loss[b]	
		Heated[c]	Not heated
	(%)	(%)	(%)
Ammonia	0 (control)	....	27
	0.5	39	26
	1	31	30
	5	30	40
	10	27	42
Sodium hydroxide	0 (control)		27
	1	20	20
Sodium sulfide-sodium carbonate[d]	0 (control)		17
	11	....	16

[a]Blocks tested with minimal external nutrients.

[b]At least 3 blocks per treatment were used in 6-week tests.

[c]100°C for 1 hour.

[d]Eight % Na_2S and 3 % Na_2CO_3.

after treatment; the NaOH and the Na_2S-Na_2CO_3-treated blocks were not.

High-Decay-Promoting Conditions

Wood Exposed to Brown-Rot fungi, Vacuum Impregnated. — The standard ASTM soil-block test (1), in which the test block is placed on a vigorously growing fungus mycelium that, in turn, grows on a wood feeder block over soil, was used to determine the capacity of fungi to attack alkaline-treated wood under high- or severe-decay conditions. Southern pine blocks were impregnated under Vacuum with aqueous solutions of 1, 2.5, 5, and 10 percent NH_3 and NaOH. Half of the blocks were heated following treatment. Blocks were subjected to decay by *Lentinus lepidens and Poria monticola.*

Results

Low-Decay-Promoting Conditions

Wood Exposed toBrown-Rot Fungi, Vacuum Impregnated. — Southern pine and Douglas-fir blocks heated after treatment with NH_3 concentrations of 0.1 to 1.0 percent were more resistant to decay by *Poria monticola* than unheated blocks (Table 1). If not heated, blocks treated at the lower concentrations of NH_3 were quite variable in their ability to resist attack by *P. monticola,* but at the two highest concentrations of NH_3 (5 and 10 percent) freedom from attack was consistently obtained without heat In the heated and the unheated sweetgum impregnated with the various concentrations of NH_3, some blocks treated with 0.1 and 0.5 percent concentrations remained free from attack; in others the attack was similar to the untreated controls. This variability was overcome by higher concentrations of NH_3. Differences in decay resistance of heated and unheated NaOH-treated blocks were not significant. A 0.5 percent solution of NaOH prevented decay by *P. monticola* in pine and Douglas-fir, and a 1.0 percent solution was effective in sweetgum. Blocks treated with the Na_2S-Na_2CO_3, mixture were not decayed by *P. monticola.*

Southern pine and Douglas-fir blocks treated with 1.0 percent NH_3 and NaOH and heat suffered no weight losses in 6-week tests when exposed to the brown-rot fungus *Lentinus lepideus,* while weight losses of 12 and 14 percent occurred in the untreated Douglas-fir and pine, respectively. Decay was also reduced in the alkaline-treated wood exposed to the brown-rot fungus, *Lenzites trabea,* but generally the treated wood was not completely immune to attack. Weight losses in the treated wood ranged from 0 to 7 percent as compared to 14 to 18 percent in the untreated wood after 6 weeks.

Table 4. - AVERAGE WEIGHT LOSS BY POLYPORUS VERSICOLOR AND P. ANCEPS OF AMMONIA-TREATED WOOD UNDER LOW-DECAY-PROMOTING CONDITIONS.[a]

Fungus	Percent weight loss[b]					
	Birch		Southern pine		Douglas-fir	
	NH_3 + heat[c]	Control	NH_3 + heat[c]	Control	NH_3 + heat[c]	Control
Polyporus versicolor	20	12	9	12	0	0
P. anceps	17	12	8	12	11	13

[a]Blocks tested with minimal external nutrients.

[b]At least 3 blocks per treatment in 6-week tests, except southern pine inoculated with P. versicolor that was exposed for 8 weeks.

[c]Vacuum impregnated with 1% NH_3 and heated at 100°C for 1 hour.

Table 5. - AVERAGE WEIGHT LOSS AND DISCOLORATION BY WHITE ROTTERS AND WOOD STAINERS ISOLATED FROM STORED WOOD CHIPS ALKALINE-TREATED UNDER A LOW-DECAY-PROMOTING CONDITION.[a,b]

Isolate	Sweetgum treated with:						Southern pine treated with:					
	NH_3 + heat[c]	Control	NaOH[d]	Control	Na_2S–Na_2CO_3[e]	Control	NH_3 + heat'	Control	NaOH[d]	Control	Na_2S–$Na2CO_3$[e]	Control
					WEIGHTLOSSBYWHITEROTTERS(PERCENT)							
ME-461	30	18	20	14	21	15	8	12	6	7	6	7
ME-452	35	36	18	21	23	25	9	13	3	6	3	11
ME-451	26	33	8	27	16	28	8	10	2	8	2	8
ME-6	28	17	....	....	11	13	10	7	....	....	0	6
BC-10	31	16	....	....	18	15	13	8	....	....	2	4
					DISCOLORATION BY WOOD STAINERS							
B1C-13	Heavy	Heavy	....	....	Heavy	Heavy	Heavy	Heavy	....	....	None	Moderate
MC-8	do	do	....	....	do	do	do	do	....	....	None	do

[a]Blocks tested with minimal external nutrients.

[b]At least 6 blocks per treatment in 10-week tests.

[c]1 % NH_3, heated at 100°C.

[d]1 % NaOH.

[e]Mixture of 8% Na_2S and 3% Na_2CO_3.

Wood Exposed to Brown-Rot Fungus, Soaked Blocks. – No significant weight loss was produced by *Poria monticola* in southern pine and in Douglas-fir blocks that were heated after only a 5-minute soak in aqueous solutions of NaOH (1 and 5 percent) or of NH_3 (1 and 10 percent). A 5-minute soak without heating the blocks also prevented weight loss by *P. monticola* in blocks treated with aqueous solutions of 1 and 5 percent NaOH; 10 percent NH_3; and the mixture of Na_2S-Na_2CO_3. However, the results in Table 2 show that blocks not heated after treatment in 1 percent NH_3 required soaking considerably longer than 5 minutes to obtain consistent immunity to fungus attack.

Wood Exposed to White-Rot Fungi, Vacuum Impregnated. – Contrary to the results with the brown-rot fungi, treatment with the three solutions did not increase resistance of sweetgum to the white rotter, *Polyporus versicolor;* in several instances decay was increased (Table 3). Decay resistance to *P. versicolor* and *P. anceps* was also not increased in NH_3-treated birch, southern pine, and Douglas-fir (Table 4). Evidently conditions were not severe enough for *P. versicolor* to attack Douglas-fir, because there was no decay in either the treated or the untreated wood.

Five white-rot fungi and two staining fungi isolated from outdoor chip piles also degraded alkaline-treated sweetgum and southern pine (Table 5). None of the alkaline treatments significantly reduced white-rot decay in sweetgum. Decay in the NaOH- and Na_2S-Na_2CO_3-treated southern pine was apparently somewhat reduced by the treatments, but decay in the untreated controls was too low to conclude that the treatment reduced decay.

High-Decay-Promoting Conditions

Wood Exposed to Brown-Rot Fungi, Vacuum Impregnated. – Weight losses produced by the brown rotters, *Poria monticola* and *Lentinus lepideus,* in heated NH_3- and NaOH-treated pine blocks in the soil-block test were considerable (Table 6). Contrary to the low-decay-promoting test, NH_3- and NaOH-treated southern pine blocks were very susceptible to brown rot. The only significant reduction in decay was in the blocks treated with 10 percent NaOH exposed to *L. lepidens.*

Discussion

In laboratory tests to promote low decay, alkaline treatment improved decay resistance of southern pine, Douglas-fir, and sweetgum only against brown-rot fungi. When alkaline-treated southern pine was exposed to high-decay conditions via the soil-block test, it was not resistant to brown-rot fungi. In field tests ammonia-treated southern pine panels were not decay resistant when buried in the ground (2). Alkaline-treated sweetgum and southern pine were readily degraded by white-rot and staining fungi in laboratory tests to promote low decay.

Since softwoods are more prone to brown rot than to white rot in above-ground situations, a treatment that protects only against brown rot could possibly increase the decay resistance of a softwood. This might explain the improved resistance found in ammonia-treated pine panels exposed outdoors above ground in closely piled stacks (2).

Table 6. – AVERAGE WEIGHT LOSS OF VACUUM-IMPREGNATED ALKALINE-TREATEDSOUTHERNPINEEXPOSEDTOBROWN-ROT FUNGI UNDER HIGH-DECAY-PROMOTING CONDITIONS.[a]

Concentration of treating solution	Percent weight loss produced by:[b]			
	Lentinus lepideus		Poria monticola	
	NH_3 + heat[c]	NaOH + heat[c]	NH_3 + heat[c]	NaOH + heat[c]
0.0 (control)	20	20	50	54
1.0	26	23	62	64
2.5	23	15	56	65
5.0	23	16	60	64
10.0	20	9	63	60

[a]Blocks tested by soil-block method (ASTM D 2017).

[b]At least 3 blocks per treatment in 8-week test.

[c]Heated at 100°C.

Hardwoods, however, probably would not be protected by alkaline treatment because they are most frequently attacked by white rotters in hove-ground use; the results of these tests indicate that resistance of alkaline-treated hardwoods to white-rot attack is not increased by alkaline treatment. The ineffectiveness on hardwoods is probably of comparatively small practical concern, because hardwoods are not used much above ground outdoors.

Laboratory tests are convenient and serve well in screening preservative treatments. The best evaluation of the relative decay resistance of wood treated with alkali must come from field tests. The effectiveness of treatment in the field may differ due to spore inoculum rather than mycelium inoculum and to decrease in cross-sectional area of exposed wood compared to that in test blocks. Future field tests of alkaline-treated wood should include both softwood and hardwood species and, perhaps, more severe decay conditions than have been imposed in previous testing of southern pine (2).

Summary

Resistance to brown-rot attack was increased in tests promoting low-decay conditions if wood was treated with alkaline solutions by vacuum impregnation or by a 5-minute soak with or without heat. The alkaline-treated wood, however, was readily decayed if exposed to brown-rot fungi in high-decay-promoting conditions. Both heated and unheated alkaline-treated woods were degraded by white-rot and by staining fungi in low-decay-promoting tests.

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