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Potential for using borate mixtures as groundline preservative pastes

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ABSTRACT

The potential for combining borates with differing degrees of water solubilities into pastes for remedial treatment of surface decay on utility poles was investigated using a small block test. Pastes containing disodium octaborate tetrahydrate (DOT) as a component tended to be most able to diffuse inward from the surface, but other borates with lower water solubilities, especially sodium tetraborate decahydrate and sodium tetraborate pentahydrate, moved inward at protective levels. Boron movement increased at the higher moisture level (60 %) and with prolonged incubation times (3 vs 6 weeks). The results suggest that combining borates with differing water solubilities would be an effective method for producing both immediate protection against fungal attack coupled with prolonged slow release to limit renewed fungal activity. Field trials are recommended to confirm these results.

1. Introduction

External decay is typically controlled by supplemental preservative paste application that arrests existing fungal attack and limits other fungi from entering the wood [1-4]. Preservative pastes provide protection for a limited period and are re-applied on a 10 to 15 year retreatment cycle, depending on the climatic conditions [5]. Most pastes contain multiple fungicides that protect the wood surface but also diffuse inward for short distances to kill existing fungi [6-9]. Copper and boron are currently among the most commonly used components in these systems [10]. Copper compounds can include copper naphthenate, copper hydroxide, and oxine copper. These compounds have limited mobility in wood and are primarily included to provide surface protection against renewed fungal attack. The most common co-biocides are usually disodium octaborate tetrahydrate (DOT) or sodium tetraborate decahydrate (NaTBT). Both compounds have high degrees of water solubility and can easily move 3 to 25 mm inward from the wood surface, inhibiting established fungal activity within wood [11-17]. While copper is a highly effective fungicide, there are increasing concerns about the potential for this metal to migrate away from poles and into the surrounding environment. One alternative is to develop pastes containing only borates with varying degrees of water solubility. This would create differential rates of boron movement and loss, potentially providing both surface and internal wood protection (Table 1). For example, zinc borate (ZnB) is widely used as a component in composite wood panels and wood plastic composites because of its ability to slowly release boron, but is not currently registered for remedial treatment applications [13]. Combinations of small amounts of fast releasing DOT with larger amounts of less soluble borates such as ZnB might provide immediate control of fungal attack followed by longer term protection against renewed fungal invasion.

The objective of this work was to assess the potential for delivering effective levels of boron into wood using borates with differing degrees of water solubility.

2. Materials and methods

Wood Preparation: Douglas-fir sapwood (*Pseudotsuga menziesii* (Mirb) Franco) lumber [nominal 50 by 100 mm by various lengths] was cut into 37.5 by 87.5 by 150 mm long pieces. No attempt was made to cut the blocks to a true radial or tangential orientation because the test primarily assesses longitudinal movement. A 37.5 mm diameter by 5 mm deep hole was drilled in the middle of one 87.5 mm wide face of each block (Figure 1). Blocks were oven dried at 50°C for 48 hours and weighed (nearest 0.01 g) before being immersed in distilled water and subjected to a 30-minute vacuum at 20 mm (Hg) followed by a one hour pressure period at 820 kPa. The samples were weighed and assigned to be conditioned to either 40% or 60% MC (as determined by the oven-dry weight) in an open laboratory area. Blocks were periodically

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*Corresponding author: jeff.morrell@oregonstate.edu weighed until the desired target weight was reached. A 40-mm square of duct tape was placed over the hole and the blocks were dipped in molten paraffin to retard moisture loss. The waxed blocks were stored in plastic bags at 5°C for 2-3 weeks to allow moisture to become more evenly distributed.

Paste Preparation: Pastes were prepared by combining a given mixture of boron compounds (totaling 47.8%) with 17.4% bentonite clay, 28.1% ethanol (95%), and water (6.7%) (w/w basis). Pastes were thoroughly mixed before being applied. A block was weighed, the duct tape was pulled back from the treatment hole, and 8 g of a given paste was added to the drilled hole. The duct tape was replaced, the blocks were placed in individual bags, and incubated at 5°C for 3 or 6 weeks.

Disodium octaborate tetrahydrate (DOT), sodium tetraborate decahydrate (NaTBD), sodium tetraborate pentahydrate (NaTBP), zinc borate (ZnB), and di-calcium hexaborate pentahydrate (CaHBP) were evaluated (Table 1). Only DOT and NaTBD are EPA registered for use as remedial paste treatments. Pastes were formulated using 100% of a given compound, as well as mixtures containing [3:1], [1:1], or [1:3] of that compound with one other compound. Overall, 51 paste combinations were examined and each combination had five replicates for both target MC.

Boron Assessment: Boron distribution was assessed on three blocks from each treatment after 3 weeks and the remaining two blocks after 6 weeks. Duct tape and paste were removed from the drilled hole. Wood around each drilled hole was cut away and the resulting block was cut into zones corresponding to 0–6, 6–13, and 13–25 mm from the surface of the drilled hole. Wood from a given zone was oven dried (50 C for 48 hours) before being ground to pass a 20-mesh screen.

Ground wood (0.5–1.0 g) was placed into a beaker with 100 ml of deionized water, heated for 30 minutes at 100°C, cooled, and filtered. Boron content in the extract was determined using the Azomethine H-Carminic acid method, as described in American

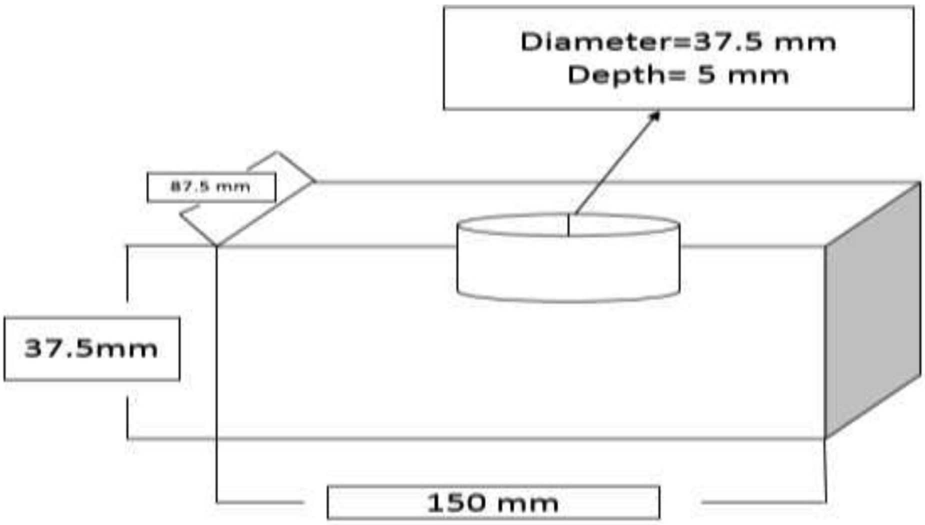

Figure 1. Diagram showing a test block with a drilled hole for paste application.

Table 1. Characteristics of boron compounds evaluated as potential groundline paste components.

Trade Name	Source	Chemical name	Elemental boron content (%)	Water solubility (%) @ 25ºC
TIMBOR	Rio Tinto Minerals (Boron, CA)	Sodium octaborate tetrahydrate (DOT)	67	~20
Borax Decahdyrate	Etimine USA INC (Pittsburgh, PA)	Sodium tetraborate decahydrate (NaTBD)	36.47	5.8
Etibor48	Etimine USA Inc	Sodium tetraborate pentahydrate (NaTBP)	47.80-49	4.4
Ulexite	Etimine USA Inc	Sodium-calcium pentaborate octahydrate (CaPDO)	37	0.76
Colemanite	Etimine USA Inc	Di-calcium hexaborate pentahydrate (CaHBP)	40	0.81
Borogard ZB	Rio Tinto Minerals	Zinc borate (ZnB)	48.05	<0.28

Wood Protection Association Standard A65-15 [18]. Values were expressed on a % Boric Acid Equivalent basis (% BAE) (% w/w).

Data Analysis: The data were subjected to an Analysis of variance (ANOVA) to examine the effects of wood MC or incubation period on boron content. Mean boron concentrations in the blocks were examined by treatment group, moisture content, and incubation time using a Tukey's honest significant difference (HSD) test (α = 0.05).

3. Results and discussion

Boron levels in the blocks were examined by time-after-treatment and distance from the surface. The threshold for protection against fungal attack differs depending on whether the wood is inside a larger beam subjected to internal decay primarily by basidiomycetous fungi, or exposed on the surface where soft rot attack would be the primary mode of failure. The threshold for protection against internal fungal attack is about 0.15% BAE, while the threshold for external protection is 0.50% BAE [19-21]. For this discussion, we used 0.5% BAE as the target threshold in the outer zone and 0.15% BAE in the second zone inward from the surface.

Boron levels in the outer 6 mm were at or above 0.5% BAE in all of the single borate treatments 3 weeks after application (Table 2, Figure 2). Boron levels were slightly higher for 60% MC blocks than those at 40% MC, although differences were small. Boron levels were highest in blocks receiving DOT, which also has the highest water solubility of the borates tested; however, boron levels in the remaining treatments were similar despite the nearly 200 fold differences in water solubility between DOT and ZnB (Table 1). Boron levels in single borate treatments increased slightly in the outer assay zone with an additional 3 weeks of incubation and, with the exception of DOT treated blocks, concentrations became less variable (Figure 3). Once again, boron levels were slightly higher in blocks at 60% moisture content in four of the six single borate treatments. The absence of a consistent difference in boron levels in the outer zone may reflect the fact that paste moisture, coupled with wood moisture, should have facilitated movement inward from the surface. We would expect most of this movement to be limited to the very outer-most portion of the 6 mm assay zone.

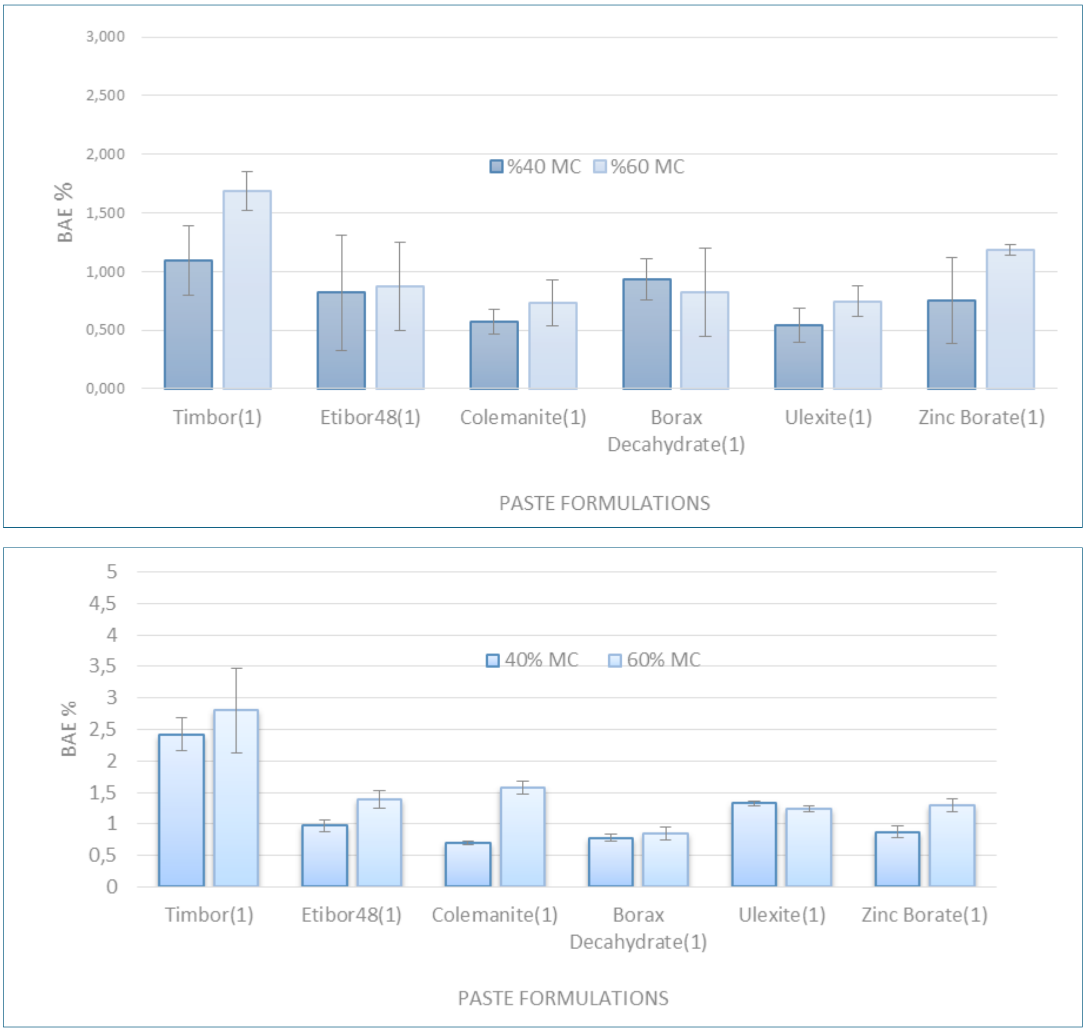

Figure 2. Boron levels 0–6 mm from the surface in Douglas-fir sapwood blocks conditioned to 40% or 60% MC, treated with one of six different paste formulations, and incubated for 3 or 6 weeks (BAE = boric acid equivalent).

Table 2. Residual boron levels 0-6 and 6-13 mm inward from the surface of Douglas-fir sapwood blocks 3-weeks after application of various boron paste combinations.[a]

Paste Components		**Ratio**	**Boron Level (% BAE)**			
Paste 1	**Paste 2**		**40% Moisture content**		**60% Moisture content**	
			0-6 mm	**6-13 mm**	**0-6 mm**	**6-13 mm**
Na-DOT	-	-	**1.09 (0.30)**	0.04 (0.01)	**1.68 (0.17)**	**0.23 (0.10)**
Na-TBD	-	-	**0.82 (0.50)**	0.01 (0.01)	**0.88 (0.38)**	0.06 (0.01)
Na-TBP	-	-	**0.57 (0.11)**	0.02 (0.02)	**0.73 (0.19)**	0.07 (0.02)
Na/CaPBO	-	-	**0.93 (0.18)**	0.05 (0.01)	**0.82 (0.38)**	0.05 (0.01)
Ca-HBP	-	-	**0.54 (0.15)**	0.02 (0.01)	**0.75 (0.13)**	0.04 (0.01)
ZnB	-	-	**0.75 (0.37)**	0.01 (0.01)	**1.18 (0.04)**	0.05 (0.01)
DOT	NaTBD	3:1	**1.02 (0.18)**	0.03 (0.02)	**1.50 (0.18)**	0.14 (0.07)
DOT	NaTBD	1:1	**1.45 (030)**	0.06 (0.03)	**1.72 (0.19)**	**0.15 (0.08)**
DOT	NaTBD	1:3	**1.15 (0.18)**	0.06 (0.02)	**1.76 (0.13)**	0.12 (0.04)
DOT	NaTBP	3:1	**1.56 (0.31)**	0.03 (0.02)	**1.87 (0.63)**	0.10 (0.05)
DOT	NaTBP	1:1	**1.74 (0.34)**	0.08 (0.04)	**1.67 (0.20)**	**0.37 (0.16)**
DOT	NaTBP	1:3	**1.56 (0.28)**	0.01 (0.01)	**1.38 (0.16)**	**0.23 (0.05)**
DOT	CaPBO	3:1	**1.22 (0.65)**	0.03 (0.01)	**1.62 (0.13)**	**0.24 (0.08)**
DOT	CaPBO	1:1	**1.52 (0.05)**	0.04 (0.01)	**1.66 (0.26)**	**0.17 (0.13)**
DOT	CaPBO	1:3	**1.57 (0.60)**	0.02 (0.01)	**1.82 (0.45)**	**0.26 (0.19)**
DOT	NaHBP	3:1	**1.97 (0.46)**	0.07 (0.03)	**1.45 (0.04)**	0.11 (0.04)
DOT	NaHBP	1:1	**1.55 (0.31)**	0.05 (0.05)	**1.60 (0.07)**	**0.22 (0.12)**
DOT	NaHBP	1:3	**1.10 (0.09)**	0.05 (0.01)	**1.59 (0.13)**	**0.17 (0.07)**
DOT	ZnB	3:1	**2.17 (0.30)**	0.11 (0.01)	**1.74 (0.46)**	**0.20 (010)**
DOT	ZnB	1:1	**1.58 (0.24)**	0.06 (0.02)	**1.79 (0.19)**	**0.23 (0.15)**
DOT	ZnB	1:3	**1.04 (0.21)**	0.04 (0.01)	**1.57 (0.15)**	**0.15 (0.06)**
NaTBP	NaTBP	3:1	0.46 (0.01)	0.01 (0.00)	**0.60 (0.10)**	0.07 (0.02)
NaTBP	NaTBP	1:1	**0.65 (0.08)**	0.03 (0.02)	**0.68 (0.17)**	0.06 (0.01)
NaTBP	NaTBP	1:3	**1.04 (0.07)**	0.03 (0.01)	0.46 (0.15)	0.07 (0.00)
NaTBP	CaPBO	3:1	**1.13 (0.41)**	0.02 (0.01)	**0.99 (0.09)**	0.05 (0.01)
NaTBP	CaPBO	1:1	**0.65 (0.18)**	0.03 (0.01)	**0.90 (0.16)**	0.07 (0.03)
NaTBP	CaPBO	1:3	**0.98 (0.33)**	0.04 (0.03)	**0.90 (0.22)**	0.08 (0.03)
NaTBP	CaHBP	3:1	**0.72 (0.21)**	0.07 (0.08)	**0.61 (0.13)**	0.06 (0.01)
NaTBP	CaHBP	1:1	**1.03 (0.48)**	0.02 (0.02)	**0.75 (0.26)**	0.06 (0.01)
NaTBP	CaHBP	1:3	0.49 (0.04)	0.02 (0.02)	**0.69 (0.19)**	0.05 (0.01)
NaTBP	ZnB	3:1	**0.67 (0.17)**	0.01 (0.01)	**0.90 (0.16)**	0.06 (0.01)
NaTBP	ZnB	1:1	**1.01 (0.35)**	0.13 (0.13)	**1.08 (0.10)**	0.05 (0.01)
NaTBP	ZnB	1:3	**0.92 (0.49)**	0.02 (0.02)	**0.96 (0.18)**	0.04 (0.01)
CaHBP	NaTBD	3:1	**0.56 (0.10)**	0.03 (002)	**0.93 (0.12)**	0.05 (0.00)
CaHBP	NaTBD	1:1	0.47 (0.10)	0.12 (0.09)	**0.80 (0.30)**	**0.15 (0.15)**
CaHBP	NaTBD	1:3	**0.70 (0.10)**	0.01 (0.01)	**0.69 (0.22)**	0.06 (0.01)
CaHBP	CaPBO	3:1	**0.70 (0.12)**	0.01 (0.01)	**0.92 (0.26)**	0.06 (0.01)
CaHBP	CaPBO	1:1	**0.66 (0.23)**	0.01 (0.01)	**0.77 (0.24)**	0.05 (0.01)
CaHBP	CaPBO	1:3	**0.67 (0.09)**	0.02 (0.01)	**1.10 (0.27)**	0.05 (0.01)
CaHBP	ZnB	3:1	**0.54 (0.05)**	0.02 (0.01)	**0.84 (0.15)**	0.06 (0.02)
CaHBP	ZnB	1:1	**0.74 (0.27)**	0.05 (0.01)	**0.72 (0.23)**	0.06 (0.01)
CaHBP	ZnB	1:3	**0.61 (0.13)**	0.02 (0.01)	**0.82 (0.18)**	0.07 (0.04)
NaTBD	ZnB	3:1	0.46 (0.20)	0.00 (0.01)	**0.74 (0.21)**	0.05 (0.01)
NaTBD	ZnB	1:1	**0.93 (0.49)**	0.03 (0.01)	**0.93 (0.11)**	0.05 (0.01)
NaTBD	ZnB	1:3	**1.06 (0.36)**	0.02 (0.01)	**0.56 (0.29)**	0.05 (0.01)
NaTBD	CaPBO	3:1	0.45 (0.20)	0.01 (0.01)	**1.24 (0.26)**	0.06 (0.01)
NaTBD	CaPBO	1:1	**0.53 (0.06)**	0.01 (0.01)	**0.89 (0.17)**	0.05 (0.01)
NaTBD	CaPBO	1:3	**0.81 (0.05)**	0.07 (0.01)	**1.59 (0.81)**	0.04 (0.01)
CaPBO	ZnB	3:1	**0.64 (0.04)**	0.04 (0.00)	**1.19 (0.18)**	0.03 (0.00)
CaPBO	ZnB	1:1	**0.71 (0.50)**	0.03 (0.02)	**0.91 (0.22)**	0.04 (0.01)
CaPBO	ZnB	1:3	0.45 (0.08)	0.01 (0.02)	**1.07 (0.11)**	0.07 (0.03)

[a] Values represent triplicate analysis of each treatment and depth combination. Values in parenthesis represent one standard deviation. Values in bold font are above the threshold for fungal protection in that sampling zone.

In addition, some of the original paste may have been inadvertently left on the block surface and then ground with the wood. While every effort was made to remove paste in the treatment hole prior to cutting, we cannot exclude the possibility that some residual paste was left behind.

Boron levels in the outer zones of blocks treated with various borate combinations followed trends similar to those found with single paste formulations (Tables 2, 3). In general, the presence of DOT in any paste was associated with boron levels in the outer zones that were above the threshold for fungal protection regardless of the ratio used or wood MC. All other borate combinations and singular pastes resulted in boron levels that were lower than those found with

DOT combinations 3 weeks after treatment, but were generally above the threshold for fungal protection. Sub-threshold levels were found with 7 borate combinations that did not contain DOT. Six of these were in blocks at 40% moisture content, illustrating the benefits of moisture on boron movement. All of the sub-threshold levels were above 0.45% BAE, suggesting boron levels were approaching threshold.

Boron levels in the outer zone of blocks receiving single paste treatments tended to increase slightly with an additional 3 weeks of incubation. The effect was more noticeable in blocks at the higher moisture content. Boron levels in the outer zones of blocks treated with combinations containing DOT tended to be similar to those containing DOT alone. Boron levels in non-DOT combination treatments also increased with prolonged incubation, although the levels were slightly lower than those found with DOT. The results indicate that boron can reach effective levels in blocks even when less water-soluble formulations are employed. The incorporation of some DOT appeared to provide a slightly higher probability of delivering adequate boron in the wood.

Boron levels 6-13 mm inward were 10 to 20 times lower than those found in the outer zone 3 weeks after application of single-component pastes, reflecting the relatively short diffusion period (Figure 3). Boron levels were higher in blocks at 60% MC, but differences were only substantial for blocks receiving DOT. Boron levels in the remaining treatments were well below 0.5% BAE and only 60% MC blocks treated with DOT alone reached the 0.15% BAE threshold for protection against internal decay. The results suggested that boron was not diffusing at substantial levels inward from the wood surface. Incubating blocks for an additional 3 weeks was associated with increased boron levels in all treatments (Figure 3, Table 3). Boron levels in blocks at 60% MC treated with only DOT were above threshold for external protection, while those at 40% MC remained below that level but above the internal decay threshold. Boron levels in the remaining treatments were all well below the threshold for protection against external decay, but approached the level for internal protection.

The trends observed with single borate pastes were also observed with the combination systems (Figure 3). Boron continued to diffuse inward over the additional six week period, especially in blocks conditioned to 60% moisture content. Boron levels in the inner zone of all DOT-containing combinations except the 3:1 DOT:NaTBD system were above the internal threshold level in blocks conditioned to 40% moisture

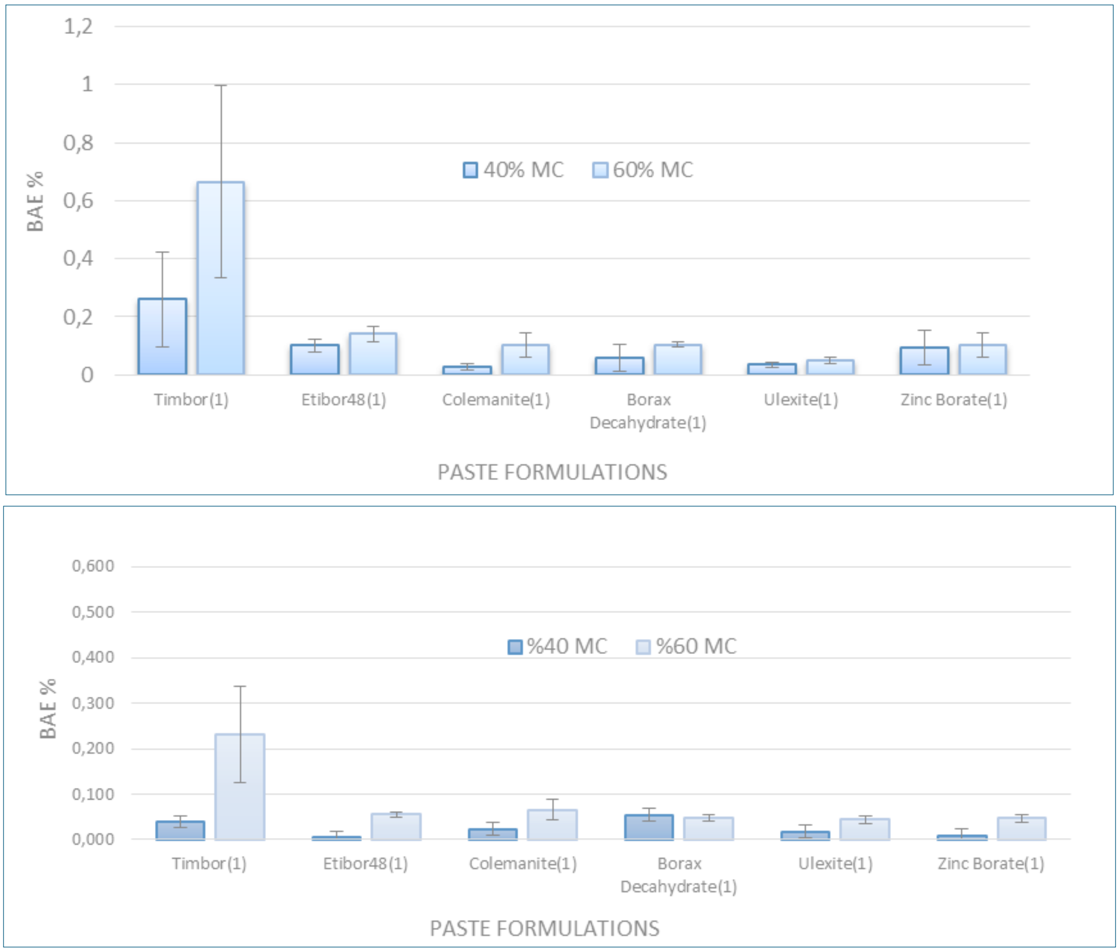

Figure 3. Boron levels 6–13 mm from the surface in Douglas-fir sapwood blocks conditioned to 40% or 60% MC, treated with one of six different paste formulations, and incubated for 3 or 6 weeks (BAE = boric acid equivalent).

Table 3. Residual boron levels 0-6 and 6-13 mm inward from the surface of Douglas-fir sapwood blocks 6-weeks after application of various boron paste combinations.

Paste Component		**Ratio**	**Boron Level (% BAE)**[a]			
Paste 1	**Paste 2**		**40% Moisture content**		**60% Moisture content**	
			0-6 mm	**6-13 mm**	**0-5 mm**	**6-13 mm**
Na-DOT	-	-	**2.42 (0.71)**	**0.26 (0.20)**	**2.80 (0.87)**	**0.67 (0.41)**
Na-TBD	-	-	**0.97 (0.01)**	0.10 (0.03)	**1.39 (0.09)**	0.14 (0.03)
Na-TBP	-	-	**0.70 (0.10)**	0.03 (0.02)	**1.81 (0.32)**	0.07 (0.02)
Na/CaPBO	-	-	**0.78 (0.05)**	0.06 (0.07)	**0.85 (0.18)**	0.10 (0.01)
Ca-HBP	-	-	**1.33 (0.54)**	0.03 (0.01)	**1.24 (0.11)**	0.05 (0.010
ZnB	-	-	**0.87 (0.07)**	0.09 (0.09)	**1.30 (0.27)**	0.10 (0.06)
DOT	NaTBD	3:1	**1.92 (0.20)**	0.14 (0.06)	**2.68 (0.48)**	**0.67 (0.51)**
DOT	NaTBD	1:1	**1.96 (0.22)**	**0.34 (0.23)**	**2.72 (0.37)**	**0.44 (0.31)**
DOT	NaTBD	1:3	**2.12 (0.84)**	**0.25 (0.10)**	**2.08 (0.45)**	**0.67 (0.12)**
DOT	NaTBP	3:1	**2.57 (0.33)**	**0.38 (0.45)**	**4.06 (1.04)**	**0.39 (0.18)**
DOT	NaTBP	1:1	**2.49 (0.57)**	**0.22 (0.12)**	**3.38 (1.53)**	**0.40 (0.19)**
DOT	NaTBP	1:3	**2.22 (0.72)**	**0.29 (0.15)**	**2.07 (0.63)**	**0.34 (0.28)**
DOT	CaPBO	3:1	**2.64 (0.95)**	**0.23 (0.27)**	**2.78 (1.57)**	**0.78 (0.33)**
DOT	CaPBO	1:1	**2.45 (0.47)**	**0.41 (0.37)**	**2.00 (0.35)**	**0.36 (0.07)**
DOT	CaPBO	1:3	**1.64 (0.44)**	0.12 (0.07)	**1.72 (0.97)**	**0.25 (0.10)**
DOT	NaHBP	3:1	**2.62 (0.27)**	**0.20 (0.12)**	**2.68 (0.53)**	**0.65 (0.24)**
DOT	NaHBP	1:1	**2.02 (0.22)**	**0.38 (0.33)**	**3.06 (0.82)**	**0.58 (0.44)**
DOT	NaHBP	1:3	**2.04 (0.62)**	**0.16 (0.08)**	**2.03 (0.76)**	**0.28 (0.31)**
DOT	ZnB	3:1	**2.02 (0.27)**	**0.22 (0.030**	**3.45 (1.04)**	**0.24 (0.08)**
DOT	ZnB	1:1	**2.53 (0.58)**	**0.15 (0.02)**	**2.37 (0.21)**	**0.37 (0.13)**
DOT	ZnB	1:3	**2.01 (0.32)**	**0.19(0.10)**	**1.83 (0.60)**	**0.37 (0.14)**
NaTBP	NaTBP	3:1	**1.33 (0.23)**	0.09 (0.02)	**1.36 (0.05)**	**0.17 (0.15)**
NaTBP	NaTBP	1:1	**1.24 (0.01)**	0.09 (0.07)	**2.29 (0.38)**	0.09 (0.04)
NaTBP	NaTBP	1:3	**1.13 (0.00)**	0.06 (0.08)	**1.37 (0.11)**	0.10 (0.02)
NaTBP	CaPBO	3:1	**1.05 (0.02)**	0.01 (0.00)	**1.47 (0.52)**	0.08 (0.05)
NaTBP	CaPBO	1:1	**1.08 (0.03)**	0.04 (0.02)	**1.42 (0.15)**	0.08 (0.01)
NaTBP	CaPBO	1:3	**1.14 (0.08)**	0.04 (0.01)	**1.44 (0.75)**	0.14 (0.10)
NaTBP	CaHBP	3:1	**1.22 (0.40)**	0.05 (0.01)	**1.38 (0.30)**	0.13 (0.03)
NaTBP	CaHBP	1:1	**1.11 (0.11)**	0.05 (0.04)	**1.68 (0.81)**	**0.30 (0.00)**
NaTBP	CaHBP	1:3	**1.21 (0.01)**	0.04 (0.01)	**1.36 (0.24)**	0.10(0.03)
NaTBP	ZnB	3:1	**1.60 (0.42)**	0.05 (0.02)	**1.29 (0.21)**	**0.20 (0.20)**
NaTBP	ZnB	1:1	**1.12 (0.14)**	0.06 (0.02)	**1.39 (0.24)**	0.12 (0.03)
NaTBP	ZnB	1:3	**1.52 (0.05)**	0.06 (0.02)	**1.62 (0.37)**	**0.26 (0.07)**
CaHBP	NaTBD	3:1	**1.10 (0.00)**	0.08 (0.07)	**1.40 (0.06)**	0.13 (0.01)
CaHBP	NaTBD	1:1	**1.08 (0.44)**	0.13 (0.16)	**1.78 (0.72)**	**0.26 (0.10)**
CaHBP	NaTBD	1:3	**1.12 (0.18)**	0.11 (0.08)	**0.91 (0.60)**	0.12 (0.02)
CaHBP	CaPBO	3:1	**1.18 (0.28)**	0.08 (0.01)	**1.18 (0.04)**	0.14 (0.06)
CaHBP	CaPBO	1:1	**0.95 (0.16)**	0.02 (0.02)	**1.07 (0.03)**	0.12 (0.05)
CaHBP	CaPBO	1:3	**1.01 (0.41)**	0.03 (0.00)	**1.20 (0.13)**	0.07 (0.00)
CaHBP	ZnB	3:1	**1.27 (0.47)**	0.06 (0.07)	**1.38 (0.14)**	0.06 (0.01)
CaHBP	ZnB	1:1	**0.75 (0.03)**	0.09 (0.12)	**1.34 (0.06)**	**0.15 (0.05)**
CaHBP	ZnB	1:3	**0.77 (0.04)**	0.01 (0.01)	**1.23 (0.31)**	0.06 (0.01)
NaTBD	ZnB	3:1	**1.18 (0.34)**	0.09 (0.05)	**1.13 (0.28)**	0.09 (0.03)
NaTBD	ZnB	1:1	**1.41 (0.32)**	0.05 (0.01)	**1.39 (0.16)**	**0.18 (0.05)**
NaTBD	ZnB	1:3	**1.50 (0.08)**	0.06 (0.05)	**1.27 (0.24)**	0.13 (0.04)
NaTBD	CaPBO	3:1	**0.95 (0.01)**	0.05 (0.06)	**1.42 (0.15)**	0.12 (0.08)
NaTBD	CaPBO	1:1	**0.97 (0.28)**	0.06 (0.08)	**1.73 (0.81)**	0.13 (0.03)
NaTBD	CaPBO	1:3	**1.21 (0.17)**	0.03 (0.02)	**1.59 (0.35)**	0.06 (0.00)
CaPBO	ZnB	3:1	**1.11 (0.15)**	0.03 (0.00)	**1.28 (0.20)**	0.07 (0.05)
CaPBO	ZnB	1:1	**1.06 (0.37)**	0.04 (0.04)	**1.81 (0.84)**	0.11 (0.00)
CaPBO	ZnB	1:3	**1.24 (0.45)**	0.05 (0.05)	**1.79 (0.66)**	0.14 (0.00)

[a] Values represent duplicate analyses of each treatment depth combination. Values in parenthesis represent one standard deviation. Values in bold font are above the threshold for fungal protection in that sampling zone.

content, and the one lower level was just shy of the threshold. Boron levels in blocks conditioned to 60% MC and treated with DOT-containing combinations were all above the internal threshold and five of 15 treatments were over the threshold for protection against external fungal attack. Boron levels in blocks conditioned to 40% MC and treated with the remaining paste combinations were all below the threshold; however, there was evidence of further boron diffusion in blocks conditioned to 60% moisture content. Boron levels in blocks receiving NaTBP and NaTBD, CaHBP or ZnB, as well as treatments with ZnB and CaHBP or NaTBP were above the threshold, although there was no consistent trend with regard to ratios of the two components in each test. The short-term nature of this test and low replication make it difficult to further delineate treatment differences.

While all of the compounds tested were capable of delivering an effective amount of boron to the outer 6 mm of wood, relatively few were capable of releasing biologically effective amounts of boron to diffuse further inward. Most of the more effective combinations contained DOT, which also has the highest water solubility of the compounds tested. However, boron was present at effective levels away from the surface in blocks treated with less water-soluble boron compounds when the blocks were conditioned to the higher moisture content. Moisture is clearly critical for boron release from borate systems as well as for diffusion into wood [22]. Moisture contents of wood in soil contact are generally above the fiber saturation point (i.e. >30 % moisture content) except in drier parts of the country, although exact moisture levels are generally not studied. External preservative pastes are generally designed to provide surface protection against fungal attack, and have little effect on fungi established further into the wood. As a result, the limited diffusion within the test period may not affect efficacy of the system. The goal of using borates with differing solubilities was to take advantage of wood moisture content to effect differential rates of boron release and diffusion. In practice, DOT would rapidly solubilize and diffuse into the wood to arrest existing fungal attack. Less soluble borate would stay nearer the surface slowly releasing boric acid that would be available to limit renewed fungal attack. The less soluble borate would perform a role similar to that provided by copper in the existing paste systems. Previous field trials suggest that most external preservative pastes remain at effective levels in wood for 3 to 5 years after application. Wood remains protected because the sub-threshold levels slow recolonization until the next treatment cycle. The results of these tests suggest borate mixtures may be able to produce a similar effect for wood in service.

4. Conclusions

Pastes containing borate compounds with differing solubilities produced reasonable boron movement into the outer 6 mm of wood, but were more variable further inward. Pastes with DOT as a component produced the best results, but levels were also acceptable in blocks treated with several pastes containing less water-soluble boron compounds. The results suggest further tests are warranted to delineate paste ratios that deliver rapid boron movement to arrest fungal attack coupled with slower diffusion to maintain protection for longer periods.

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