Durability Performance of Boron/Copper Naphthenate Dual-Treated Queensland Maple (*Flindersia brayleyana*)

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Abstract

The potential for using a disodium octaborate tetrahydrate and oil-borne copper naphthenate dual dip treatment to protect timber in aboveground exposures was assessed on Queensland maple (*Flindersia brayleyana*). Boron penetration was complete 2 weeks after treatment and boron levels continued to increase in the center of the samples over a 12-week diffusion period. The use of higher boron concentrations enhanced uptakes, but prolonged dipping times produced smaller gains in uptake. Preliminary results from field trials in an aboveground decay test suggest that the dual treatments are performing slightly better than boron alone, but the results are still early. Further assessments are planned.

Australia has many tree species with durable heartwoods (Bootle 1983, Standards Australia 2022), but many others are characterized by less durable, impermeable heartwoods that resist preservative treatment. The inability to treat the heartwood of these species to meet 5-mm minimum preservative penetration in the heartwood as described in standard AS/NZS1604 precludes their use in exterior applications (Standards Australia 2021).

Developing alternative protection methods would expand market opportunities for these species. One possible approach to overcoming the treatment challenges is dual dip treatment where the freshly cut wood is first treated with a water-soluble preservative, allowed to season, and then treated with an oil-soluble system. Boron is an ideal system for the initial treatment because of its activity against both fungi and insects as well as its ability to diffuse through wet timber (Carr 1959, Smith and Williams 1969, Cockcroft and Levy 1973, Barnes et al. 1989, Amburgey et al. 2003), but it leaches out of timber exposed in high-moisture applications (Lloyd 1995). Using an oil-soluble overcoat may help to prevent or at least slow leaching of boron from the timber. First tested in Malaysia (Arthur and Kim 2024) and then commercialized in North America, a dual treatment approach has been used successfully for over 20 years for treating railway sleepers. Amburgey et al. (2003) and Amburgey and Sanders (2007, 2009) dipped freshly cut railway sleepers in concentrated solutions of disodium octaborate tetrahydrate (DOT) and then proceeded to the normal air-seasoning process. Seasoned ties were pressure treated with either creosote or oil-borne copper naphthenate and installed in track in a high-decay hazard zone in the southeastern United States where they performed exceptionally well. Subsequently, the dual treatment process was widely adopted by the US mainline railroads. Dual treatment has several benefits. First, the borate treatment limits the development of decay during air seasoning

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(Schoeman et al. 1997), resulting in sounder timbers before treatment. The overtreatment may then help provide some protection against in-service leaching of the boron or have some other synergistic effect that improves the performance of the dual-treated timber. This approach has also been used with copper naphthenate as a pastelike, groundline treatment for southern pine posts (Amburgey and Freeman 1993) and as a follow-on treatment on bridge timbers (Lloyd et al. 2017, 2020). Copper naphthenate topical treatment performance has been reported in Cookson's (2013) 40-year field test report and dual treatment with borate might also be feasible for Australian timbers, but there are no recent reports on the application of this approach.

The objective of this study was to examine boron movement in an Australian hardwood and then assess field performance of the same material with or without a copper naphthenate overtreatment to see if an oil-borne coating would slow borate loss or provide synergy to improve resistance to biodeterioration. This study was part of a broader two-part investigation, on improving the durability of low durability Australian hardwoods and accelerating testing timeframes, undertaken by the National Institute for Forest Products Innovation (Wood et al. 2023a; Wood et al. 2023b).

Materials and Methods

Freshly sawn 90-mm-wide by 35-mm-thick boards of varying lengths of Queensland maple (*Flindersia brayleyana* F. Muell) were cut to 700-mm lengths and weighed. The boards were selected to minimize the presence of the pinkish, brown heartwood. Smaller samples remaining from the cut timbers were weighed, oven dried at 104°C, and reweighed to determine initial moisture content.

The boards were allocated to be left untreated or dipped in solutions containing 5 or 10 percent DOT (boric acid equivalent [BAE]; Table 1). The boards were reweighed after treatment and the difference between initial and final masses was used to calculate net solution uptake.

The boards were solid piled and covered with plastic to retard drying. Boron movement was assessed 2, 4, 8, and 12 weeks after dipping by cutting a 100-mm section from one end of each board. The section was air dried for several days with limited air flow to minimize boron movement to the wood surface, then oven dried at 104°C and stored for later examination. The remaining section was replaced into the pile for additional diffusion. This process was repeated 4, 8, and 12 weeks after dipping. At the end of the sampling process, the remaining 300-mm-long piece was allowed to air dry.

Boron penetration into the samples cut at each time point was assessed by cutting three ~5-mm sections off the inside end of each piece (i.e., the face not directly exposed to drying). The freshly exposed surface on one section was then sprayed with a solution containing turmeric followed by another containing salicylic acid as per American Wood Protection Association Standard A68 (AWPA 2024c). A reddish color indicated the presence of boron. The remaining cross-sections were then cut into zones corresponding to 0 to 10 and 10 to 17 mm from the surface. These materials were ground to pass a 20-mesh screen, extracted in hot water, and the resulting extract was analyzed according to AWPA method A65, the azomethine H method (AWPA, 2024b). Separate tests of multiple hot-water extractions indicated that the first hot-water extraction recovered 93 percent of the boron in the wood.

The remaining 300-mm-long section of each piece left after 12 weeks of storage was cut into two 150-mm-long sections. One section was left untreated; the other was dipped for 3 minutes in an oil-borne 2 percent (as Cu) solution per AWPA Standard HSF-17 (AWPA, 2023). The solution used is sold as copper naphthenate by Arch Wood Protection Pty Ltd, Trentham, Victoria (sold as Arch CN Timber Oil); this is supplied in a non-drying oil designed to give water repellency (according to company literature).

The 150-mm-long samples were then exposed above ground according to the procedures described in AWPA Standard E18 ground proximity test (AWPA, 2024d). Briefly, 50-mm-thick concrete blocks were placed on the ground and the test pieces were placed on the blocks. The assembly was covered with a permeable mesh cloth that allowed rain to enter but limited ultraviolet light exposure (see Fig. 1). The test limited drying, creating ideal conditions for aboveground fungal decay. The test site is located at the Queensland Department of Primary Industries Maroochy Field Station (26°38′28″S, 152°56′17″E). The subtropical site receives regular coastal rainfall and has a Scheffer index of 121 for the risk of aboveground decay (Scheffer 1971). The region experiences average daily high temperatures between 16°C and 26°C, with approximately 1,800 mm of annual precipitation, most pronounced from December through April. It is important to note that a portion of the exposure occurred during a La Niña event with above-average rainfall. For example, the region experienced approximately 1,900 mm of precipitation between January and May

Table 1.—Boron treatments applied to Queensland maple and net retentions as determined by mass gain.

Boron concentration (% boric acid equivalent [BAE])	Dipping time (min)	Replicates	Net retention (% BAE)[a]
5	6	12	0.061 (0.017)
5	15	5	0.071 (0.027)
10	3	11	0.137 (0.181)
10	6	13	0.154 (0.045)

[a] Values represent means; values in parentheses represent 1 SD.

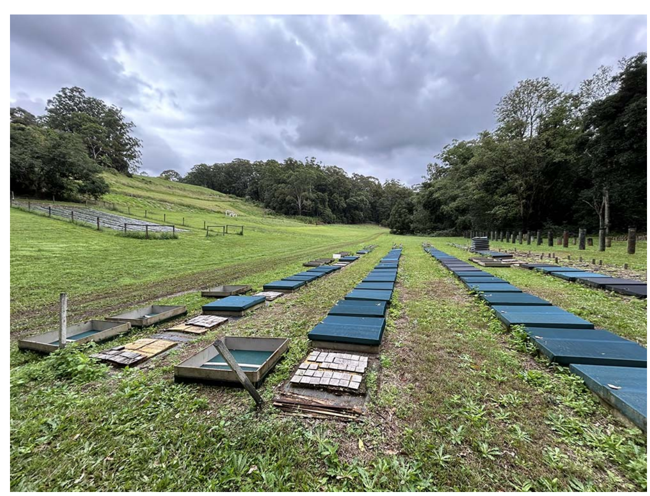

Figure 1.—Field trial set up at Nambour, Queensland showing arrangement of ground proximity arrays. Treated samples lie on concrete blocks that are enclosed and shaded by a 70 percent ultraviolet-resistant water-permeable shade cloth to create a wind-sheltered, high-humidity microenvironment to increase the risk of decay. Samples are assessed annually.

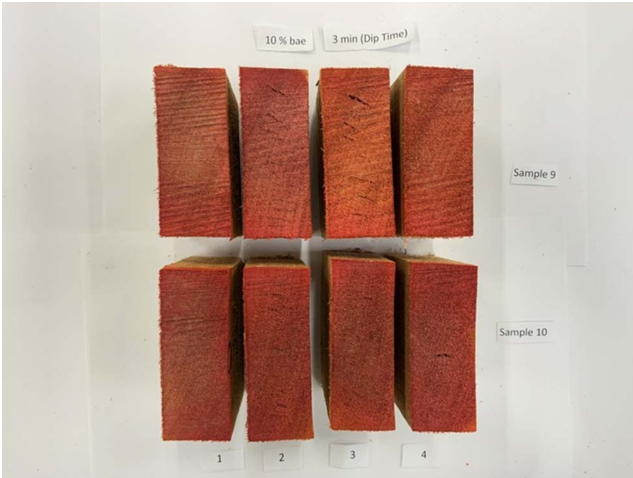

Figure 2.—Example of crosscuts from Queensland maple samples dipped for 3 minutes in a 10 percent boric acid equivalent disodium octaborate tetrahydrate solution and stored for 1 to 8 weeks (1 = 1 wk, 2 = 2 wk, 3 = 4 wk, and 4 = 8 wk) under nondrying conditions. Samples were dried and a fresh cut was made; the surface was then sprayed with a curcumin/salicylic acid indicator to develop the reddish color indicative of boron.

2022, whereas the average precipitation for the 5 years prior, over the same period, was approximately 644 mm (CSIRO, Bureau of Meteorology 2024). The condition of the samples was visually assessed after 15, 26, and 40 months of exposure on a scale from 10 (no damage) to 0 (complete failure) as described in the Standard.

Results and Discussion

The average moisture content of 10 samples cut from the parent boards before treatment was 101 percent (oven dry basis). Boron diffusion requires wood over the fiber saturation point (Smith and Williams 1969) and the test samples were well over that level.

Solution uptake

Net boron retentions on a solution basis were consistently higher in samples dipped in the 10 percent BAE solution but there was considerable variation between samples (Table 1). There was only a 12 percent increase in retention when the dipping time was doubled for the 10 percent solution. Similarly, increasing the dipping time from 6 to 15 minutes with a 5 percent solution resulted in a 15 percent increase in net solution uptake. In both cases the increased treatment times produced only marginal gains in solution uptake, likely reflecting the high moisture content at the time of treatment.

There is currently no boron retention specification for exterior, aboveground applications in the Australian Standards, but the AWPA specifies a retention of 4.85 kg/m^3 (BAE basis) for dual-treated ties (AWPA 2024a). Queensland maple has an average air-dry density of 580 kg/m^3, which would translate to a target loading of 0.836 percent BAE (Bootle 1983). This value was far higher than either the net uptakes or boron analysis from the current study, indicating that higher solution concentrations would be needed to meet this requirement. DOT is among the most soluble of the borates (Uysal et al. 2018) and doubling the solution concentration to 20 percent would approach this target level as determined by the chemical assays. Note in the United States some treatments are done with a momentary immersion at ambient temperature in thickened 24 percent DOT solution concentration (Kim et al. 2011) or a double or extended treatment in a heated 30 percent solution.

Boron penetration

Boron penetration was generally complete in all samples within 2 weeks after dipping (see Fig. 2). The boron indicator system is useful for assessing treatment, but it is important to note that it is sensitive at levels well below the threshold for fungal protection (Edlund 1983, Schoeman et al. 1998), so a reaction does not infer adequate retention, which is why analysis was necessary.

Boron retentions

Boron levels in the samples varied widely over the course of the diffusion period, reflecting the fact that samples were taken from different locations on each parent board (Table 2). As expected, boron levels were higher in samples dipped in the 10 percent BAE solution, but there was no marked increase in boron levels when dipping times were doubled. This likely reflects the high moisture contents of the boards at the time of dipping, which limited additional liquid uptake. Prolonged dipping might still be attractive if it reduced interboard variability, but the standard deviations suggest that this was not the case.

Boron concentrations were consistently higher in the outer zones of all samples, even after 12 weeks of diffusion storage, although there was a trend toward high levels in the inner zones. This suggests that boron distribution would eventually become more uniform if sufficient moisture remained in the wood.

Aboveground performance

Untreated samples exposed in a ground proximity test have begun to show some signs of decay after 40 months of exposure but are still relatively sound (Table 3). Of interest, copper

Table 2.—Boron retentions (as % boric acid equivalent [BAE] mass/mass) in the inner and outer zones of Queensland maple timber 2 to 12 weeks after dipping in 5 or 10 percent disodium octaborate tetrahydrate DOT for 3 to 15 minutes.

		Boron content (% BAE mass/mass)							
		2 weeks		4 weeks		8 weeks		12 weeks	
Concentration (% BAE)	Time (min)	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
5	6	0.098 (0.064)	0.083 (0.079)	0.163 (0.059)	0.078 (0.028)	0.155 (0.047)	0.101 (0.038)	0.187 (0.031)	0.126 (0.046)
	15	0.112 (0.074)	0.112 (0.074)	0.177 (0.118)	0.115 (0.060)	0.217 (0.017)	0.142 (0.019)	0.211 (0.026)	0.149 (0.014)
10	3	0.307 (0.102)	0.093 (0.030)	0.212 (0.089)	0.124 (0.053)	0.267 (0.119)	0.193 (0.065)	0.249 (0.147)	0.204 (0.100)
	6	0.250 (0.130)	0.099 (0.039)	0.214 (0.097)	0.143 (0.061)	0.252 (0.113)	0.210 (0.038)	0.257 (0.097)	0.184 (0.095)

Values represent means of 11–13 replicates per treatment except for samples dipped for 15 minutes in a 5 percent BAE solution, where only five samples were treated. Values in parentheses represent 1 SD.

Table 3.—Average decay ratings for Queensland maple dipped in combinations of disodium octaborate tetrahydrate and copper naphthenate (CuN) and exposed in a ground proximity decay test at a site near Nambour, QLD, Australia.

Treatment	Reps	Average decay rating[a]								
		15 months			26 months			40 months		
		Control	Boron	Boron/CuN	Control	Boron	Boron/CuN	Control	Boron	Boron/CuN
Water	8	9.88 (0.23)	—	—	9.81 (0.37)	—	—	6.13 (1.64)	—	—
CuN dip	8	10	—	—	9.56 (1.05)	—	—	6.88 (1.46)	—	—
6 min/5 percent	12	—	9.92 (0.19)	10	—	9.63 (0.86)	9.71 (0.86)	—	7.17 (1.28)	8.25 (0.71)
15 min/5 percent	5	—	10	10	—	9.20 (1.30)	8.5 (1.41)	—	6.8 (1.47)	6 (0)
3 min/10 percent	11	—	9.95 (0.15)	10	—	9.86 (023)	10	—	7.64 (0.88)	8.41 (0)
6 min/10 percent	13	—	9.96 (0.14)	10	—	9.69 (0.88)	9.85 (0.38)	—	7.69 (1.07)	8.46 (0.71)

[a] Values represent means; values in parentheses represent 1 SD.

naphthenate-dipped samples are performing similarly. Queensland maple heartwood is classified as a Durability class 3 species when exposed out of ground contact, with an expected service life of 7 to 15 years (Standards Australia 2022). However, our tests selectively used sapwood, which would have little resistance to fungal attack. All the samples have ratings of at least 8 of 10, suggesting that some decay is beginning, but there are no consistent differences in ratings with boron-alone treatments. Boron/copper naphthenate-dipped treatments are performing slightly better after 40 months of exposure. These results are very preliminary and should be viewed with some caution. At present, the limited number of replicates precludes destructive sampling to determine residual boron levels, but this will be considered as the test proceeds.

Conclusions

Boron uptakes increased with treatment solution concentration but longer dipping times did not translate to markedly higher loadings. Boron continued to diffuse inward over the 12-week diffusion period, although loadings remained higher near the surface. Although decay has begun in the samples exposed in a ground proximity test, few large performance differences have emerged, and the samples will continue to be assessed.

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