EFFECTS OF DIFFUSION TIME AND KILN DRYING ON BORATE RETENTION IN COTTONWOOD LUMBER

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Previous studies have shown that borate diffusion treatment of softwoods is effective for long-term protection from decay fungi and insects. Other studies have shown that borate compounds have low toxicity to human beings and the environment. Diffusion treatments of lumber and wood products with borate have been extensively used in Australia, New Zealand, Europe, and North America (3, 4, 5, 7, 9).

However, some major problems need to be studied before the potential for borate as a wood preservative can be fully exploited (6). For example, borate compounds are water soluble, which allows borates to readily diffuse into wood at moisture contents above fiber saturation point (FSP); however, borates may readily leach from treated wood as water is pulled from the core to the surface of lumber during kiln drying. One possible way to limit borate leaching during kiln drying is by first air drying the wood to reduce MC.

In this paper, we examined 1) the movement of borate preservative during diffusion storage and 2) the effects of moisture content (diffusion storage time) and kiln drying on borate retention in the central core of 4/4 cottonwood lumber.

Materials

Wood Samples

Two 10-foot logs were extracted from one 18-inch dbh cottonwood tree (Populus deltoides Marsh.) from southern Illinois bottomland in September 1994. Then, two cants measuring 6" x 15" x 10' were sawn from each of the two logs and soaked in a water tank to maintain their green condition. Finally, three of these cants were each sawn, one per week for 3 consecutive weeks, into 10 sample boards (Fig. 1) measuring 1" x 4"x 9'. The fourth cant was sawn into boards for use as kiln moisture samples and as dummy boards placed between sample boards.

Preservative Solution

Approximately 150 gallons of nominal 15% boric acid equivalent (BAE) borate solution was prepared for the test by diluting 50 gallons of 45% BAE

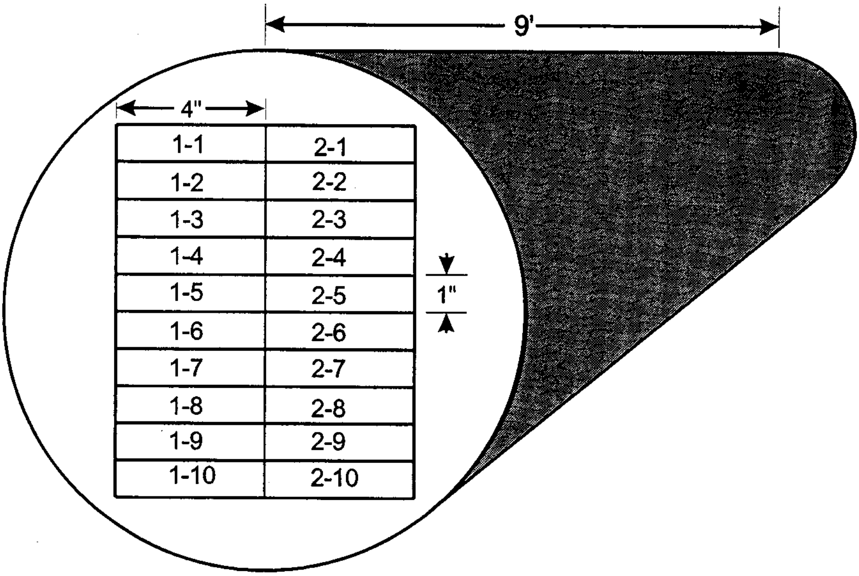

FIGURE 1. Locations of 10 sample boards per cant and two cants per log.

Diffusol[1] concentrate in 100 gallons of tap water at ambient temperature. This concentrate contained 0.11% of kathon (Hickson Corp., Conley, GA) for control of mold and mildew growth during diffusion storage.

Experimental Procedures

1. Each week, right after the 10 sample boards (1" x 4" x 9') were sawn from one cant, the green moisture content (GMC) of those boards was determined (Fig. 2).

2. The 10 sample boards per week were dipped in the borate solution for 5 minutes, then held above the treating tank for about 30 minutes to allow excess solution to drip into the treating tank.

3. These 10 sample boards were transported to the diffusion storage area and covered with a sheet of solid plastic to allow the borate to diffuse into the core of each board. Steps 1, 2, and 3 were repeated three times in three consecutive weeks.

4. Target wood MCs were 60%, 40%, and 20%, for diffusion storage times of 2, 3, and 4 weeks, respectively.

[1]The use of trade or corporation names in this article is for the information and convenience of the readers. Such use does not constitute an official endorsement or approval by the USDA Forest Service.

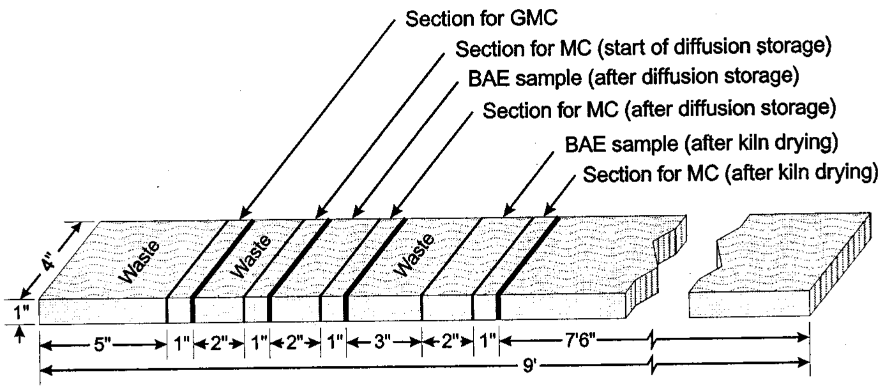

FIGURE 2. Sampling diagram for each board.

5. During diffusion storage, another sample from each board of each group of 10 boards was cut and MC determined (Fig. 2). The results were used to monitor the change of MC and adjust plastic sheets to speed up or slow down the drying rate of each group.

6. At the end of diffusion storage, sample strips for borate content and MC of each board were taken from one end of each board (Fig. 2).

7. All 30 boards of the three groups were dried together in a steam-heated experimental kiln, using the standard drying schedule T10-F5 for 4/4 cottonwood lumber (8).

8. The location of each board in the stack was randomly determined to avoid the possible difference in drying capability within the stack in the dry kiln.

9. After kiln drying, sample strips for borate content and MC of each board were taken again and the warpage of each board was also measured (1).

10. Each of the 30 borate sample strips was divided into shell and core (Fig. 3) and converted into sawdust before they were sent to the Chemical Analysis Laboratory of the University of Georgia for the analyses of boron content.

11. A series of ANOVAs and Duncan's new multiple-range tests were used to examine: 1) the effect of diffusion time on the level of penetration, 2) the combined effects of MC (diffusion time) and kiln drying on the borate retention in the central core of each board, and 3) the warpage among the 3 groups.

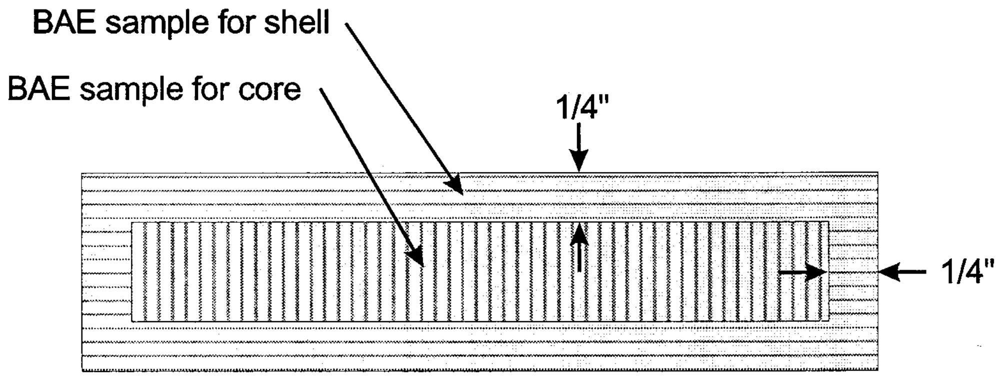

FIGURE 3. BAE samples for shell and core.

Results and Discussion

Effect of Diffusion Time on Borate Movement

The summary data in Table 1 show borate readily diffuse into 4/4 cottonwood. Within 2 weeks after dipping, the mean % BAE in cross sections (1"thick) was nearly 1.0%. This result was 2 to 3 times higher than the level attained by the 2/3" outer shell of 2" by 4" hardwood boards (northern red oak, white oak, white ash, yellow-poplar) in our earlier study (2). Also, within 2 weeks, the mean % BAE in all the core samples from the three groups reached beyond the 0.2% BAE, the level at which boards are considered to be fully treated (10). Therefore, if borate can be retained in the core during kiln drying, then the diffusion time of less than 2 weeks would be adequate to treat 4/4 cottonwood lumber.

The mean % BAE in each of the three groups for the shell was significantly higher than the mean % BAE in its corresponding core (Table 1). This finding was expected because borate ions move along a concentration gradient from the surface of each board into the central core of the board. Therefore, before the diffusion process reaches an equilibrium, the concentration of % BAE in the shell will always be higher than the concentration of % BAE in the core.

The concentration of % BAE in the core increased with diffusion time (Table 1). This result was also expected because after 2 to 4 weeks of diffusion storage, boards from all three groups still maintained a fairly steep borate concentration gradient between their shell and core. The % BAE in the core should continue to increase with diffusion time. In addition, the increase of % BAE in the cores of boards from the three groups may, in fact, be caused by the higher % BAE in the corresponding shells, because the shells also showed an increase of % BAE with diffusion time.

TABLE 1. Green moisture content and uptake of borate preservative of 4/4 cottonwood lumber.

Group	Diffusion time (week)	Green MC (%)	Time in water tank (day)	Mean percent BAE shell (%)	core	x-section
1	4	117.9	1	2.521	0.540	1.654
2	3	144.8	8	1.941	0.290	1.219
3	2	137.5	15	1.471	0.283	0.952

This brings our attention to the possible effect of GMC and/or percent heartwood on the total loading (uptake) of borate preservative during the 5-minute dipping treatment. It appeared that the total borate uptake (mean % BAE in cross sections) was inversely related to the GMC of sample boards. The phenomenon was more readily apparent in group 1 and group 2, for these two groups of sample boards were sawn from the same butt log (Fig. 1), and both groups of boards contained an approximately equal amount of heartwood. Therefore, the difference in the total borate uptake between group 1 and group 2 was attributed to the difference in GMC between the 2 groups. The nearly 27% higher MC in group 2 may dilute the borate preservative solution taken by the sample boards during the 5-minute dipping treatment.

Effects of MC and Kiln Drying on Borate Retention in the Core

There was a trend toward loss of % BAE after kiln drying for boards above the FSP (Table 2). While groups 1 and 2 appeared to have a small to moderate gain in % BAE after kiln drying, group 3, the wettest group, showed a nearly 13% loss in % BAE after kiln drying. Furthermore, the shells of boards from group 3 showed the largest gain (22.2%) in % BAE after kiln drying, compared to groups 1 and 2. These results imply that 1) borate ions moved very little in borate-treated boards with MC below FSP during kiln drying; 2) borate ions continued to move into cores from shells in boards with MC near the FSP; and 3) borate ions were pulled back to the shells from cores in boards with MC high above the FSP during kiln drying.

At the end of kiln drying, all sample boards exhibited few defects. We did not observe any visible end checks, surface checks, or collapse. There was no measurable cup among the 30 sample boards. The degree of twist and crook was also minimal. However, there was a moderate bowing, especially group 1, among the 3 groups of boards (Table 3).

TABLE 2. Mean % BAE in boards from the three MC groups before and after kiln drying.

Moisture Content (Nominal) (%)	Shell			Core		
	Before	After (% BAE)	A-B	Before	After (% BAE)	A-B
20.0 (20.0)	2.521	2.604	0.083B	0.540	0.565	0.025AB
44.8 (40.0)	1.941	2.298	0.357A	0.290	0.360	0.070A
54.4 (60.0)	1.471	1.798	0.327A	0.283	0.247	-0.036B

Values followed by the same letter within a column are not significantly different according to Duncan's new multiple-range test (p = 0.05).

TABLE 3. Mean warpage of borate treated 4/4 cottonwood lumber after kiln drying[a].

Group	Air-dried MC (%)	Kiln-dried MC (%)	Mean warpage			
			Cup	Crook	Bow (in.)	Twist
1	20.0	6.7	0A	0.12A	0.81A	0.03A
2	44.8	6.9	0A	0.02B	0.11B	0.03A
3	54.4	6.8	0A	0.09A	0.35AB	0.04A

[a] The warpage was measured on 7 1/2-foot boards. Values followed by the same letter within a column are not significantly different according to Duncan's new multiple-range test (p = 0.05).

Summary

The preliminary results showed that:

Cottonwood is an easy hardwood species to be treated with water soluble diffusible preservative.

Factors controlling borate concentration in the córe are: species, preservative loading, diffusion time, and green moisture content.

Borate treated cottonwood boards with MC lower than 40% showed little loss of borate in the core during kiln drying.

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