Potential for using through-boring to improve groundline treatment of Australian wood species: A preliminary study

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Abstract

An aging electricity distribution system and reduced availability of naturally durable tropical hardwoods in Australia will combine in the next decade to produce a major shortage of poles. One approach to mitigating this shortage is to utilize lower durability species and improve the penetration of preservatives into the refractory heartwood by introducing additional pretreatment processes. A potential method for improving preservative penetration in the critical ground-line zone is through-boring. This process, in which holes are drilled through the pole perpendicular to the grain in the ground-line zone, is widely used in the western United States for treatment of Douglas-fir and may be suitable for many Australian wood species. The potential for improving heartwood penetration in eucalypts with alkaline-copper-quaternary (ACQ) compound was assessed on heartwood specimens from four species (*Eucalyptus cloeziana* F.Muell., *E. grandis* W.Hill ex Maiden, *E. obliqua* L'Her. and *E. pellita* F.Muell.) and *Lophostemon confertus* (R.Br.) Peter G.Wilson & J.T.Waterh). Longitudinal ACQ penetration was extremely shallow in *L. confertus* and only slightly better in *E. cloeziana*. Longitudinal penetration was good in both *E. obliqua* and *E. pellita*, although there was some variation in treatment results with length of pressure period. The results suggest that through-boring might be a reasonable approach for achieving heartwood penetration in some *Eucalyptus* species, although further studies are required to assess additional treatment schedules and to determine the effects of the process on flexural properties of the poles.

Australian utilities have long employed naturally durable hardwoods to support their overhead electrical distribution lines, and over 5 million poles currently serve this role across the country (Francis and Norton 2006). Many of these poles were installed in the post World War II expansion period and are potentially reaching the end of their useful service lives. At the same time, changes in public land policy have placed many formerly accessible hardwood resources that might serve as replacements off limits to continued harvest. The same report estimated that demand for poles by Australian utilities will increase from the current rate of 60,000 to 65,000 poles per year to well over 100,000 in 2014. Presently, there is an insufficient supply of Durability Class 1 and 2 (Australian Standard AS5604, 2005) poles to meet this burgeoning demand. Francis and Norton (2006) summarized this problem and identified a number of possible strategies for bridging the supply gap including improving maintenance of in-service poles to reduce the need for replacements, the utilization of plantation softwoods, and the use of less durable hardwoods, treated in a manner to confer effective protection to the refractory, low durability heartwood.

Over the past decade, a variety of hardwood plantations have been established across Australia. While many of these stands have been established for the production of pulp for paper production, some species planted also have potential for use as poles. One drawback to the use of some plantation hardwood species that could be used for poles is the relatively low natural durability of the heartwood. Australian utilities had a large resource of highly durable hardwoods. This resource allowed utilities to pay little attention to protection of the heartwood in the preinstallation preservative treatment process because protection of sapwood was adequate for obtaining acceptable performance of these species (Crews

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et al. 2004). It is likely that those days have passed, and utilities will need to identify methods for improving the performance of less durable heartwood.

The obvious approach to improving eucalypt durability is preservative treatment; however, many of the plantation species produce relatively thin bands of permeable sapwood surrounding a thick core of low durability heartwood. Conventional pressure treatments are designed to treat the sapwood and are largely unable to produce acceptable heartwood penetration. In the absence of improved heartwood treatment, users of less durable plantation hardwoods will be faced with continuing internal decay or insect issues at ground line that will increase maintenance costs and reduce service life. Current maintenance and remedial practices are specifically focused on improving heartwood durability, and many of the utilities now employ holes drilled abaxially into the poles around the critical ground-line zone (Greaves and McCarthy 1986, 1993). These holes are used to introduce diffusing preservatives with the intent of creating a treated and protected inner zone.

A related development, in which holes are drilled through the poles, has been adopted in the United States to protect thin sapwood, low durability poles. The U.S. Pacific Northwest has an extensive supply of Douglas-fir. This species grows tall and straight, but also has a thin sapwood shell surrounding a 'moderately' durable heartwood core (Graham 1980). In the 1960s, utilities using this species were experiencing extensive internal decay that reduced service life to as little as 12 years. In their search for solutions to this problem, they determined that drilling numerous holes through the pole, perpendicular to the grain, in a regularly spaced pattern around the ground line could be used to improve heartwood treatment in this critical zone and thereby the life of a pole without adversely affecting flexural properties (Merz 1959, Brown and Davidson 1961, Graham et al. 1969, Grassel 1969). Termed "through-boring", the process involves drilling regularly spaced holes at a slight downward angle through the pole beginning 900 mm below ground line and extending 600 mm above that line (**Figs. 1 and 2**). The holes expose additional end-grain to preservative flow and the result is a ground-line zone that has nearly complete preservative protection. As a result of their efforts, through-boring is widely used for treatment of Douglas-fir poles (Mankowski et al. 2002). Subsequent tests have shown that the through-bored zone remains free of decay decades after installation and Douglas-fir poles now have average service lives that are estimated to exceed 60 years (Morrell and Schneider 1994). A recent, extensive pole test in which 140 Douglas-fir poles were loaded to failure has shown that holes as large as 13 mm in diameter can be used on poles with no significant loss in flexural properties (Elkins 2005, Elkins et al. 2007). These results, if transferable to the eucalypt species from Australian plantations, could provide an alternative method for markedly enhancing the durability of these species.

Dale (1977) designed a machine for boring out the center of eucalypt poles providing a means of treating the refractory heartwood while taking out the low strength, low durability wood close to the pith of the tree; an added bonus was reducing the risk of pole split development. The machine was used briefly on hardwood poles in Papua New Guinea but, as yet has not been used in Australia as a means of treating eucalypt pole heartwoods.

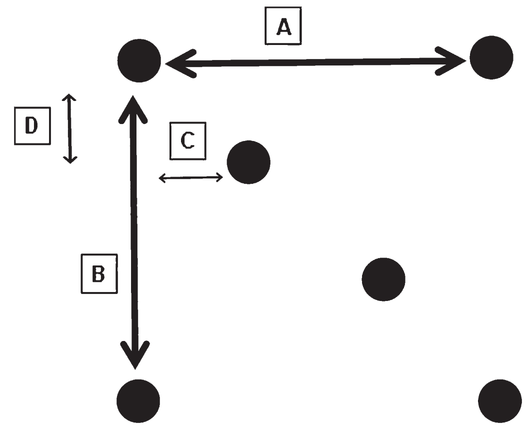

Figure 1. — Example of a through-boring pattern where the distances between individual holes (A, B, C, and D) can be varied to produce the desired degree of treatment.

An important aspect of the ability of a species to be through-bored would be acceptable longitudinal preservative penetration into the heartwood. In general, longitudinal penetration should be between 50 and 75 mm so that preservative movement from holes can create a sufficient degree of overlap to produce protection. Previous studies of Douglas-fir suggest that poles will be free of internal decay in the through-bored zone, even when as little as 60 to 70 percent of the heartwood is treated. This relationship may differ in hardwoods, given the more variable treatment patterns produced by differential treatment of the vessels and fibers, but it provides a starting point for assessment.

In this paper, tests designed to assess longitudinal penetration of preservative into selected Australian plantation hardwoods subjected to various treatment cycles are described. Results are presented and discussed and the direction of further work outlined.

Materials and methods

The timber species tested were *Eucalyptus cloeziana* F.Muell., *E. grandis* W.Hill ex Maiden, *E. obliqua* L'Her., *E. pellita* F.Muell., and *Lophostemon confertus* (R.Br.) Peter G.Wilson & J.T.Waterh. Heartwood of air-dried lumber that was primarily quartersawn was obtained and cut into test specimens (**Table 1**). One end of each test specimen was coated with a marine sealant to retard longitudinal fluid penetration. The test specimens were then weighed (nearest g). Two test specimens of each species were allocated to each treatment trial. Trials 1 to 3 were performed using test specimens that were 400 mm long, while Trials 4 to 7 used test specimens 200 mm long.

Test specimens were vacuum-pressure-impregnation (VPI) treated using vacuum periods ranging from 5 to 45 minutes, followed by pressure periods varying from 1 to 16 hours. All but one trial used a 1.5 percent solution of alkaline-copper-quaternary (ACQ) compound formulated using monoethanol amine, while the last treatment used the same solution amended with 3.0 percent ammonia.

For each trial, the samples were placed into the treatment vessel, a vacuum of −95 KPa was drawn over the wood for the required time, then the preservative was slowly drawn into the vessel without losing the vacuum. The pressure was then

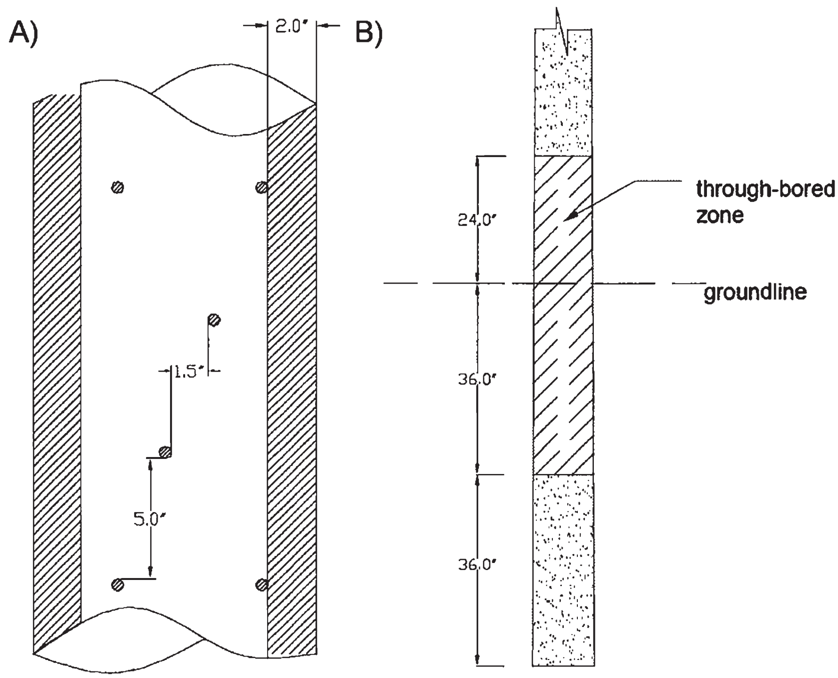

Figure 2. — Examples of (A) a typical through-boring pattern and (B) the zone to which it would be applied on a pole.

Table 1. — Wood species and dimensions employed to evaluate the potential for using through-boring on Australian wood species.

	Sample dimensions[a] (mm)	
Wood species	Trials 1 to 3	Trials 4 to 7
E. cloeziana	NT[b]	40 by 120 by 200
E. obliqua	25 by 100 by 400	30 by 130 by 200
E. grandis	25 by 100 by 400	24 by 100 by 200
E. pellita	NT	35 by 100 by 200
L. confertus	25 by 100 by 400	NT

[a] Dimensions are thickness by width by length in grain direction.
[b] NT = not tested.

increased to 1.38 MPa and held for the required time period. At the end of the cycle, the pressure was partially released, and then the last 0.345 MPa was used to force the solution from the vessel. The wood was removed, blotted dry, and weighed. The difference between initial and final weight was used to determine net solution absorption.

The test samples were then air-dried prior to being rip sawn lengthwise into three equivalent pieces. The freshly exposed surfaces were brushed free of any sawdust and then sprayed with chrome azurol S to detect copper distribution which served as an indicator of ACQ penetration (Australian Standard AS1605.2, 2006). Penetration was measured as the average distance the preservative penetrated from the unsealed end. In addition, the percentage of cut surface penetrated was visually estimated on each test specimen at zones 0 to 100, 100 to 200, and 200 to 400 mm from the unsealed end for the initial trial and 0 to 100 and 100 to 200 mm from the unsealed end in the second trial. These zones were selected to assess the ability of fluid to penetrate longitudinally for varying distances along the end grain.

Results and discussion

As expected, uptakes and preservative penetration varied widely among the species tested. *L. confertus* was extremely difficult to penetrate, with less than 2 mm of end-penetration regardless of pressure period. This species was excluded from further consideration, and two other species (*E. pellita* and *E. cloeziana*) were evaluated in its place.

Net solution uptake

Net solution uptakes were negligible for *L. confertus*, but ranged from 16.5 to 46.2 percent weight gain for *E. obliqua* and 26.9 to 40.8 percent for *E. grandis*. These uptakes suggest a reasonable potential for treatment (**Table 2**).

Solution uptakes in the second trial were slightly more variable, ranging from 17.6 to 32.2 percent weight gain for *E. grandis* and 18.0 to 67.1 percent for *E. obliqua* (**Table 3**). Net uptakes for *E. cloeziana* ranged from 11.9 to 21.8 percent weight gain, while those for *E. pellita* ranged from 23.1 to 67.5 percent.

Longitudinal preservative penetration

The results for each trial were averaged for each species. Average longitudinal preservative penetration in the first trial ranged from 80 to 88 mm for *E. grandis* and 22 to 55 mm for *E. obliqua,* depending on the pressure period (**Table 2**, ammonia data excluded). Penetration improved only slightly with increasing pressure period with *E. grandis*. Longitudinal penetration improved as the pressure period was increased from 3 to 6 hours in one trial of *E. obliqua*, but penetration in the other 6-hour trial was the same as that found after 3 hours. Preservative penetration was much shallower in the set of *E. obliqua* test specimens treated for 16 hours which actually resulted in much shallower penetration than for shorter pressure periods. But, it is unclear whether the reduced degree of penetration was due to natural wood variability or some problem associated with the treatment conditions.

The results of Trials 1 through 3 indicate that longitudinal penetration of *E. obliqua* was marginal and therefore potentially unsuitable for use in through-boring. Penetration of *E. grandis*, however, was well within the range that would be suitable for this process.

Longitudinal penetration in *E. obliqua* in the second set of trials tended to be much better than in the first three trials, ranging from 33 to 158 mm (**Table 3**, ammonia data excluded). As with the first set of materials, penetration was poorest in the 16-hour trial. Ignoring the 16-hour trial data, penetration increased steadily with increasing pressure period, although the variation in penetration in some individual sections remained high.

Penetration in *E. cloeziana* was relatively shallow, ranging from 30 to 55 mm, with the 16-hour trial samples having the

Table 2. — Net solution absorption and degree of preservative penetration on exposed cut surfaces in three wood species pressure-treated with ACQ using selected vacuum and pressure periods.

Wood species	Treatment times		Net uptake	Treatment results[a]			
				Mean longitudinal penetration	Degree of penetration (%)		
	Vac	Press			0 to 100 mm	100 to 200 mm	200 to 400 mm
	------- (hr) -------		(% wt/wt)	(mm)			
E. grandis	0.75	3	26.9	80 (30)	63 (15)	50 (13)	53 (15)
	0.75	6	40.8	88 (41)	60 (1)	43 (12)	48 (12)
	0.75	6	38.3	88 (33)	78 (10)	63 (12)	58 (8)
E. obliqua	0.75	3	20.3	43 (22)	43 (19)	23 (16)	25 (12)
	0.75	6	21.8	55 (20)	57 (25)	33 (23)	34 (20)
	0.75	6	46.2	44 (31)	48 (19)	33 (26)	33 (29)
	0.75	16	16.5	22 (16)	23 (14)	6 (2)	9 (2)
L. confertus	0.75	3	2.1	< 2	< 2	< 2	< 2
	0.75	6	5.4	< 2	< 2	< 2	< 2
	0.75	6	2.5	< 2	< 2	< 2	< 2

[a] Values represent means of two samples for each percentage weight gain and measurements on six surfaces per trial for longitudinal penetration. Values in parentheses represent one standard deviation.

Table 3. — Effect of treatment process on penetration of ACQ (longitudinal and percentage of surface area) into various eucalypt species.

Wood species	Treatment times		Net solution uptake	Treatment results[a]		
				Mean longitudinal penetration	Degree of penetration (%)	
	Vacuum	Pressure			0 to 100 mm	100 to 200 mm
	-------- (hr) --------		(% wt/wt)	(mm)		
E. cloeziana	0.75	1	17.1	50 (15)	48 (15)	20 (13)
	0.75	3	21.8	55 (12)	62 (16)	17 (6)
	0.50	6	14.1	52 (15)	55 (14)	42 (31)
	0.50	6[b]	23.0	45 (17)	50 (12)	25 (17)
	0.75	16	11.9	30 (13)	42 (13)	12 (6)
E. grandis	0.75	1	17.6	48 (17)	52 (17)	9 (2)
	0.75	3	18.8	50 (14)	62 (18)	10 (0)
	0.50	6	25.5	57 (8)	65 (8)	28 (20)
	0.50	6[b]	16.5	23 (20)	25 (17)	25 (17)
	0.75	16	32.2	33 (20)	33 (19)	33 (8)
E. pellita	0.75	1	34.7	93 (8)	80 (11)	52 (19)
	0.75	3	23.1	100 (17)	87 (12)	43 (36)
	0.50	6	57.0	83 (19)	77 (15)	53 (34)
	0.50	6[b]	35.1	25 (6)	40 (11)	15 (17)
	0.75	16	67.5	123 (84)	73 (32)	62 (41)
E. obliqua	0.75	1	54.5	95 (35)	65 (18)	60 (9)
	0.75	3	39.1	113 (95)	60 (44)	92 (200)
	1.00	2[b]	15.5	7 (10)	8 (15)	5 (10)
	0.50	6	67.1	158 (38)	88 (41)	80 (11)
	0.50	6[b]	14.8	110 (104)	60 (46)	50 (58)
	0.75	16	18.0	33 (21)	33 (12)	13 (6)

[a] Values represent means of six measurements/treatment. Values in parentheses represent one standard deviation.
[b] Treatment performed using 1.5% ACQ amended with 3% ammonia.

shallowest penetration. This species has naturally durable (Durability Class 1) heartwood that should not require treatment. It was included because of interest in determining if this material could be treated in the event the faster grown plantation timbers are found to be less durable than the native forest resource.

Longitudinal penetration in *E. grandis* samples in the second set of trials tended to be shallower than that from the first test, ranging from 33 to 57 mm. Eliminating the 16-hour trial samples, there was a steady increase in longitudinal penetration with pressure period; however, the depth of longitudinal penetration was marginal and therefore unlikely to be useful for use in through-boring. Further tests would be required to determine if the heartwood of this species is sufficiently permeable to benefit from through-boring.

Longitudinal penetration in *E. pellita* samples ranged from 83 to 123 mm. In this case, the samples treated using a 16-hour pressure period had the deepest penetration, although all of the treatments produced penetration levels that would be sufficient for through-boring. *E. pellita* is classified as a Durability Class 2 species (Australian Standard AS5604, 2005) and through-boring is likely to be effective in the event that plantation-grown *E. pellita* is less durable than the native forest material.

Degree of preservative penetration

Given the limited replication, these trials should be considered as preliminary in nature, but they provide some guidance concerning which species might be suitable for further study. Through-boring, as originally designed, is intended to result in nearly complete treatment of the heartwood; however, field inspections of poles in service in the United States indicate that poles with less than complete penetration will still perform extremely well (Morrell and Schneider 1994). Utilities in Australia have adopted the practice of abaxially bored eucalypt poles to extend their service lives. Thus, it is clear that introducing preservative to refractory heartwood zones in pole timbers by various hole boring configurations such as through-boring and abaxial boring provides an effective option for pole management. Clearly diffusion or penetration from the hole sites is critical to the success of such management strategies.

While longitudinal preservative penetration is important, preservative distribution in the impregnated area will also play a role in pole performance. For the purposes of this assessment, 60 percent or greater penetration was considered to be sufficient to produce acceptable pole performance. This is admittedly an arbitrary figure based upon performance of coniferous poles (Morrell and Schneider 1994) and needs to be confirmed through field trials with hardwoods. Calculations of the strength of any treated annulus, *vis-a-vis* the untreated core, is another method of determining what percentage of treatment (penetration) is required.

The degree of preservative penetration in the first trials tended to be reasonably uniform with *E. grandis*, ranging from 60 to 78 percent in the first 100 mm, and 43 to 63 percent in the second 100 mm from the unsealed end of the samples (**Table 2**). Penetration in *E. obliqua* ranged from 23 to 57 percent and 6 to 33 percent in the outer and second 100-mm zones, respectively. Once again, penetration was extremely poor in the 16-hour samples of *E. obliqua*. If these samples are ignored, then the range in degree of penetration was quite small for this species. Using the 60 percent penetration target, all of the trials produced acceptable penetration in the outer 100 mm for *E. grandis*. None of the trials achieved the required target with *E. obliqua,* although one 6-hour trial was within 3 percent of the target.

Penetration values in the second trial (trials 4 to 7) could only be measured to 200 mm from the unsealed end, but they showed similar trends. For the purposes of the remainder of this discussion, the 16-hour trial data will be ignored. Mean preservative penetration ranged from 48 to 62 percent for *E. cloeziana*, 52 to 65 percent for *E. grandis*, 77 to 87 percent for *E. pellita*, and 60 to 88 percent for *E. obliqua*. Clearly, all of these species could be successfully treated to the target level. Penetration in the next 100 mm inward from the unsealed end fell off quite sharply for both *E. grandis* and *E. cloeziana*, but remained close to the target for *E. pellita*. Penetration in *E. obliqua* remained well above the target.

The addition of ammonia to the treatment solution produced puzzling results. Ammonia is presumed to enhance wood treatment through a combination of wood swelling and dissolution of extractives deposited on pit membranes (Hartford 1973). Ammonia is routinely added to treatment solutions in western North America to enhance treatment of ACQ (AWPA 2004). The addition of 3.0 percent (wt/wt) ammonia to the treatment solution used in these trials produced slight improvements in solution uptake of all of the species except *E. obliqua*. Penetration, as measured using a copper indicator, however, was either unchanged or less than that found during the comparable 6-hour trial without ammonia. The lack of an ammonia effect is perplexing given the excellent results obtained in other species in North America. One possible explanation was that the solutions were employed without heating (which is often used in the United States with this system [Hartford 1973]), although it was surprising to see no effect, even without heat.

The results indicate that the heartwood of both *E. obliqua* and *E. pellita* are candidates for further assessment of through-boring. While prior experiences with this technique on softwoods implies that the treatment levels achieved would confer protection against internal decay, penetration patterns observed in the hardwoods clearly differed from those obtained in softwoods. In general, the penetration patterns observed in the hardwoods were patchier than those seen in conifers. These results are consistent with previous observations of penetration patterns in eucalypt species (Greaves 1977, Greaves and Levy 1978). In the more difficult-to-treat species, this patchiness was largely defined by vessel associated penetration, with little in the way of fiber penetration. Penetration patterns tended to be better in *E. obliqua* and *E. pellita*, but there was still a tendency to leave patches of untreated fibers. The impact of these patches on pole longevity is unknown, although it is important to remember that untreated patches are surrounded by relatively well-treated ones. It should be difficult for a fungus or insect to penetrate through the well-treated portions of the heartwood to reach the less thoroughly treated material. Morris et al. (2004) examined a similar effect when exposing untreated material sandwiched between pieces treated to 1.9 kg/m^3 and 3.7 kg/m^3 with copper, chrome, and arsenic (CCA) salts. He concluded that sufficient copper transferred from the treated timber to the untreated wood to prevent decay for 6 years under the conditions of exposure. In addition, the impact of small decay pockets in the heartwood that are confined within larger zones of preservative-treated wood on overall pole flexural properties is likely to be minimal since the fungus would then have to grow through chemical-treated wood to levels above the threshold for fungal growth.

Conclusions

The results suggest that the performance of at least two of the species tested (*E. obliqua* and *E. pellita*) could be improved by through-boring but the process needs to be assessed on a broader sample of each species. In addition, it will be important to assess the effect of differential preservative distribution between vessels and fibers on performance as well as the effects of through-boring on flexural properties.

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