FIVE-YEAR FIELD TRIALS USING PRESERVATIVE-TREATED, SECOND-GROWTH DOUGLAS-FIR EXPOSED IN GROUND CONTACT IN AUSTRALIA

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ABSTRACT

The durability of preservative-treated stakes of second-growth Coastal Douglas-fir was evaluated in a field plot in northern Queensland, Australia. Results from this field trial indicate that second-growth Douglas-fir can be treated with preservatives to meet Australian standards and will provide long-term durability in adverse environments. Data presented indicate that within a 5-year time frame, the importance of minimum penetration parameters decreases as retention increases.

Lack of experience in Australia with treated Coastal Douglas-fir (Pseudo-*tsuga menziesii*) impedes consideration of this commodity for utilization in engineered structures, such as stress-laminated bridge decks and in other construction. The objective of this study was to address questions about treatability of second-growth Douglas-fir and document its durability in a high decay hazard site in Northern Queensland. Specific objectives were to document the treatability of wood from second-growth Coastal Douglas-fir trees with alternative preservatives and provide a database on the performance of alternative treatments for Douglas-fir exposed in ground contact in a tropical environment.

MATERIALS AND METHODS

WOOD

The lumber used in this trial came from the Pacific Coastal region of Oregon, a region where Douglas-fir is generally regarded as permeable **(Fig. 1).** The lumber was obtained from a mill that was cutting second-growth timber. Thus, the lumber resource used in this study is considered representative of second-growth material that is currently being harvested.

The Douglas-fir lumber was 50-mm-(2-in.-) thick material and was not kiln-dried prior to shipment to the Forest Products Laboratory (FPL) in Madison, Wis. Upon arrival at FPL, the lumber was kiln-dried following a mild schedule that began with a dry-bulb temperature of 43.3°C (110°F) and concluded with 71.1°C (160°F), with a 4.4°C (8°F) depression between wet- and dry-bulb throughout. This drying schedule was more conservative than that developed for Coastal Douglas-fir of this thickness (4).

The dried lumber was then longitudinally cut into members approximately 50-mm (2-in.) square or 19-mm (3/4-in.) square and 2.43 m (8 ft.) long, with the longest dimension parallel to the grain. All material was vacuum impregnated with deionized water. Material was subjected to a vacuum of 68.6 mm (27 in.) Hg for 15 minutes, then flooded with water and allowed to stand overnight at atmospheric pressure.

The 50-mm by 2.54-m (2-in. by 8-ft.) material was incised to a depth of 8 mm

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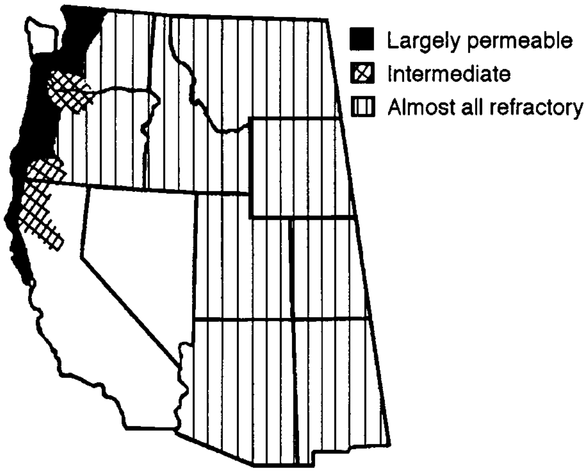

Figure 1. – Heartwood permeability of Douglas-fir varies with geographic source. In general, coastal areas are permeable; Cascade Mountain sources are moderately impermeable; Intermountain sources are impermeable (7).

TABLE 1. – Stake size and disposition.

Stake size	Disposition of stakes
50 by 50 by 500 mm (2 by 2 by 20 in.)	Stakes of this dimension were installed in North Queensland because the dimension simulates actual construction materials. Depth measurements of preservative penetration were also made with this stake size. Results from preservative penetration studies and field trials in Australia are reported here.
19 by 19 by 457 mm (3/4 by 3/4 by 18 in.)	Stakes of this size were used to compare retention levels, calculated from gain-in-weight during treatment, with retention levels determined by chemical analysis. Those comparisons are included in this report.

TABLE 2. – Preservatives used in this study.

	Oilborne		
Waterborne	Chlorothalonil	Copper naphthenate	Creosote
--------------- (%) ---------------		(% copper)	(%)
0.37	0.37	0.31	7.5
0.75	0.74	0.62	15.0
1.50	1.48	1.25	30.0
3.00	2.96	2.50	60.0

(0.32 in.), with an experimental knife incisor that produced approximately 1,200 incisions per square meter (130 per ft.^{2}). The 19- by 19-mm (3/4- by 3/4-in.) material was incised to a depth of 5 mm on the radial surfaces only. Because of the prototype incisor design, metal particles were sometimes sloughed from the incising head and related assembly and deposited around the incisions on the wood surface. Following incising, the wood was again kiln-dried using a schedule that began with an initial dry-bulb temperature of 47.6°C (120°F) and concluded with a dry-bulb temperature of 65.5°C (150°F). A 5.5°C (10°F) depression between dry- and wet-bulb temperatures was maintained throughout the drying schedule.

Following redrying, the 50- by 50-mm material was cut into 500-mm-(20-in-) long stakes. Stakes were all or mostly heartwood. Small amounts (% of cross-sectional area) of sapwood occurred in some stakes. Most stakes were free of knots, but we did accept stakes with knots less than half the thickness of the stake. The 19- by 19-mm material was cut into 457-mm (18-in.) lengths. Stake size and disposition are shown in **Table 1.**

All stakes were equilibrated to a constant weight in a controlled environment at which wood equilibrates to 12 percent moisture content. Then, equilibrated stakes within each size group were weighed and arrayed according to weight. Stakes were then divided into 30 sequential groups, based upon weight, for each stake size. For each treatment, one stake was randomly selected from each group. Thus, each treatment group included the same representation of wood density. Within each size category, each group had a comparable mean weight and a comparable distribution of weight. The total range of weight within the arrays of the respective stakes sizes was ±22 percent of the mean.

PRESERVATIVES

Preservatives included in this study were either in advanced stages of development or were commercially used in either Australia or the United States when the study began. The preservatives used in this study were the following:

ACQ-B: A waterborne ammoniacal copper quat system. The American Wood Preservers' Association (AWPA) recently accepted this preservative. The quaternary ammonium is didecyldimethylammonium chloride. The ratio of copper as CuO to Quat is 2:1 (AWPA P5-92) (3).

ACZA: A waterborne ammoniacal preservative that was developed to consistently achieve penetration in Douglas-fir and other species. This was the reference, ammoniacal treatment. The ratio of copper as CuO to zinc as ZnO and to arsenic as As_2O_5 is 2: 1 : 1 (AWPA P5-92) (3).

Cu citrate 2:1: A waterborne ammoniacal preservative that was being proposed for acceptance by AWPA when this study was initiated. It is now included within AWPA standards. On a weight/weight basis, the molar ratio of copper (as CuO) to citrate ($C_6H_4O_7$) is 4: 1. On a percentage basis, the CuO:citrate ratio is 2: 1 (1).

Creosote ("P1"): Creosote meeting AWPA P1-91 (3) is used as another reference preservative.

Chlorothalonil: An oilborne preservative that was being proposed for acceptance by AWPA (9) when this study began. It is now included within AWPA standards. The active ingredient (a.i.) is tetrachloroisophthalonitrile.

Copper naphthenate: An oilborne preservative (AWPA P8-91) (3) containing copper naphthenate.

TREATMENTS

Thirty stakes of each size were treated with one of four levels of a.i. of each preservative **(Table 2).** All treatments were done at FPL. The full-cell process was used throughout. For each treatment, both sizes of stakes were treated together. Creosote was diluted with toluene to simulate an empty-cell process. Copper naphthenate and chlorothalonil were dissolved in No. 2 diesel oil, which met (6) AWPA requirements for hydrocarbon solvent Type A (AWPA P9-92) (3), then diluted with toluene to achieve desired solution concentration of diesel fuel and a.i. All treating solutions with copper naphthenate were mixed with toluene so that the amount of No. 2 diesel fuel was only 30 percent by weight of the total solution. Treating solutions with chlorothalonil were adjusted so that the diesel fuel composed 22 percent, by weight, of the total solution. Treating solutions of copper citrate 2:1 were prepared by diluting the concentrate with deionized water. Treating solutions of ACZA and ACQ-B were also prepared by diluting concentrates with deionized water, but the concentration of ammonia in each treating solution was also adjusted to a multiple of the a.i. The ammonia concentration in the treating solutions of ACZA and ACQ-B were, respectively, 1.4 and 2.0 times the concentration of a.i

With all treatments, stakes were treated with no end seal in a pan within a pressure retort. A vacuum of 68.6 mm (27 in.) Hg was applied for 30 minutes. The respective treating solutions were flooded over the evacuated stakes, and pressure was applied. A pressure of 861.8 kPa (125 psi) was held overnight (about 14 hr.). At the conclusion of the pressure cycle, the treating solution was removed from the pans.

Immediately after the treating solution was drawn off, stakes treated with creosote, copper naphthenate, chlorothalonil, and copper citrate 2: 1 were removed from the pans, blotted dry, and weighed. Stakes treated with either ACQ-B or ACZA were subjected to a final vacuum of 71 mm (28 in.) Hg for 30 minutes prior to weighing. This was accomplished by closing the treating cylinder again and pulling a vacuum. Stakes were supported in pans so that solutions emerging from the treated

TABLE 3. –Average preservative retention of thirty 50- by 50-mm stakes as determined from weight gain during treatment.

Preservative	Concentration of a.i. treating solution Target	Concentration of a.i. treating solution Actual[a]	Average retention computed using targeted concentration of a.i.		Average retention computed using actual concentration of a.i.	
	--------------(%)--------------		(kg/m^3)	(pcf)	(kg/m^3)	(pcf)
Ammoniacal copper citrate (CC)	0.37	0.40	2.56	0.16	2.78	0.17
	0.75	0.78	5.07	0.32	5.28	0.33
	1.5	1.54	10.72	0.67	11.00	0.69
	3.0	1.63	21.76	1.36	11.87	0.74
Ammoniacal copper quaternary ammonium (ACQ-B)	0.37	0.22	2.48	0.15	1.48	0.09
	0.75	0.65	5.11	0.32	4.43	0.28
	1.5	1.18	10.40	0.65	8.18	0.51
	3.0	2.20	20.44	1.28	14.99	0.94
Ammoniacal copper zinc arsenate (ACZA)	0.37	0.38	2.51	0.16	2.57	0.16
	0.75	0.66	5.16	0.32	4.54	0.28
	1.5	1.50	10.71	0.67	10.71	0.67
	3.0	2.60	21.47	1.34	18.61	1.16
Copper naphthenate	0.31	0.30	1.28	0.08	1.28	0.08
	0.62	0.64	2.78	0.17	2.87	0.18
	1.25	1.19	5.23	0.33	4.98	0.31
	2.5	2.55	10.97	0.69	11.22	0.70
Chlorothalonil	0.37	0.42	1.60	0.10	1.79	0.11
	0.74	0.82	3.20	0.20	3.54	0.22
	1.48	1.48	6.62	0.41	6.62	0.41
	2.96	2.87	13.52	0.84	13.11	0.82
Creosote	7.5	12.3	32.94	2.06	54.02	3.38
	15.0	20.0	69.48	4.34	92.64	5.79
	30.0	38.1	135.72	8.48	172.37	10.77
	60.0	--[b]	303.13	18.95	--[b]	--[b]
30 percent diesel in toluene			134.11	8.38		

[a] Concentration of active ingredient (a.i.) as determined by chemical analysis of the treating solution prior to treatment.

[b] Not determined. Retention of stakes treated with targeted 60 percent concentration of creosote computed only from targeted value of a.i. in treating solution

wood could drip free from treated stakes. After the final vacuum was released, stakes were removed from the pans, blotted dry, and weighed.

Stakes treated with creosote, copper naphthenate, and chlorothalonil were air-dried after weighing. All stakes that were treated with waterborne ammoniacal systems were wrapped in polyethylene after weighing and prior to drying. This was done to promote intrawall redistribution of the alkaline preservatives. Stakes treated with ACQ-B and copper citrate 2:1 were wrapped for 7 days; stakes treated with ACZA were wrapped for 3 days. These stakes were then kiln-dried to a moisture content of 20 to 25 percent. Stakes were dried for 7.5 days at a constant dry-bulb temperature of 54.4°C (130°F), with a 4.4°C (8°F) depression in wet-bulb temperature.

ANALYSIS OF TREATMENT

The concentration of a.i. in each treating solution was determined by chemical analysis and retention levels are based upon those analyses. At the time of treatment, the retention of each preservative in the treated wood was calculated on the basis of gain in weight during treatment **(Table 3).** After treatment, 10 stakes from each set of 30 50- by 50-mm stakes per treatment were randomly selected and reserved for determination of preservative penetration. The remaining 20 50- by 50-mm stakes/treatment were installed in the field plot in Queensland.

TABLE 4. - Ratings used to visually estimate percentage of cross section of stake that was being destroyed by decay fungi and termites. [a]

Degrade caused by wood decay fungi		Degrade caused by termites	
Rating	Cross section degraded	Rating	Cross section degraded
10	none, wood sound	10	none, wood sound, l-2 nibbles
9	trace to 3%	9	slight feeding - 3%
8	3% to 10%	8	3% to 10%
7	10% to 30%	7	10% to 30%
6	30% to 50%	6	30% to 50%
4	50% to 75%	4	50% to 75%
0	> 75% failure (breaks)	0	> 75% failure (breaks)

[a] AWPA E7-93 (3).

TABLE 5. - Penetration patterns for preservatives in 50-by 50-mm stakes of second-growth Douglas-fir.

		No. of steaks					
				Cross section penetrated			
Preservative	Concentration of a.i. in treating solution [a]	Penetration on at least one side limited to incisions	Penetration on all sides continuous between incisions	0 to 25%	25 to 50%	50 to 75%	> 75%
	(%)						
Ammoniacal copper citrate	0.40	8	2	1	6	1	2
	0.78	3	7		1	2	7
	1.54	1	9			2	8
	1.63	1	9			1	9
Ammoniacal copper quat Type-B	0.22	9	1	9			1
	0.65	8	2		6	2	2
	1.18	2	8				6
	2.20		10				10
Ammoniacal copper zinc arsenate	0.38	10		9	1		
	0.66	7	3	2	3	2	3
	1.50	4	6		3	5	2
	2.60	2	8			1	8
Copper naphthenate	0.30		10				10
	0.64		10				10
	1.19		10				10
	2.55		10				10
Chlorothalonil	0.42		10				10
	0.82		10				10
	1.48		10				10
	2.87		10				10
Creosote	12.3	3	7	2	2		6
	20.0		10				10
	38.1		10				10
	60		10				10

[a] Determined by chemical analysis of treating solution for all a.i.s except the highest concentration of creosote. The targeted 60 percent concentration of creosote was not confirmed by chemical analysis.

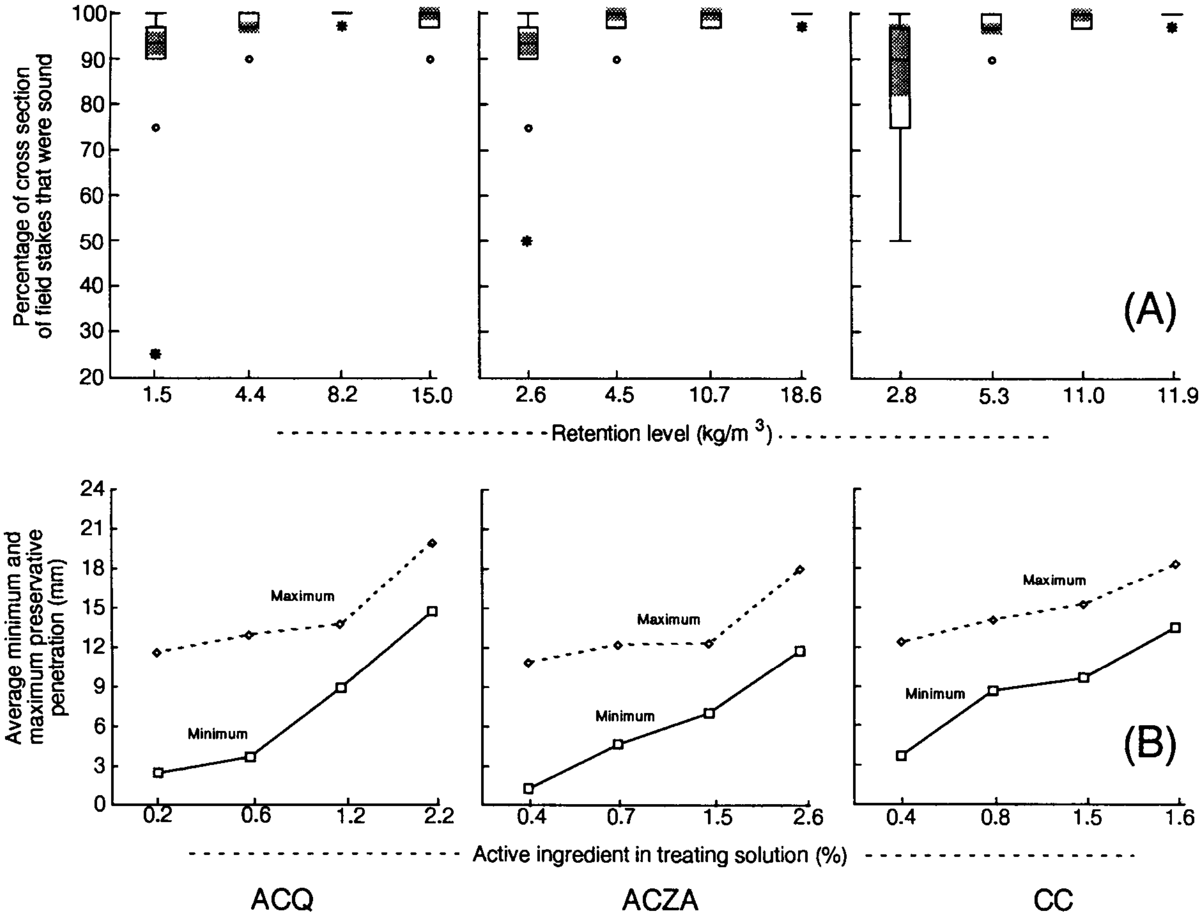

Figure 2. – Durability of Douglas-fir stakes treated with inorganic preservatives and exposed for 5 years in North Queensland (A) compared with average minimum and maximum penetration of inorganic preservatives observed in 10 Douglas-fir stakes randomly selected from those stake populations at time of treatment (B).

Ten stakes were also randomly selected from each set of 30 19- by 19-mm stakes per treatment. For all treatments except the one with 60 percent creosote, each of those 10 stakes per treatment was chemically analyzed to determine the actual retention in each stake. Results of those analyses are reported here. The remaining 20 19- by 19-mm stakes were installed in another location and results are not reported here.

PENETRATION

Each of the 10 50- by 50-mm stakes reserved for penetration studies was crosscut into halves. Depth of penetration was visually determined on one cross-sectional face of the treated member. Penetration by creosote was observed directly. Penetration of chlorothalonil was assessed indirectly through the use of Red O dust to determine penetration of solvent in accordance with AWPA A3-97 (3). Chrome azurol S was used in accordance with AWPA A3-97 (3) to detect the presence of copper within the treated wood.

The following three criteria were used to evaluate penetration:

- Estimated percentage of cross-sectional area that was treated.
- Number of stakes within set of 10 in which all sides had uniform treatment, i.e., wood between incisions was treated as well as wood in the immediate vicinity of incisions.
- Maximum and minimum penetration that was observed. When wood between incisions at any location was not uniformly penetrated, the minimum penetration that occurred between incisions was recorded as the minimum value.

RETENTION

Each of the 10 19-by 19-by 147-mm (3/4- by 3/4- by 18-in.) stakes, randomly selected from sets of 30 stakes per treatment, were analyzed individually for retention of a.i. at FPL. The entire cross section at mid-length of each stake was analyzed using atomic absorption spectroscopy for metals (AWPA A11-93) (3), gas chromatography for chlorothalonil (AWPA A20-97) (3), and solvent extraction for creosote (AWPA A6-97) (3).

EFFICACY EVALUATION

Field plot. – Durability of treated Coastal Douglas-fir was evaluated in northern Queensland, Australia. The plot is near Innisfail, Queensland (latitude 17° south), and is in a wet tropical environment. Mean annual precipitation is 3556 mm (140 in.). Mean annual temperature is 22.7°C (72.9°F). The clay-loam soil is of basaltic origin.

INSTALLATION

Procedures used in establishing and maintaining field plots were in accordance with those described in ASTM D 1758 (2), except for modifications described herein. Treated and control stakes were shipped by airfreight to the

TABLE 6. – Ratings for attack by decay fungi and termites in preservative-treated Douglas-fir stakes after 5 years exposure in ground contact in Northern Queensland

Preservative	Average retention computed from gain in weight during treatment of 30 stakes[a,b]		Summary statistics of ratings for 20 stakes[a] per preservative by retention combination			
			Decay		Termites	
			Lowest quartile	Median	Lowest quartile	Median
	(kg/m^3)	(pcf)				
Ammoniacal copper citrate	2.78	0.17	7	8	10	10
	5.58	0.33	9	9	10	10
	11.00	0.69	9	10	10	10
	11.87	0.74	10	10	10	10
Ammoniacal copper quat	1.48	0.09	8	8.5	10	10
Type-B	4.43	0.28	9	9	10	10
	8.18	0.51	10	10	10	10
	14.99	0.94	9.5	10	10	10
Ammoniacal copper zinc arsenate	2.57	0.16	8.5	8.5	10	10
	4.54	0.28	9	10	10	10
	10.71	0.67	9	10	10	10
	18.61	1.16	10	10	10	10
Copper naphthenate	1.28	0.08	9	9	10	10
	2.87	0.18	10	10	10	10
	4.98	0.31	10	10	10	10
	11.22	0.70	10	10	9.5	10
Chlorothalonil	1.79	0.11	7.5	8	10	10
	3.54	0.22	8	9	10	10
	6.62	0.41	8	9	10	10
	13.11	0.82	9	9.5	10	10
Creosote	54.02	3.38	7	8	10	10
	92.64	5.79	8	9	10	10
	172.37	10.77	10	10	10	10
	303.13	18.95	10	10	10	10
30 percent diesel in toluene	134.11	8.38	8.5	9	10	10
Untreated control			0	0	0	0

[a] Stakes are 50 by 50 mm in cross section. Thirty stakes were treated per preservative by retention combination. Ten of these were randomly withdrawn for determination of penetration. The remaining twenty were installed in the field plot in Queensland.

[b] Retention computed using actual concentration of a.i. as determined by chemical analysis of treating solution (with exception of 30% creosote solution).

field location in Queensland. The 50- by 50-mm stakes were installed in the Queensland plot in October 1993, 1 month after treatment. Twenty replicate stakes per treatment and 20 replicate stakes of each of 2 controls were installed. One control was untreated stakes. The other control consisted of stakes that were treated by the full-cell process with an oil solution composed of 30 percent No. 2 diesel: 70 percent toluene on a weight/weight basis. The retention of oil in the treated stakes was approximately 134 kg/m^3 (8.3 pcf) **(Table 3).** Stakes were set out in a randomized block design.

INSPECTION

Stakes were inspected annually. At each inspection, the percentage of cross-sectional area degraded by termites or decay fungi was visually estimated according to criteria defined in AWPA E7-93 (3) **(Table 4).**[1]

RESULTS

PRESERVATIVE TREATMENT

The range of retention levels achieved encompasses retention levels required for products used in ground-contact exposure.

The organic systems yielded more uniform penetration of the entire cross section than did the waterborne preservatives **(Table 5).** Uniform cross-sectional penetration was observed at the three higher retention levels of creosote and was indicated at all retention levels of the other two organic systems. The least uniform cross-sectional distribution of organic systems occurred at the lowest retention of creosote **(Table 5).**

With the inorganic systems, all indices of penetration improved as the concentration of a.i. increased **(Table 5; Fig. 2).** The increases in concentration of a.i. were usually matched by a proportionate increase in ammonia in the

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[1] All inspections were conducted by Scott Kleinschmidt, Qld DPI, Forestry, accompanied by one or more of the authors.

treating solution except with the highest concentration of copper citrate. Consequently, the targeted retention was not achieved with copper citrate, although good penetration occurred. With copper citrate and ACQ, a sharp reduction in the frequency of stakes lacking continuous penetration between incisions occurred with specific, incremental gains in concentration of a.i. With copper citrate, this occurred between 0.40 and 0.78 percent a.i. that yielded retention levels of 2.78 and 5.52 kg/m^3 **(Tables 3** and **5).** With ACQ-B, this occurred between concentration of 0.65 and 1.18 percent a.i. that yielded computed retention levels of 4.43 and 8.18 kg/m^3, respectively **(Tables 3** and **5).** With ACZA, this reduction in frequency of stakes with discontinuities of penetration occurred progressively as retention levels increased **(Table** 5). The average minimum depth of penetration observed at any point in the cross section of treated stakes gradually increased as retention levels of ACZA and copper citrate increased **(Fig.** 2). With ACQ, increases in minimum penetration did not occur until concentrations of a.i. exceeded 0.65 percent.

DURABILITY

Half the untreated control stakes failed within the first year, and all but one residual stake failed during the first 2 years of exposure. In contrast, the population of stakes that were treated to the upper three retention levels of all preservatives did quite well **(Table 6).** Failure in untreated controls was due to both decay and termites. *Heterotermes* spp. attacked untreated stakes but very little termite attack occurred on treated stakes. Degrade of treated stakes was due primarily to decay **(Table 6).**

With the inorganic, waterborne treatments, decay ratings seemed more strongly linked to retention than to indices of minimal penetration. This was particularly noticeable with ACZA, where several stakes with discontinuous penetration patterns were observed at all retention levels **(Table 5).** Average minimum penetration observed in ACZA-treated stakes increased with each increment of retention, whereas decay ratings were uniform across the upper three retention levels **(Fig. 2).** With ACQ, improvement in decay ratings occurred at an increment of retention before gains in minimum penetration occurred. **(Fig. 2; Table** 5). With copper citrate, gains in decay ratings occurred simultaneously with increased average minimum pene-

TABLE 7. – Preservative retention of ten 19- by 19-mm stakes as determined from weight gain during treatment and by chemical analysis after treatment.[a]

Preservative	Concentration of a.i. Target	Concentration of a.i. Actual[b]	Average retention computed from gain in weight during treatment[c]		Average retention determined through chemical analysis of treated stakes	
	----------- (%)	-----------	(kg/m^3)	(pcf)	(kg/m^3)	(pcf)
Ammoniacal copper citrate	0.37	0.40	2.88	0.18	3.52	0.22
	0.75	0.78	5.51	0.34	5.60	0.35
	1.5	1.54	11.46	0.72	11.52	0.72
	3.0	1.63	11.84	0.74	17.12	1.07
Ammoniacal copper quaternary	0.37	0.22	1.47	0.09	3.04	0.19
ammonium	0.75	0.65	4.41	0.28	5.28	0.33
Type-B	1.5	1.18	8.11	0.51	11.84	0.74
	3.0	2.20	14.65	0.92	20.96	1.31
Ammoniacal copper zinc arsenate	0.37	0.38	2.71	0.17	3.2	0.20
	0.75	0.66	4.66	0.29	5.28	0.33
	1.5	1.50	10.28	0.64	8.80	0.55
	3.0	2.60	18.81	1.18	18.4	1.15
Copper naphthenate	0.31	0.30	1.35	0.08	0.35	0.02
	0.62	0.64	2.73	0.17	2.46	0.15
	1.25	1.19	4.92	0.31	3.27	0.20
	2.5	2.55	11.00	0.69	7.79	0.49
Chlorothalonil	0.37	0.42	1.77	0.11	4.00	0.25
	0.74	0.82	3.59	0.22	9.12	0.57
	1.48	1.48	6.65	0.42	17.12	1.07
	2.96	2.87	13.11	0.82	35.84	2.25
Creosote	7.5	12.3	59.47	3.72	48.16	3.01
	15.0	20.0	94.82	5.93	96.64	6.04
	30.0	38.1	194.43	12.15	180.48	11.28
	60.0	58.9	401.12	25.07	--[d]	--[d]
30 percent diesel in toluene			132.42	8.28		

[a] Ten stakes were randomly selected and withdrawn from each set of 30 stakes per treatment for chemical analysis.

[b] Actual concentration of treating solution determined through chemical analysis of treating solution prior to treatment.

[c] Retention levels were computed using actual concentration of treating solution.

[d] Not determined. Retention reported in paper is based upon computation by weight gain.

tration and reduced frequency of discontinuous penetration **(Fig. 2; Table 5).** With the inorganic preservatives, internal decay accounted for the low decay ratings in stakes at the lowest retention levels.

DISCUSSION

For low-durability timber that is to be exposed in ground contact, Australian standard AS 1604 Timber-Preservative-treated-Sawn and Round (8) specifies that all the sapwood must be penetrated and the preservative must penetrate 10 mm into the exposed heartwood for non-critical applications and 20 mm for critical end use. The standard also specifies minimum retention levels for each penetration zone.

This field trial provided an opportunity to evaluate retention compared with penetration as treating criteria. The importance of minimal penetration at low retention levels seems to be evidenced by the presence of internal decay in populations of stakes treated with the lowest retention levels of waterborne preservatives. As retention levels increase, however, the relative importance of minimum penetration and even uniformity of penetration seems to decrease. It may be surmised that as retention levels (based on gain-in-weight calculations) increase, more chemical can influence the wood/soil interface. The gain in decay resistance associated with the first incremental increase of retention of ACQ without improvement in minimum penetration statistics seems to support this hypothesis. With ACZA, decay performance increased at the first increment of preservative loading, whereas the average minimum depth and uniformity of penetration progressively increased with each increment in concentration of treating solution.

Standards for treated products usually prescribe specific retention levels of chemical within defined assay regions. In this study, referencing response parameters for wood treated with inorganic preservatives to concentrations of treating solution may be less prone to error of interpretation than are references to calculated retention levels. Calculations were based on weight gain of preservative per unit volume of wood treated. When the entire cross section of the item was treated, as shown with the 19- by 19-mm members **(Table 7),** there was relative agreement between calculated and analytical values. When preservative loadings were restricted to the periphery of the 50- by 50-mm stakes with a larger cross-sectional area, the calculated loading was probably somewhat less than what actually occurred in the treated region. This difference was most pronounced with the lowest retention levels of waterborne preservatives. It declined as the concentration of treating solution increased because as the concentration of a.i. increased, the area of cross section that was penetrated increased. With the organic systems, for which good cross-sectional penetration was observed, this was not of consequence.

The rating system used to make a quantitative estimate of biodegradation in the test stakes is reliable when applied to populations of stakes, as presented here. To be sure, some experimental (human) variation occurs in selection between individual ratings, but the relative degree of error is proportionate to the amount of degradation that occurs. In a prior study, we were able to develop a linear relationship between visual, field ratings, and resultant compressive strength of experimental stakes (5). In this study, the soft surface of treated Douglas-fir presented a challenge in rating the onset of decay. Consequently, ratings for individual stakes sometimes alternated between 10 and 9 from year to year, but no reversals in ratings of 8 or less occurred.

CONCLUSIONS

Second-growth Coastal Douglas-fir can be penetrated by wood preservative to meet Australian standards and will provide at least 5-year durability in adverse environments. Current data show that within a 5-year time frame, the importance of minimum penetration parameters decreases as retention increases. A hypothesis is proposed that this reflects the effect of increased concentration of preservative at the wood-soil interface.

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