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# Distribution of Borates Around Point Source Injections in Dry Wood Members

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*Keywords*
Borates
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**Summary**

Sometimes, field cuts of treated wood are required. With some wood species, these cuts expose untreated wood that is subject to attack by decay fungi, unless preservatives are applied to those surfaces, The objectives of this research were to determine at time of injection and 8 weeks after injection (1) the distribution patterns of water and several preservative solutions around points of injection in several wood species and (2) the influence of glycol on the initial distribution of injected borate solutions. Solid members of northern red oak, eastern cottonwood, Southern Pine, and laminated beams of red maple or Douglas-fir were used in this investigation. The Southern Pine members were predominantly sapwood; Douglas-fir and red oak were predominantly heartwood. The other two were mill run materials. Wood moisture content at time of treatment was below the fiber saturation point. The distribution of preservative about the injection point was observed in 10 replicate units of each wood species. Results showed that the relative amount of borate that can be introduced by either pressure injection of solutions into localized depots is species dependent. We observed equivalency in loadings between pressure injection and insertion of fused borate rods for cottonwood and red maple, but a reduced loading potential for pressure-injected solutions in Douglas-fir and Southern Pine. The distribution pattern of injected borates, within 8 weeks of injection, was more influenced by wood species than by solution formulation (i.e., water or glycol), volume injected, or injection pressure. At comparable injection pressures, longitudinal penetration and injection volume were greatest in red oak, followed by cottonwood, red maple, Southern Pine, and Douglas-fir.

## Introduction

Most wood components for bridges, retaining walls, or other major transportation structures are cut or bored prior to treatment with wood preservatives. However, sometimes field cuts of treated wood are required. With some wood species, these field cuts or borings expose a core of untreated wood in the center of the treated member. This exposed core is subject to attack by decay fungi or insects, unless preservatives arc applied in the field.

The insertion of solid, fused borate rods into affected members is a technology that is gaining interest as a method for field treatment of timbers (Dietz and Schmidt 1988; Dirol 1988; McCarthy *et al.* 1993; Ruddick and Kundzewicz 1992). Dickinson (1990) regards the development of fused borate rods for *in-situ* treatments as a major advance in the use of borates. Both Dickinson (1990) and Schmidt (1990) emphasized the need to understand the moisture characteristics of wood in service as being critical to the development of effective treating practices with diffusible preservatives.

A thorough understanding of the relationship between wood moisture content and borate movement within wood remains an elusive goal. Initial concepts emphasized the principle that a rather high level of wood moisture content favored diffusion of borates within wood. Below a moisture content of about 60 percent, diffusion was perceived to slow down more and more as the wood dried (Smith and Williams 1969). Borates diffuse longitudinally through Douglas-fir heartwood at moisture content levels of about 40% or greater (Morrell *et al.* 1990). Diffusion of borates in window joinery made of *Pinus sylvestris* L. is fairly rapid, if the wood moisture content exceeded the fiber saturation point (25% to 30%) (Edlund *et al.* 1983). Dirol (1988) observed a correlation between wood moisture content and boron diffusion in several wood species. Diffusion patterns of boric acid from fused disodium octaborate rods inserted into 4-cm-thick Spruce-Pine-Fir (various species) deck boards were determined by wood moisture content (Dietz and Schmidt 1987). Good diffusion occurred when wood moisture content exceeded 25%. The limited longitudinal diffusion of borate in fir (persumably either Alpine fir or Balsam fir) was attributed to the low moisture content of that wood. Greater diffusion in Southern Pine and spruce (various species) was associated with a higher wood moisture content. Little transverse movement has been observed from borate solutions applied to lateral surfaces of Douglas-fir heartwood at low moisture content levels (Grace and Yamamoto 1994; Morrell and Freitag 1995). Morrell and Freitag (1995) concluded that with Douglas-fir, borates should be considered primarily a topical surface treatment at wood moisture content levels between 20% and 50%. In contrast, Peylo and Willeitner (1995) concluded that boron diffuses at moisture content levels even less than 20%.

Some have expressed concern that wood decay fungi can survive at a moisture content less than that needed for effective redistribution of soluble preservatives within wood (Bravery *et al.* 1990). Localized, pressure injection of solutions of diffusible preservatives into orifices placed at critical locations may mitigate this concern, if preservatives could be distributed into structurally important wood at time of application, i.e., before the wood moisture content increases to a level at which decay fungi can grow. Previously, Edlund *et al.* (1983) observed the ability of borate/glycol solution to spread in timber *(Pinus sylvestris* L.) with moisture levels below the fiber saturation point. Dirol (1988) observed a diffusion of borate applied in liquid form to a distance of a few centimeters from the point of introduction in wood that was at a moisture content of less that 25%.

The spatial distribution of the diffused borate may also be significant and seems to be species or tissue dependent. Longitudinal diffusion of borates to distances greater than 120 mm from the depot and with good lateral distribution occurred in sapwood portions of *Pinus sylvestris* joinery treated with fused borate rods and with borate/glycol solutions (Edlund *et al.* 1983). Longitudinal diffusion of borates adequate to protect *Eucalyptus obliqua* in an accelerated field simulator was only 20 to 50 mm from the fused rods (Greaves *et al.* 1982).

The objectives of our research were to determine the following for wood below the fiber saturation point, at time of injection and 8 weeks after injection:

- The distribution patterns of water and several preservative solutions around points of injection in several wood species.
- The influence of glycol on the initial distribution of injected borate solutions.
- The post-treatment distribution of injected preservatives soon after treatment.

## Materials and Methods

This investigation was conducted principally with wood members that were below the fiber saturation point and were not previously treated with preservatives. The distribution of preservative about the injection point (depot) was observed in 10 replicate units of each wood species. In addition, water and borate solutions were injected into Southern Pine members that had previously been treated with chromated copper arsenate (CCA). The purpose of these injections was to determine if preservative penetration of the transition zone between sapwood and heartwood is possible.

Solid members of northern red oak *(Quercus rubra* L.), eastern cottonwood *(Populus deltoides* Bartr. Ex Marsh., Southern Pine [most probably longleaf pine *(Pinus palustris* Mill.)], and laminated beams of red maple *(Acer rubrum* L.) or Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) were used. The 17-cm-thick oak members represented timbers of heavy construction. Southern Pine and cottonwood units (Table 1) typified dimensions of individual members of a stress-laminated bridge deck. The laminated beams, although narrower than would probably be used in a bridge, were composed of S-cm-thick laminates that would be representative of that type of construction. The Southern Pine members were predominantly sapwood; Douglas-fir and red oak were predominantly heartwood. The other two were mill run materials. All wood members except the oak had been kiln dried, stored indoors after drying, and were at a moisture content of 7% to 8% at time of treatment. The oak members had been stored indoors for approximately 1 year prior to being utilized and were at a moisture content of approximately 17% to 18% at time of treatment. A Delmhorst Instrument Co. (Towaco, Njadd) G-30[1] meter was used to determine the moisture content of the untreated wood units prior to injection. The moisture content of sapwood in the CCA-treated Southern Pine was estimated on a basis of weight loss during drying.

All units were cut to a length of 30cm (12 in. ) prior to injection treatments. All preservative treatments (Table 2) were inserted at mid-length into holes that were drilled through the narrow face of each unit (Fig. 1). Holes, 9.5-mm diameter, were drilled to depths of either 75 or 100mm and positioned equidistant from both sides of the units. Holes were drilled to a defined depth so that the void volume of the hole could be determined (Table 3). With the laminated units, the insertion hole penetrated through se-veral laminates.

No splitting occurred around the holes, either during drilling or insertion of rods, plugs, or nozzles. Solutions were injected by a nozzle pressed against commercially available fittings that were driven into the 9.5-mm-diameter holes in the wood units, Cross sections of commercially available injection fittings, which commonly contain check valves to prevent liquid from escaping after injection, are shown in Figure 2. Valves with tapered flanges were effective at sealing the hole under pressure and were used throughout this investigation. Fittings with 90° annular sealing rings were not able to hold more than a 3.4 x $10^4$ N/m$^2$ (5 psig) and were not used after preliminary trials to evaluate performance of fittings.

A MacMillan Company (Georgetown, TX) Model 101 liquid flow sensor was interfaced with an A/D (analog to digital) card in a personal computer with Labtech Notebook software to record flow rates and times. The area under the flow rate/time curves was integrated to determine the volume of liquid injected. Flow recording was terminated when the flow rate reached zero or liquid was observed exiting the cut ends of the beams.

Injection pressures used for the tests were chosen so that the maximum flow rate did not exceed 500cm$^3$min$^{-1}$, the maximum for the flow transducer. The pressure used for the Southern Pine

**Table 1.** Dimension and moisture content of test members[a] for borate injection

| Furnish | Dimension cm | cm | Moisture content (%) Mean ± standard deviation |
|---|---|---|---|
| Oak ties | 22 | 17 | 17.5 ± 7.2 |
| Red maple laminate | 18 | 7 | 8.3 ± 0.8 |
| Douglas-fir laminate | 15 | 7 | 7.4 ± 1.9 |
| Cottonwood | 14 | 5 | 7.0 ± 1.1 |
| Southern Pine | 18 | 4 | 7.6 ± 0.3 |
| CCA-treated Southern Pine | 19 | 4 | 20.1 ± 2.3 (estimated)[b] |

[a] All beams were approximately 30cm long. [b] Moisture meter is not accurate for treated wood.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

**Table 2.** Specifications of preservative treatments

| Solution | Composition[a] | Specific gravity at 20 °C |
|---|---|---|
| Dye | 0.1 % Methylene Blue in $H_2O$ | 1.00 |
| Borate | 15 % $Na_2B_8O_{13}$ in $H_2O$ (saturated) | 1.11 |
| Naphthenate | 2 % (as Cu) Copper Naphthenate in $H_2O$ | 1.03 |
| Borate/glycol | 15 % $Na_2B_8O_{13}$, 26 % ethylene glycol in $H_2O$ (saturated) | 1.16 |
| Boracol 20[b] | 16 % $Na_2B_8O_{13}$, 63 % ethylene glycol | 1.22 |
| Fused borate rods | 2.5 cm long by 0.8 cm diameter, 2.14 g $Na_2B_8O_{13}$ each | – |

[a] All $Na_2B_8O_{13}$ used to make solutions was in the form of $Na_2B_8O_{13} \cdot 4\,H_2O$. [b] Boracol 20 specifications reported by manufacturer (CSI, Harrisburg, NC)

**Table 3.** Summary of penetration results

| Species | Solution[b] | Volume ($cm^3$) Mean ± standard deviation | Hole depth[a] (cm) | Hole volume ($cm^3$) | Penetration median (cm) |
|---|---|---|---|---|---|
| Cottonwood | Dye | 14.3 ± 8.1 | 7.6 | 5.4 | > 15 |
| Cottonwood | Borate | 13.0 ± 4.3 | 7.6 | 5.4 | > 15 |
| Cottonwood | Glycol | 7.4 ± 3.0 | 7.6 | 5.4 | > 15 |
| Cottonwood | Naphthenate | 9.1 ± 4.0 | 7.6 | 5.4 | > 15 |
| Southern Pine | Dye | 10.0 ± 3.5 | 10 | 7.2 | 3.8 |
| Southern Pine | Borate | 10.0 ± 2.5 | 10 | 7.2 | 3.8 |
| Southern Pine | Glycol | 8.4 ± 1.5 | 10 | 7.2 | 3.8 |
| Southern Pine | Naphthenate | 8.2 ± 1.4 | 10 | 7.2 | 3.8 |
| Southern Pine (CCA) | Dye | 10.7 ± 4.5 | 10 | 7.2 | 3.8 |
| Southern Pine (high p)[f] | Dye | 16.5 ± 4.5 | 10 | 7.2 | 3.8 |
| Douglas-fir | Dye | 5.1 ± 0.7 | 7.6 | 5.4 | 2.5 |
| Douglas-fir | Borate | 5.4 ± 1.1 | 7.6 | 5.4 | 1.3 |
| Douglas-fir | Glycol | 5.2 ± 0.7 | 7.6 | 5.4 | 1.3 |
| Douglas-fir | Naphthenate | 3.4 ± 2.0 | 7.6 | 5.4 | 1.3 |
| Oak | Dye | 36.0 ± 9.9 | 10 | 7.2 | 3.8 |
| Oak | Borate | 18.2 ± 6.7 | 10 | 7.2 | 13 |
| Oak | Glycol | 22.2 ± 6.2 | 10 | 7.2 | 13 |
| Oak | Naphthenate | 17.9 ± 8.3 | 10 | 7.2 | > 15 |
| Red maple | Dye | 6.7 ± 1.9 | 7.6 | 5.4 | > 15 |
| Red maple | Borate | 11.0 ± 4.7 | 7.6 | 5.4 | 7.5 |
| Red maple | Glycol | 7.0 ± 1.8 | 7.6 | 5.4 | 10 |
| Red maple | Naphthenate | 6.7 ± 1.5 | 7.6 | 5.4 | > 15 |

[a] hole diameter = 0.95 cm; injector length = 3.5 cm, first 1.6 cm occluded. [b] See Table 2 for details.

and Douglas-fir was 2.1 x $10^5$ N/$m^2$ (30 psig) for all injections, except in one test with Southern Pine on the effect of pressure at 5.5 x $10^5$ N/$m^2$ (80 psig)); pressure of 1.0 x $10^5$ N/$m^2$ (15 psig) was used for the red maple and oak; and pressure of 3.4 x $10^4$ N/$m^2$ (5 psig) was used for the cottonwood. Figure 3 shows typical injection flow traces for relatively impermeable and permeable species, respectively. Traces for species that were difficult to inject showed a rapid increase in flow rate at the start of the injection followed by a rapid decrease to a flow rate of zero. The decrease in flow from permeable species was indicated by a slow (or no) return to zero, The flow diagram of relatively permeable species can also be mimicked by solution escaping through deep checks. Therefore, flow recording was also terminated when liquid was observed exiting through checks.

The specific gravity values of the injection solutions in Table 2 were determined experimentally by weighing 50$cm^3$ volumes of the solutions. The 15% solution of $Na_2B_8O_{13}$ in $H_2O$ appeared to be saturated as a result of the nearly complete dissolution of the borate.

Distribution of preservatives about the injection holes was determined at time of treatment and 8 weeks following treatment. Half (from injection hole to unit end) of each unit was crosscut into sequential 2.5-cm-thick slices within 24 hours after their respective treatments. The other half was stored at approximately 10°C (+/– 5°C) for 8 weeks prior to examination. These were stored inside a building and sheltered from exterior exposure to rain or other external sources of moisture. The cut surfaces were not protected to retard drying.

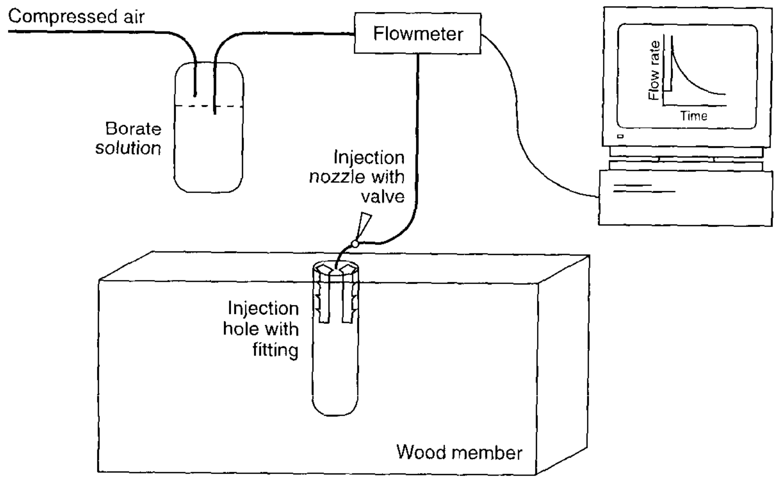


**Fig. 1.** Experimental setup

Longitudinal and lateral movements of solutions about the injection hole were determined visually on the surfaces of the cross sections that were cut, sequentially at distances of 2.5 cm from the injection point, With sections examined soon after treatment, observations were breed primarily on visual examination of liquid flow within wood without the use of additional chemical indicators. Penetration at a specific distance was indicated either by the dark colors associated with the dye and copper naphthenate solutions or by wetting of wood by the borate treatments (Table 2). Solutions of turmeric followed by a HCL/salicylic acid solution were used to indicate presence of borates (AWPA 1995a) This chemical indicator was used soon after treatment to confirm selected visual observations on a few cross sections and after 8 weeks to determine the distribution of borates within the wood in all wood samples.

Longitudinal penetration was difficult to ascertain. Sometimes, longitudinal penetration extended to the cut end by small pores or a crack, while the bulk of the fluid only penetrated a portion of the distance. The bulk flow sometimes would also diminish to a series or a few very small channels of flow with no discrete terminus. To provide some reference that would at least characterize the major differences, we recorded the maximum distance at which we observed evidence of a cone of penetration. Lateral penetration was monitored in the same manner, and it was immediately obvious that some redistribution of some solution over the cut surface of the cross sections had occurred during sawing. That redistributed material was not included in our recording of lateral distribution. Because of the difficulties in measuring the dimensions of flow, we regard the volumetric measurements to be the most quantitative. Median values are reported for observations of longitudinal flow made soon after treatment. Detailed summary statistics are given for observations that were made 8 weeks after treatment.

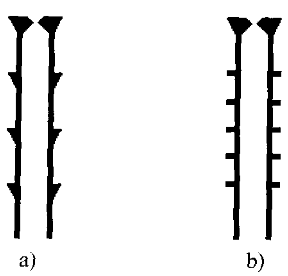


**Fig. 2.** Cross sections of sealing (a) and non-sealing (b) pressure injection fittings.

We also injected CCA-treated Southern Pine members with water and borate solutions to determine if injected liquids would penetrate the heartwood and the transition zone between sapwood and heartwood. Movement of the injected liquids into the heartwood and sapwood of the beams was again based upon visual reading of calorimetric responses. Presence of heartwood and indications of the heartwood/sapwood transition in the Southern Pine were ascertained with O-anisidine and $NaNO_2$ solutions (AWPA 1995b). A Methyl Orange solution was used with Douglas-fir (AWPA 1995b) Chrome Azurol S indicator solution (AWPA 1995a) was used to indicate the presence of copper in the CCA-treated Southern Pine sapwood.

## Results

The amount of solution injected into wood was greatest for red oak followed by cottonwood, laminated red maple, Southern Pine, and Douglas-fir (Table 3). A fluid volume of up to two times the hole volume can be injected into cottonwood and red maple, but little uptake of solution beyond the void volume of the hole occurred with Douglas-fir (Tables 3, 5). The relative differences among species in injection volumes/unit volume of injection hole were indicative, but not closely correlated, with between species differences in longitudinal penetration distance. Indeed, the distribution pattern of borates, observed 8 weeks after treatment (Table 4), seemed influenced more by wood species than by solution formulation, volume injected, or injection pressure (Table 3).

Results with red oak (Table 3) are somewhat spurious. Some red oak beams had large checks that transported or held large volumes of fluid. With the glycol formulation, longitudinal movement tended to cease when the flow path encountered a check that provided opportunity for escape of the solution to the side of the member. With the aqueous formulation, some escape to the side of the oak member occurred through these checks. However, this longitudinal flow continued, albeit without lateral spread (Fig. 4).

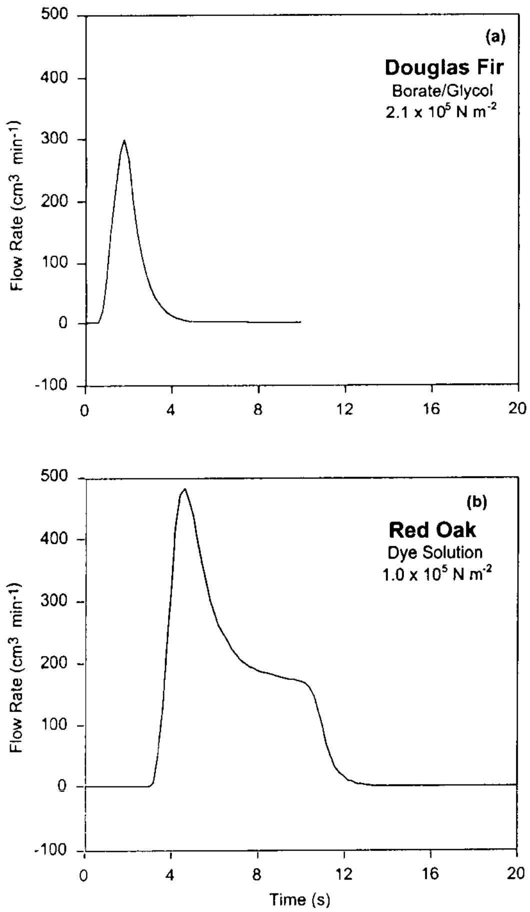


**Fig. 3.** Typical injection flow rate trace for (a) refractory species and (b) penmeable species.

A comparison of amounts of $Na_2B_8O_{13}$ that can be inserted by injection of either aqueous or glycol solutions of borates with the amount of $Na_2B_8O_{13}$ that can be inserted with a single, 0.33 by 1.0 in. (8.3 by 25.4 mm) fused borate rod is given in Table 5. The rod/fluid $Na_2B_8O_{13}$ ratio indicates the amount of preservative in the form of solid $Na_2B_8O_{13}$ that can be inserted into a 76- by 9.5-mm (3- by 0.375 -in.) hole per the amount of preservative that can be injected into the same-sized hole. Discounting results from the red oak (as a result of the large cracks) ratios ranged from 1 for cottonwood to 2.4 for Douglas-fir. With Southern Pine and Douglas-fir, injection techniques supplied about half or slightly less than 50% of the borate that is provided with a fused rod. For cottonwood and red maple, the different treatment methods introduced an equivalent amount of borate. Although the ratios, particularly for red maple and cottonwood, indicate that the presence of ethylene glycol inhibits the penetration of the borate solution, these differences are not statistically significant as indicated by the variation in mean injection volumes for each species (Table 3).

Longitudinal penetration of a slowly constricting plume of borate throughout the length of the cottonwood units was clearly evident immediately following treatment (Fig. 5) and 8 weeks after treatment in cross sections taken sequentially at 2.5 cm intervals from the injection point (depot), In other species during the 8-week interval between injection and observation, borates moved longitudinally for a few centimeters beyond the maximum penetration at time of injection.

In Southern Pine, longitudinal penetration within heartwood did not exceed 2.5cm. When longitudinal penetration was observed for the full length of the Southern Pine units, that penetration occurred within the sapwood, but not all sapwood evidenced complete longitudinal penetration. Thus, significant variation in longitudinal penetration was recorded for Southern Pine (Table 4). A significantly larger volume of water was injected into untreated Southern Pine when the injection pressure was increased to 5.5 x $10^5 N/m^2$ (80 psig) from 2.1 x $10^5 N/m^2$ (30 psig). However, the longitudinal movement of the dye solution was not observed to be different. No difference was observed between untreated and CCA-treated Southern Pine in either volume of water that could be injected or in the longitudinal penetration that was observed at injection pressures of 2.1 x $10^5 N/m^2$ (30 psig). Although penetration in the hear-

**Table 4.** Distribution of borates 8 weeks after injection

| Wood | Longitudinal movement (cm) Mean ± standard deviation | | Maximum observed width of column (cm) Mean ± standard deviation | |
|---|---|---|---|---|
| | Glycol[a] | Water[b] | Glycol | Water |
| Cottonwood | 14.7 ± 1.5 | 14.7 ± 1.5 | 1.6 ± 0.2 | 1.4 ± 0.3 |
| Southern Pine | 7.1 ± 4.2 | 4.6 ± 3.0 | 1.4 ± 0.3 | 1.3 ± 0.2 |
| Douglas-fir | 5.8 ± 4.5 | 4.8 ± 2.0 | 1.2 ± 0.3 | 1.2 ± 0.2 |
| Red maple | 14.2 ± 2.0 | 142. ± 2.0 | 1.3 ± 0.1 | 1.2 ± 0.1 |
| Red oak | 11.7 ± 4.7 | 15.2 ± 0.0 | 2.2 ± 0.6 | 2.8 ± 0.5 |

[a] Glycol solution = 15% $Na_2B_8O_{13}$ and 26% ethylene glycol in $H_2O$. [b] Water-based solution = 15% $Na_2B_8O_{13}$ in $H_2O$.

**Table 5.** Fused rod/fluid injection borate loading ratios

| Species | Injected solution | Rod/injection[a] loading ratio | Fluid/hole[b] volume ratio |
|---|---|---|---|
| Cottonwood | Borate[c] | 1.0 | 2.4 |
| Cottonwood | Glycol[d] | 1.7 | 1.4 |
| Southern Pine | Borate | 1.7 | 1.4 |
| Southern Pine | Glycol | 2.0 | 1.2 |
| Douglas-fir | Borate | 2.4 | 1.0 |
| Douglas-fir | Glycol | 2.4 | 1.0 |
| Oak | Borate | 0.9 | 2.5 |
| Oak | Glycol | 0.7 | 3.1 |
| Red maple | Borate | 1.2 | 2.0 |
| Red maple | Glycol | 1.8 | 1.3 |

[a] Ratio of mass of $Na_2B_8O_{13}$ in one fused rod to mass obtained with pressure injection of solution. [b] Ratio of volume of solution injected to void volume of hole. Hole = 0.95cm diameter, 7.5cm deep; injector length = 3.5cm, first 1.6cm occluded. [c] Borate = 15% $Na_2B_8O_{13}$ in $H_2O$. [d] Glycol = 15% $Na_2B_8O_{13}$ and 26% ethylene glycol in $H_2O$.

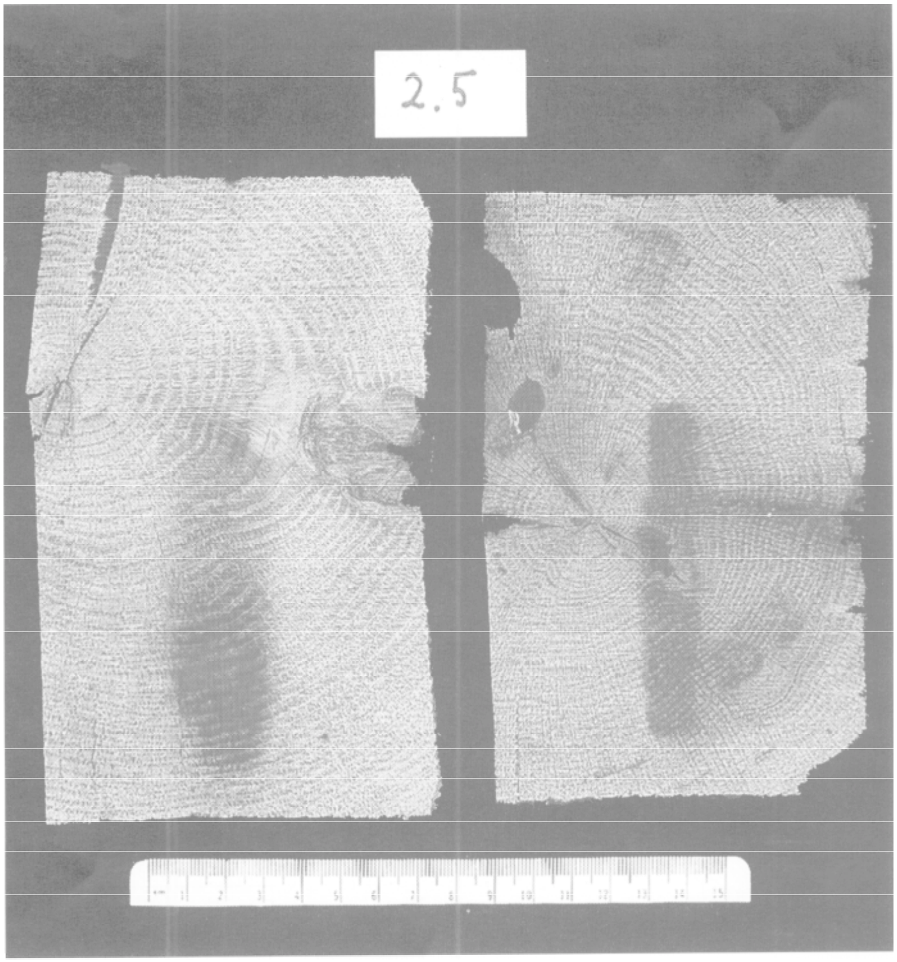


**Fig. 4.** Patterns of aqueous borate solutions in red oak. Diminished lateral distribution results when injection fluid escapes through check.

twood of Southern Pine was minimal, we gained evidence that injected borates and other solutions could penetrate the transition zone between heartwood and CCA-treated sapwood. We identified this zone by an absence of a positive reaction in both the copper and heartwood indicators.

Longitudinal penetration of injected liquids in heartwood of Douglas-fir was minimal. With both water and borate solutions, longitudinal penetration in heartwood occurred only in either latewood or the latter part of the earlywood that occurred. We observed this phenomenon in both Southern Pine and Douglas-fir.

In most cases, transverse (usually radial) penetration of the injected solutions within 1 day of injection was minimal. After 8 weeks, transverse spread of borate from the longitudinal flow path was substantially greater in oak than in any other wood (Table 4). In species other than oak, movement of only a few millimeters on either side of the flow path was observed at 8 weeks after treatment. For those species, transverse movement of the glycol solution of borate was equivalent to or slightly greater than that which occurred with the aqueous solution of borate (Table 4). In red oak, the column of borate expanded laterally to distances of 5 to more than 10mm on either side of the flow path. In oak, transverse movement of the aqueous borate solution was greater than that of the glycol formulation. With most species, maximum width usually represented only a bulbous expansion of some part of the flow pathway at a distance of 2.5 cm from the insertion hole (depot). With oak, the broadened flowage was characteristic of the depth of the flowage for nearly the entire length of observed longitudinal penetration.

Lateral displacement of the column of injected preservative as it migrated longitudinally from the depot was observed in several wood species. This was particularly striking between laminates in red maple beams (Fig. 6). Although large volumes of solution could be injected into red maple, considerable difference in longitudinal penetration of the treatment was observed among laminates.

## Discussion

In this study, we observed minimal lateral diffusion of borates along the pathway of longitudinal movement. This is consistent with results from other research on diffusion in wood of low moisture content, either from fused borate rods (Highley and Ferge 1995) inserted within the wood or

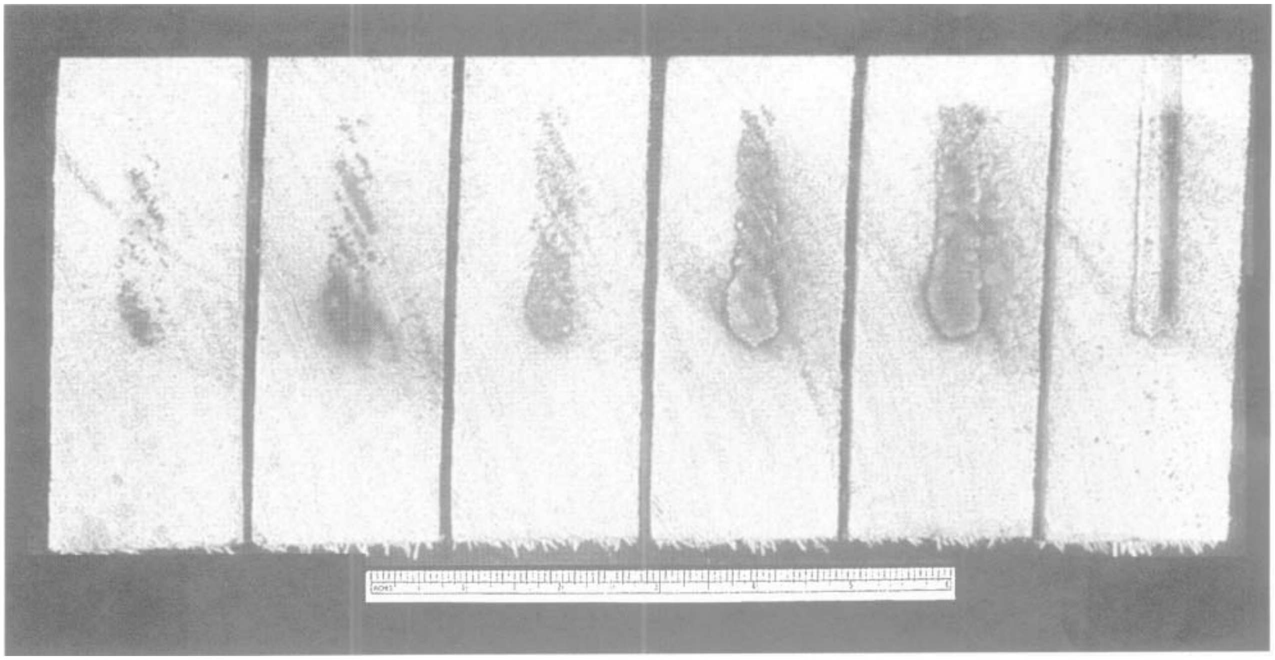

**Fig. 5.** Pattern of borate penetration (dark color) in cottonwood at sequential 2.5-cm distances from injection hole (depot) shown at right. Observation made within 24 hours of injection.

from solutions applied to one surface of a wood member (Grace and Yamamoto 1994). We observed less lateral movement in Southern Pine than did Puettmann and Williams (1992). In old pine wood at a 7% to 9% moisture content, they observed lateral diffusion of surface-applied borate/glycol solutions to a depth of 12.7 to 19.1 mm below the surface, with BAE levels that exceeded toxic thresholds for anobiid beetle larvae within the first 6.4mm from the wood surface. They also reported less penetration in new wood than in old wood.

We question whether the benefit from borate injections is substantially greater than that derived from solid rods. The limited, lateral movement of the injected borates from the longitudinal flowage of injected chemical and the potential for that entire flowage to be laterally displaced within the treated member could limit the immediate effectiveness of these treatments. Then, ultimate protection of the treated member would, as with solid-fused borate rods, depend on diffusion of the borate treatment throughout the wood. This re-emphasizes the critical importance of understanding the moisture characteristics of wood in service as a basis for obtaining success with preservative treatments that involve diffusible active ingredients.

## Conclusions

As a result of this research study, we conclude the following:

– The relative amount of borate that can be introduced by either pressure injection of solutions or insertion of fused rods into localized depots is species dependent. We observed equivalency between methods for cottonwood and red maple, but a reduced loading potential for pressure-injected solutions in Douglas-fir and Southern Pine.

The distribution pattern of injected borates, within 8 weeks of injection, is more influenced by wood species than by solution formulation, volume injected, or injection pressure.

At comparable injection pressures, longitudinal penetration and injection volume were greatest in oak, followed by cottonwood, red maple, Southern Pine, and Douglas-fir. Significant variation in permeability was evident for laminates of red maple. Radial penetration of injected solutions was greatest in red oak and minimal in cottonwood, Southern Pine, and Douglas-fir.

Pressure had a significant effect on the injection volume, but did not influence longitudinal penetration in Southern Pine.

Pressure injection of diffusible preservatives in Southern Pine may be able to provide protection to the heartwood/sapwood transition region in which CCA penetration is usually limited.

Plastic injection inserts with tapered ridges support injection pressures greater than $3.4 \times 10^4$ N/m$^2$ (5 psig).

## References

AWPA. 1995a. A3–95 Standard methods for determining penetration of preservatives and fire retardants. p. 139–144. *In*: Book of Standards. American Wood Preservers' Association, Woodstock, MD. p. 345.

AWPA. 1995b. M2–95 Standard for inspection of treated wood products. p. 222–228. *In*: Book of Standards. American Wood Preservers' Association, Woodstock, MD. p. 345.

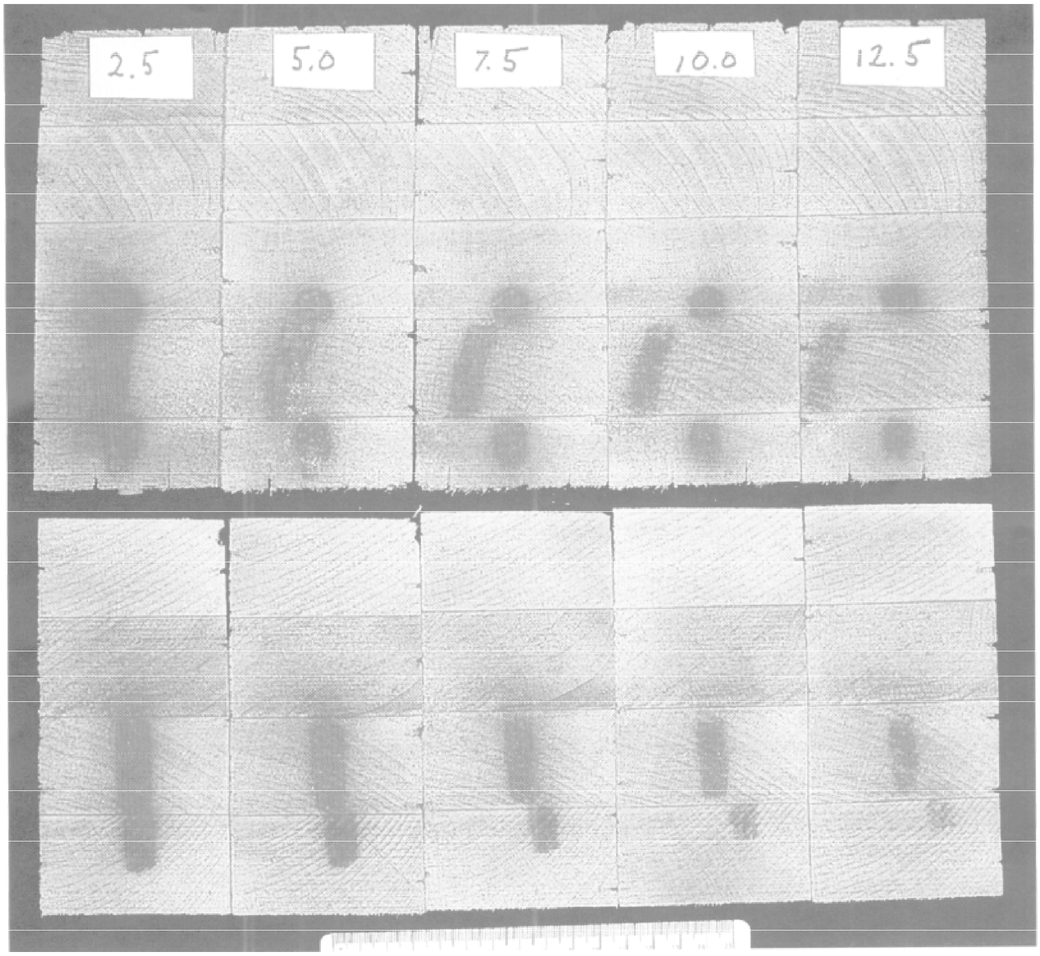


**Fig. 6.** Lateral displacement of longitudinal flow of borate solution within laminates of red maple beam.

Bravery, A.F., R.V. Berry, E.R. Miller, and R.J. Orsler. 1990. Some aspects of research protection in the timber division of the Building Research Establishment. Record of the 1990 Annual Convention of British Wood Preservation Association.

Dickinson, D.J. 1990. Remedial treatments: *in-situ* treatments and treatments of historic structures. p. 87–90. *In*: First International Conference on Wood Protection with Diffusible Preservatives. Proceedings 47355. Forest Products Research Society, Madison, WI. p. 141.

Dietz, M.G. and E.L. Schmidt. 1987. Borate rods as an on-site remedial treatment for control of decay in wood decks. J. Minnesota Academy of Sci. *53* (2), 22–26.

Dietz, M. and E. Schmidt. 1988. Fused borate and biflouride remedial treatment for controlling decay in window millwork. For. Prod. J. *38* (5), 9–14.

Dirol, D. 1988. Borate diffusion in wood from rods and liquid product application to laminated beams. International Research Group on Wood Preservation. IRG/WP/3482.

Edlund, M.L., B. Henningsson, A. Kaarik and P.E. Dicker. 1983. A chemical and mycological evaluation of fused borate rods and a borate/glycol solution treatment of window joinery. The International Research Group on Wood Preservation. IRG Secretariat, Stockholm, Sweden. Document No: IRG/WP/3225. p.36.

Grace, J.K. and R.T. Yamamoto. 1994. Simulation of remedial borate treatments intended to reduce attack on Douglas-Fir lumber by the Formosan subterranean termite (*Isoptera: Rhinotermitidae*). J. Economic Entomology *87* (6), 1547–1554.

Greaves, H., R. McCarthy, and L.J. Cookson. 1982. An accelerated field simulator trial of fused preservative rods. The Int. J. Wood Preserv. *2* (2), 69–76.

Highley, T.L. and L. Ferge. 1995. Movement of boron from fused boron rods implanted in Southern Pine, Douglas Fir, Red Oak, and White Oak timbers. The International Research Group on Wood Preservation. IRG/WP/95-30061 Paper presented 26th Annual Meeting, Helsingor, Denmark p.12.

McCarthy, K., J. Creffield, L. Cookson, and H. Greaves. 1993. Evaluation of a solid remedial wood preservative containing boron and fluorine. International Research Group on Wood Preservation. IRG/WP/93-30022.

Morrell, J.J. and C.M. Freitag. 1995. Effect of wood moisture content on diffusion of boron-based biocides through Douglas-Fir and western hemlock lumber. For. Prod. J. *45* (3), 51–55.

Morrell, J.J., C. Sexton, and A. Preston. 1990. Effect of moisture content of Douglas fir heartwood on longitudinal diffusion of boron from fused borate rods. For. Prod. J. *40* (4), 37–40.

Peylo, A. and H. Willeitner. 1995. The problem of reducing the leachability of boron by water repellents. Holzforschung *49*, 211–216.

Puettmann, M. and L. Williams. 1992. Penetration of Southern Pine floor joists by borate/glycol formulations. Wood Protection *2* (1), 29–34.

Ruddick, J. and A. Kundzewicz. 1992. The effectiveness of fused borate rods in preventing or eliminating decay in Ponderosa Pine and Douglas fir. For. Prod. J. *42* (9), 42–46.

Schmidt, E.L. 1990. Remedial decay treatment with fused borate rods: recent developments and opportunities. p. 91–92. *In*: First International Conference on Wood Protection with Diffusible Preservatives. Proceedings 47355. Forest Products Research Society. Madison, WI. p. 143.

Smith, D.N. and A.I. Williams. 1969. Wood preservation by the boron diffusion process –the effect of moisture content on diffusion time. J. Institute of Wood Sci. *22* (4), 3–10.

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