PRESERVATIVE TREATMENT EVALUATION WITH CCA AND ACQ-B OF FOUR APPALACHIAN WOOD SPECIES FOR USE IN TIMBER TRANSPORTATION STRUCTURES

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ABSTRACT

This work investigates the treatability of four Appalachian hardwoods with the waterborne preservatives CCA-C and ACQ-B. Heartwood and sapwood of the species were investigated, at least initially, for all species. Six-inch-long nominal 2 by 4 samples of red maple, yellow-poplar, hickory, and beech were end-sealed and vacuum/pressure treated with a 1 percent active ingredient solution of ACQ-B or a 2 percent solution of CCA-C. The pressure durations were varied as well as the temperature of the solution (for ACQ-B). Measurements were taken of minimum and maximum penetration, percentage of cross-sectional area penetrated, and retention of preservative as determined by x-ray fluorescence spectroscopy. The sapwood of yellow-poplar and red maple was found to be 100 percent treatable. Hickory sapwood was consistent in treatability, although limited, while beech sapwood fell somewhere between hickory and the other species. Statistical analysis indicated that the duration of pressure periods used in this study had no consistent positive effect on treatment. The preservative solution was a significant factor in improved measures of treatability in some instances.

While Appalachian hardwoods are used extensively for railroad ties (treated with creosote), many species fall into the refractory category when treated with waterborne preservatives. Also, the treatability of many of these woods has not been well documented. In the past 10 to 15 years, many of these species have seen increased use in the furniture, composite, and export markets. If the wood of these species could be satisfactorily and consistently preservative treated, their use, marketability, and value would be further enhanced for applications in adverse conditions.

Refractory softwoods have been studied with techniques that improve preservative treatment as characterized by penetration and retention.[1,2] Improvements in these criteria have been demonstrated when an ammoniacal preservative solution was used in comparison to chromated copper arsenate (CCA). These studies primarily focused on the effect of incising refractory softwoods before treating in commercial treating facilities or on a laboratory scale. Both studies compared CCA to ammoniacal preservative solutions (ACZA and ACA, respectively). When the effect of preservative was singled out, generally better or statistically significant improved penetration was observed for the ammoniacal solutions. Another study included the preservatives CCA-C and ACQ-B[3] on the treatability of red maple. The study by Smith et al. found red maple sapwood to

[1] Lebow, S.T. and J.J.. Morrell. 1993. Pressure treatment of sitka spmce lumber with ammoniacal copper zinc arsenate or chromium copper arsenate. Forest prod. J. 43(10):41-44.

[2] Gjovik, L.R. and D.R. Schumann. 1992. Treatability of native softwood species of the northeastern United States. Res. Pap. FPL-RP-508, USDA Forest Serv., Forest Prod. Lab.. Madison Wis.

[3] Smith, W. B., N. Abdullah, D. Herdman, and R.C. DeGroot. 1996. Preservative treatment of red maple. Forest Prod. J. 46(3)35-41.

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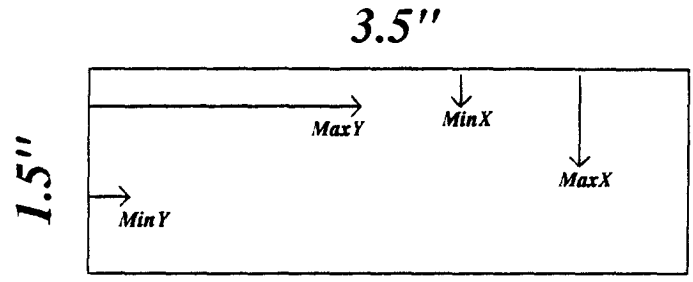

Figure 1. — Penetration measurements.

be easily treated with either preservative solution, while red maple heartwood was considerably less treatable.

This study evaluates the treatability of red maple, yellow-poplar, hickory, and beech with CCA-C and ACQ-B. An effort was made to ensure samples were all heartwood or all sapwood.

MATERIALS AND METHODS

Green logs were cut into full 2-inch random width/length boards of yellow-poplar *(Liriodendron tulipifera* L.), red maple *(Acer rubrum* L.), hickory *(Carya spp.),* and beech *(Fagus grandifolia* Ehrh.). Opening cuts were made to leave as much wane as possible, maximizing sapwood while still producing 2-inch-thick boards. This left boxed-heart cants that were cut into boards a full 2-inches in thickness.

The green, rough-cut lumber was dried below the fiber saturation point (FSP) by either airdrying or dehumidification kiln-drying. Once below FSP, oversized 2- by 4-inch blanks were ripped from the boards, making every effort to produce either sapwood or heartwood blanks. While wane on the opening-cut boards helped to identify sapwood, both proximity to the pith and ring orientation combined with discoloration were used as indicators of heartwood. The blanks were then processed through a molder/planer to produce random-length nominal 2 by 4's. Straight-grained, 6-inch-long samples that were as defect free as possible were cut and placed in a conditioning room (70°F at 65% relative humidity (RH)) to equilibrate at 12 percent moisture content (MC). Prior to vacuum/pressure treatment, samples were end-sealed with an elastomeric sealant.

A 4 percent active ingredient solution of ACQ-B was supplied by Chemical Specialties, Inc., from which a 1 percent active ingredient solution was prepared by diluting with water. A 50 percent concentrate solution of CCA-C was supplied by Osmose Wood Preserving, Inc., from which a 2 percent active ingredient solution was prepared by diluting with water. A 50 percent concentrate solution of CCA-C was also supplied by Osmose, from which a 2 percent active ingredient solution was prepared by diluting with water. Actual solution strengths for CCA-C ranged from 1.946 to 2.185 percent with the individual components falling with the ranges set in AWPA Standard P5-93 section 6.[4] Of the seven vacuum/pressure treatment cycles using ACQ-B solutions, all were in compliance with AWPA Standard P5 section 13, except for the first solution (red maple and yellow-poplar heartwood, and hickory heartwood and sapwood samples treated for 60 min. with an ambient solution temperature). This treatment cycle had somewhat elevated amounts of CuO and DDAC, and the last solution (beech heartwood and sapwood treated for 120 min. with a heated solution) had a low NH_3:CuO ratio (0.88), the latter being the result of heating.

Treatment constants were pressure (200 psi) and an initial vacuum (28 in. Hg) period of 30 minutes. Variables were pressure period duration (60, 90, and 120 min.) and solution temperature of ACQ-B (80°F, or 180°F) henceforth referred to as ambient or heated, respectively. For all treatments, the number of samples was 10.

An entire cross section from the center of the sample was ground for copper retention analysis using x-ray fluorescence spectroscopy (ASOMA), while one of the freshly sawn faces was sprayed with chrome azurol-S to aid in subsequent penetration measurements. Penetration measurements were made according to **Figure 1,** so that totals of four depth-of-penetration measurements per sample were recorded; Min(imum)X, Max(imum)X, Min(imum)Y, Max(imum)Y as well as a rating of percentage of cross section penetrated. Maximum measurements were limited to one-half the total possible distance in each dimension (i.e., 0.75 in. in the X dimension, 1.75 in. in the Y dimension). Percentage of cross section penetrated was given a rating of 0, 1, 2, or 3; where 0 = 0 to 25 percent, 1 = 25 to 50 percent, 42 = 50 to 75 percent, and 3 = 75 to 100 percent penetration.

All species, both sapwood and heartwood, were treated initially with CCA. The sapwood and heartwood results were compared, and if sapwood was found to be extremely well treated with CCA, it was judged to be very treatable in general and was dropped from further investigation with ACQ-B. This was found to be the situation for yellow-poplar and red maple. The heartwood of these species was treated with the ACQ-B to determine if results might be improved in what appeared to be refractory heartwood. Hickory sapwood showed only fair treatment results with CCA at best, and was treated with ACQ-B. Beech sapwood, which treated somewhere between hickory sapwood and the readily treatable sapwood of yellow-poplar, was also treated with ACQ-B. For red maple and yellow-poplar, where sapwood was found to be 100 percent treatable with CCA, heartwood penetration measurement data were analyzed using an unweighed means analysis of variance where the model used was:

$$y_{ijk} = \mu + T_i + P_j + (T \times P)_{ij} + \varepsilon_{ijk} \quad [1]$$

where:

μ = the overall mean penetration (in.)

T = the effect of the *i*th pressure period (min.)(i = 1, 2, or 3 or 60, 90, or 120 min., respectively)

P_j = the effect of the *j*th preservative solution (j = 1, 2, or 3- CCA, ambient ACQ-B, or heated ACQ-B, respectively)

$(T \times P)_{ij}$ = the interaction effect between

[4] American Wood-Preservers' Association. 1995. AWPA Standards 1995. AWPA, Woodstock, Md.

TABLE 1. — Frequency table of best penetration measurements for "best" species.[a]

	CCA						Ambient ACQ-B						Heated ACQ-B					
	MinX			MaxX			MinX			MaxX			MinX			MaxX		
Range (in.)	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM	AB	YP	RM
0 to .25	83.3	90.0	66.7	0	6.7	26.7	46.7	86.7	60.0	0	20.0	0	13.3	76.7	100.0	0	0	16.7
.26 to .55	16.7	10.0	13.3	10.0	26.7	16.7	43.3	6.7	30.0	26.7	33.3	20.0	73.3	16.7	0	6.7	20.0	26.7
.56 to .75	0	0	20.0	90.0	66.6	56.6	10.0	6.6	10.0	73.3	46.7	80.0	13.3	6.6	0	93.4	80.0	56.6
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	MinY			MaxY			MinY			MaxY			MinY			MaxY		
0 to .75	83.3	100.0	70.0	0	53.3	43.0	83.3	96.7	80.0	26.7	76.7	66.7	83.3	90.0	100.0	6.7	53.3	66.7
.76 to 1.30	16.7	0	10.0	23.3	16.7	0	6.7	0	13.3	33.3	10.0	10.0	6.7	0	0	3.3	6.7	10.0
1.31 to 1.75	0	0	20.0	76.7	30.0	56.7	10.0	3.3	6.7	40.0	13.3	23.3	10.0	10.0	0	90.0	40.0	23.3
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a] Data based on 30 samples. AB = beech sapwood; YP = yellow-poplar heartwood; RM = red maple heartwood.

the ith pressure period and the jth preservative solution

ε_{ijk} = the experimental error associated with y_{ijk}; all tests of significance were conducted at an alpha level of 0.05

For beech and hickory where sapwood was also a factor in the analysis, the model was:

$$y_{ijkl} = \mu + T_i + P_j + W_k + (T \times P)_{ij} + (T \times W)_{jk} (T \times W)_{jk} + (P \times W)_{jk} + (T \times P \times W)_{ijk} + \varepsilon_{ijkl} \quad [2]$$

where:

μ = the overall mean penetration (in.)

T_i = the effect of the ith pressure period (min.)(i = 1, 2, or 3 or 60, 90, or 120 min., respectively)

P_j = the effect of the jth preservative solution (j = 1, 2, 0r 3-CCA, ambient ACQ-B, or heated ACQ-B respectively)

W_k = the effect of the kth wood type (k = 1 or 2, heartwood or sapwood)

$(T \times P)_{ij}$ = the interaction effect between the ith pressure period and the jth preservative solution

$(T \times W)_{ik}$ = the interaction effect between the ith pressure period and the kth wood type

$(P \times W)_{jk}$ = the interaction effect between the jth preservative solution and the kth wood type

$(T \times P \times W)_{ijk}$ = the interaction effect between the ith pressure period the jth preservative solution and the kth wood type

ε_{ijkl} = the experimental error associated with y_{ijkl}; all tests of significance were conducted at an alpha level of 0.05

Multiple comparisons were done using Fisher's Least Significant Difference Test.

RESULTS AND DISCUSSION

For the sake of discussion, reference is made here to the AWPA Book of Standards 1995.[4] Standard C14-93 Wood for Highway Construction-Preservative Treatment by Preservative Processes, specifies penetration requirements as well as preservatives for this end use. The two preservatives investigated in this work are not included in this standard for hardwoods; however, as a point of reference, specified retention of CCA in southern pine (C14-93) is 0.60 or 0.40 pcf, depending on usage. The specified retention of ACQ-B in southern pine (C2 Lumber, Timber and lies-Preservative Treatment by Pressure Processes) is 0.25 or 0.40 pcf, depending on usage. According to standard C2, penetration of creosote, creosote solutions, and oilborne preservatives is specified for maple as follows; 80 percent of 20 cores per charge must equal or exceed 1.50 inches or 75 percent of sapwood. whichever is less (C1). Standard C1 (All Timber Products-Preservative Treatment by Pressure Processes) further states that the maximum penetration required in any piece of sawn material shall be no greater than half the width or depth of said piece, depending on the orientation of the measurement.

Assuming samples treated in this work were either all sapwood or all heartwood, the minimum penetration requirements can be stated hypothetically as follows: sapwood — 0.56 inch of thickness (75% of 1/2 of 1.5 in.) or 1.31 inches of width (75% of 1/2 of 3.5 in.); heartwood — 0.75 inch of thickness or 1.50 inches of width. Given that the randomness of borings taken from a commercial charge of treated lumber would yield average penetration values between the lowest mean minimum and the highest mean maximum penetration values obtained in this work, the likelihood that these hypothesized penetration criteria could be met, as it applies to all preservative solutions used in this work, are good for yellow-poplar and red maple. fair to poor for beech, and poor for hickory. Yellow-poplar and red maple sapwood were found to be extremely treatable with CCA and would easily exceed the aforementioned criteria. The heartwood of these species along with the sapwood of beech was not as clear-cut, yet the results approach the minimum requirements, as can be seen in **Table 1. Figures 2** and **3** show the chrome azurol-S-sprayed cross sections of sapwood and heartwood of yellow-poplar and red maple that were treated with CCA.

The assay zone for determining preservative retention in maple is 0 to 0.6

inch from the surface. Because an entire cross section was used for determining retention in this work. the analytical procedure used yielded very conservative estimates of retentions that might be achieved in the outer 0.6 inch of the wood member. Desired retention levels of CCA are apparently achievable for yellow-poplar, red maple, and beech, although some adjustment of solution strength may be necessary. CCA retention in hickory was so low that increasing solution strength to increase retention might not be feasible. Along the same line of reasoning, desired retention levels of ACQ-B would be achievable for yellow-poplar and red maple sapwood, possible for yellow-poplar and red maple heartwood and beech heartwood and sapwood, but questionable for hickory sapwood or heartwood.

Another way of evaluating the data summarized in the following sections would be to look for evidence of a viable "shell" treatment. By looking at the two minimum measurements, along with the respective standard deviation and range, it can be determined whether there is a "good" or, at least, a consistent shell of treatment. From this point of view, yellow-poplar and red maple might be successfully treated with any of the preservatives used in this work while the sapwood or heartwood of beech might be successfully treated with one of the ACQ-B solutions. Conversely, large maximum penetration values with an average percentage cross section penetrated of 0 (0% to 25%) or 1 (25% to 50%) would be an indication of erratic treatment results.

Tables summarizing penetration and retention results will be found in the following sections specific to species. The tables show the mean results by treatment with standard deviation and range of measurement for each respective treatment. Cells with a 0 in parentheses, such as (1.75(0)), indicate that all measurements were the same and, therefore, there is no standard deviation or range. Statistical analysis of preservative retention was not carried out because of the different natures of the two preservatives.

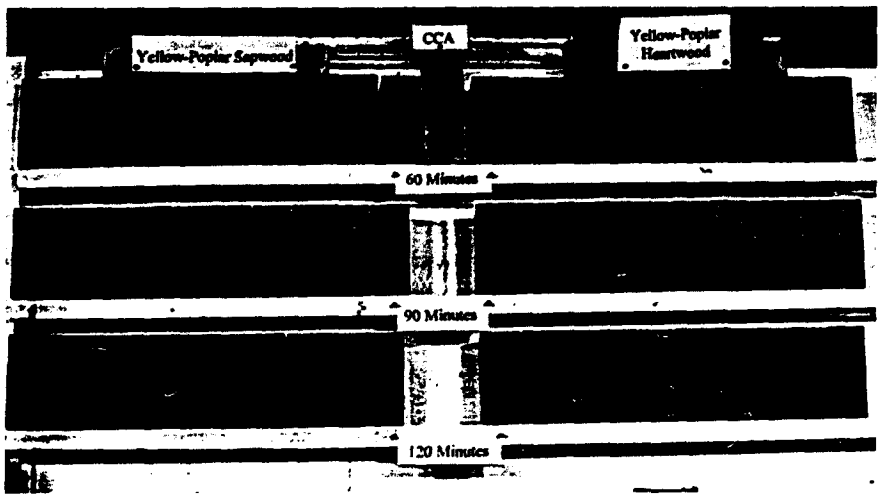

Figure 2. — Yellow-poplar sapwood and heartwood pressure treated with CCA-C.

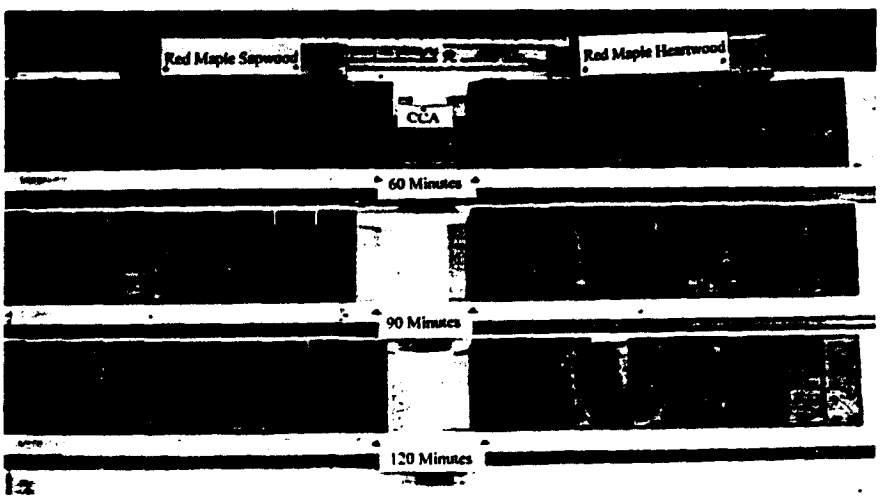

Figure 3. — Red maple sapwood and heartwood pressure treated with CCA-C.

BEECH

Tables 2,3, and **4** give the penetration and retention summary results for all treatments of beech. The results of treatment with CCA **(Table 2)** indicate that sapwood is more treatable than heartwood, but overall treatment of both heartwood and sapwood was somewhat erratic. The minimum penetration measurements are predominately low with relatively high standard deviations and ranges that include zero penetration occur in all cases but one (MhY at a 90-min. pressure period for sapwood). Retention of 0.40 pcf of CCA in beech sapwood is clearly achievable while solution strength might have to be increased to achieve the same in heartwood. The solution strength of the ACQ-B might need to be increased in order to consistently treat to 0.25 pcf.

Penetration results for beech sapwood treated with either solution of ACQ-B **(Table 3)** approach the previously discussed minimum penetration requirements, while the heartwood, treated with an ambient solution of ACQ-B **(Table 4),** shows evidence for a possible shell treatment. The mean minimum penetration measurements of heartwood treated with an ambient ACQ-B solution in all three time periods are consistently higher in comparison to the CCA or heated ACQ-B/heartwood groups with smaller standard deviations and fewer instances of ranges that include zero penetration.

In relation to the minimum penetration requirement, **Table 1** shows the frequency distribution of the minimum and maximum penetration measurements for all treatments of sapwood (ignoring time). While the percent of minimum measurements that meet or exceed the hypothesized minimum requirement for

TABLE 2. — Percentage rating of cross section penetrated, retention (pcf total oxide basis), penetration (in.), means, standard deviations, and ranges for beech treated with CCA.

Time and sample	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./sapwood	2.2 (.8)[b]	0.536 (.080)	0.09 (.08)	0.63 (.20)	0.25 (.32)	1.52 (.33)
	1 to 3[c]	.388 to .651	.00 to .23	.30 to .75	.00 to .82	1.00 to 1.75
90 min./sapwood	2.7 (.5)	0.425 (.066)	0.23 (.13)	0.73 (.05)	0.73 (.24)	1.55 (.28)
	2 to 3	.360 to .550	.00 to .39	.59 to .75	.31 to 1.05	1.10 to 1.75
120 min./sapwood	2.6 (.5)	0.481 (.066)	0.07 (.11)	0.74 (.03)	0.11 (.24)	1.69 (.19)
	2 to 3	.352 to .552	.00 to .37	.66 to .75	.00 to .78	1.15 to 1.75
60 min./heartwood	1.0 (.8)	0.267 (.113)	0.03 (.01)	0.61 (.19)	0.03 (.02)	0.80 (.38)
	0 to 3	.157 to .565	.00 to .04	.25 to .75	.00 to .06	.31 to 1.75
90 min./heartwood	1.7 (.8)	0.332 (.079)	0.02 (.02)	0.67 (.13)	0.02 (.03)	1.17 (.52)
	0 to 3	.193 to .455	.00 to .05	.40 to .75	.00 to .08	.20 to 1.75
120 min./heartwood	1.7 (1.1)	0.364 (.161)	0.09 (.23)	0.61 (.21)	0.26 (.54)	1.24 (.59)
	0 to 3	.091 to .644	.00 to .75	.15 to .75	.00 to .51	.35 to 1.75

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

TABLE 3. — Percentage rating of cross section penetrated, retention (pcf CuO), penetration (in.), means, standard deviations, and ranges for beech heartwood treated with ACQ-B.

Time and temperature	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./80°	2.4 (.84)[b]	0.153 (.024)	0.21 (.21)	0.64 (.13)	0.34 (.24)	1.10 (.56)
	1 to 3[c]	.122 to .194	.02 to .64	.47 to .75	.00 to .85	.44 to 1.75
90 min./80°	2.2 (.92)	0.169 (.037)	0.29 (.17)	0.59 (.15)	0.49 (.47)	1.01 (.59)
	1 to 3	.119 to .218	.14 to .75	.38 to .75	.11 to 1.75	.28 to 1.75
120 min./80°	2.5 (.85)	0.180 (.040)	0.20 (.14)	0.68 (.16)	0.39 (.27)	1.03 (.49)
	1 to 3	.106 to .220	.02 to .42	.31 to .75	.00 to 1.75	.52 to 1.75
60 min./180°	0.5 (.85)	0.080 (.040)	0.05 (.02)	0.46 (.19)	0.09 (.14)	0.57 (.63)
	0 to 2	.041 to .160	.02 to .09	.24 to .75	.03 to .48	.17 to 1.75
90 min./180°	1.6 (1.4)	0.123 (.058)	0.09 (.05)	0.53 (.22)	0.17 (.16)	0.85 (.64)
	0 to 3	.041 to .181	.04 to .19	.24 to .75	.03 to .49	.19 to 1.75
120 min./180°	0.2 (.42)	0.077 (.023)	0.08 (.02)	0.41 (.19)	0.07 (.03)	.49 (.23)
	0 to 1	.036 to .110	.06 to .12	.21 to .75	.03 to .12	.16 to .87

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

TABLE 4. — Percentage rating of cross section penetrated, retention (pcf CuO), penetration (in.), means, standard deviations, and ranges for beech sapwood treated with ACQ-B.

Time and temperature	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./80°	2.4 (0.97)[b]	0.165 (.020)	0.28 (.20)	0.61 (.17)	0.39 (.51)	0.98 (.47)
	0 to 3[c]	.134 to .196	.00 to .69	.26 to .75	.00 to 1.75	.36 to 1.75
90 min./80°	2.6 (.52)	0.188 (.028)	0.33 (.17)	0.64 (.14)	0.60 (.45)	1.22 (.57)
	2 to 3	.128 to .219	.22 to .75	.44 to .75	.17 to 1.75	.36 to 1.75
120 min./80°	3.0 (0)	0.212 (.016)	0.36 (.18)	0.71 (.09)	0.65 (.42)	1.35 (.44)
	- -	.179 to .225	.10 to .75	.52 to .75	.34 to 1.75	.78 to 1.75
60 min./180°	2.9 (.32)	0.197 (.032)	0.36 (.16)	0.73 (.07)	0.62 (.43)	1.43 (.53)
	2 to 3	.135 to .236	.19 to .75	.54 to .75	.29 to 1.75	.51 to 1.75
90 min./180°	3.0 (0)	0.195 (.025)	0.46 (.15)	0.71 (.09)	0.68 (.39)	1.75 (0)
	- -	.139 to .213	.20 to .75	.62 to .75	.40 to 1.75	- -
120 min./180°	3.0 (0)	0.200 (.015)	0.41 (.13)	0.75 (0)	0.65 (.40)	1.75 (0)
	- -	.170 to .221	.25 to .75	- -	.30 to 1.75	- -

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.

TABLE 5. — ANOVA probability level of significance for beech penetration categories and "best" treatment(s).

		MinX	MaxX	% rating	MinY	MaxY
A[a]	Probability[b]	0.000	0.000	0.000	0.000	0.000
	Significantly best mean	2	2	2	2	2
B[c]	Probability	0.000	0.038	0.000	0.000	0.021
	Significantly best mean	2 = 3	1 = 2	2	2 = 3	1
AB[d]	Probability	0.000	0.000	0.000	0.004	0.000
	Significantly best mean	(2,3)	(2,3) = (2,1)	(2,3) = (2,2)	(2,3) = (2,2)	(2,3) = (2,1)
C[e]	Probability	0.036	0.320	0.013	0.034	0.031
	Significantly best mean	2 = 3	NS[f]	2 = 3	2 = 3	2 = 3

[a] 1 = heartwood; 2 = sapwood.
[b] Probability of larger F-value.
[c] 1 = CCA; 2 = ambient ACQ-B; 3 = heated ACQ-B.
[d] Interaction of heartwood/sapwood × preservative.
[e] 1 = 60 minutes; 2 = 90 minutes; 3 = 120 minutes.
[f] NS = no significance.

penetration is low, the percentage of maximum measurements that meet or exceed the minimum requirement range from 40 to 90 percent.

Table 5 summarizes the statistical analysis for treatments of beech in relation to heartwood/sapwood, preservative solution, and the respective interaction. The statistical results **(Table 5)** for beech clearly indicate sapwood is more treatable than heartwood. When preservative solution is singled out, a "best" preservative is not readily apparent. One or both of the ACQ-B solutions was best or equally best in four of five categories while CCA was best or equally best in two categories. The reason CCA shows up as statistically "best" in the maximum penetration categories and not in the

TABLE 6. — Percentage rating of cross section penetrated, retention (pcf total oxide basis), penetration (in.), means, standard deviations, and ranges for yellow-poplar treated with CCA.

Time and sample	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./sapwood	3.0 (0)[b]	0.614 (.042)	0.74 (.03)	0.75 (0)	1.67 (.24)	1.75 (0)
	- -	.569 to .708	.64 to .75	- -	.99 to 1.75	- -
90 min./sapwood	3.0 (0)	0.622 (.042)	0.67 (.17)	0.75 (0)	1.56 (.45)	1.75 (0)
	- -	.564 to .699	.34 to .75	- -	.37 to 1.75	- -
120 min./sapwood	3.0 (0)	0.641 (.039)	0.69 (.20)	0.75 (0)	1.58 (.55)	1.75 (0)
	- -	.560 to .692	.11 to .75	- -	.00 to 1.75	- -
60 min./heartwood	0.7 (1.2)	0.322 (.161)	0.13 (.11)	0.49 (.20)	0.08 (.06)	0.58 (.62)
	0 to 3[c]	.144 to .620	.03 to .44	.22 to .75	.03 to .23	.11 to 1.75
90 min./heartwood	2.3 (.7)	0.571 (.104)	0.11 (.06)	0.72 (.05)	0.12 (.05)	1.39 (.48)
	1 to 3	.382 to .707	.05 to .26	.62 to .75	.05 to .23	.27 to 1.75
120 min./heartwood	1.7 (1.2)	0.443 (.158)	0.12 (.08)	0.58 (.19)	0.19 (.17)	0.78 (.53)
	0 to 3	.209 to .673	.04 to .28	.16 to .75	.06 to .51	.36 to 1.75

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

TABLE 7. — Percentage rating of cross section penetrated, retention (pcf CuO), penetration (in.), means, standard deviations, and ranges for yellow-poplar heartwood treated with ACQ-B.

Time and temperature	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./80°	1.1 (1.2)[b]	0.123 (.056)	0.17 (.18)	0.56 (.19)	0.22 (.21)	0.74 (.55)
	0 to 3[c]	.063 to .201	.03 to .59	.25 to .75	.04 to .71	.28 to 1.75
90 min./80°	0.8 (.8)	0.110 (.035)	0.08 (.04)	0.39 (.24)	0.08 (.06)	0.38 (.25)
	0 to 2	.068 to .181	.05 to .17	.14 to .75	.04 to .23	.14 to .89
120 min./80°	1.4 (1.2)	0.102 (.04)	0.19 (.21)	0.49 (.21)	0.28 (.52)	0.76 (.57)
	0 to 3	.040 to .195	.06 to .75	.28 to .75	.05 to 1.75	.27 to 1.75
60 min./180°	1.9 (1.3)	0.118 (.049)	0.20 (.21)	0.66 (.13)	0.48 (.59)	0.90 (.61)
	0 to 3	.062 to .204	.01 to .75	.54 to .75	.10 to 1.75	.37 to 1.75
90 min./180°	2.4 (.8)	0.114 (.034)	0.27 (.18)	0.68 (.12)	0.38 (.50)	1.04 (.58)
	1 to 3	.071 to .173	.14 to .75	.38 to .75	.12 to 1.75	.38 to 1.75
120 min./180°	2.3 (.9)	0.121 (.041)	0.22 (.10)	0.62 (.18)	0.25 (.12)	1.06 (.60)
	1 to 3	.080 to .183	.11 to .40	.30 to .75	.09 to .47	.28 to 1.75

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

other categories of penetration can be explained as long tangential "spikes" of penetration within one or two annual rings running perpendicular to the side of the sample, accounting for little of the total penetration. The interaction of heartwood/sapwood and preservative solution showed similar results with a heated solution of ACQ-B being significantly better than one or both of the other solutions in combination with sapwood for all categories. Consistent statistical significance was found in relation to heartwood/sapwood, preservative solution, and the respective interaction between the two. Significance in relation to time, for all categories, except MaxX, was also indicated, as can be seen in **Table 5,** although no obvious interpreta-

TABLE 8. — ANOVA probability level of significance for yellow-poplar heartwood penetration categories and "best" treatment(s).

		MinX	MaxX	% rating	MinY	MaxY
A[a]	Probability[b]	0.012	0.001	0.001	0.016	0.016
	Significantly best mean	3	3 = 1	3	3	3 = 1
B[c]	Probability	0.843	0.630	0.053	0.732	0.732
	Significantly best mean	NS[d]	NS	NS	NS	NS
AB[e]	Probability	0.364	0.012	0.087	0.380	0.012
	Significantly best mean		(1,2)[f]			
			(3,2)			(1,2)[f]
		NS	(3,1)	NS	NS	(3,3)
			(3,3)			(3,2)
			(1,3)			

[a] 1 = CCA; 2 = ambient ACQ-B; 3 = heated ACQ-B.
[b] Probability of larger F-ratio.
[c] 1 = 60 minutes, 2 = 90 minutes, 3 = 120 minutes.
[d] NS = no significance.
[e] Interaction of preservative × time.
[f] All equally best. 1 = 60 minutes; 2 = 90 minutes; 3 = 120 minutes.

TABLE 9. — Percentage rating of cross section penetrated, retention (pcf total oxide basis), penetration (in.), means, standard deviations, and ranges for red maple treated with CCA.

Time and sample	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./sapwood	3.0 (0)[b]	0.707 (.077)	0.54 (.24)	0.75 (.02)	1.11 (.61)	1.68 (.22)
	- -	.594 to .820	.28 to .75	.70 to .75	.40 to 1.75	1.06 to 1.75
90 min./sapwood	2.6 (.7)	0.619 (.133)	0.36 (.37)	0.75 (0)	0.85 (.86)	1.69 (.19)
	1 to 3[c]	.357 to .776	.00 to .75	- -	.00 to 1.75	1.18 to 1.75
120 min./sapwood	3.0 (0)	0.756 (.071)	0.64 (.24)	0.75 (0)	1.55 (.52)	1.75 (0)
	- -	.644 to .842	.07 to .75	- -	.12 to 1.75	- -
60 min./heartwood	0.0 (0)	0.189 (.056)	0.04 (.02)	0.27 (.11)	0.03 (.02)	0.18 (.10)
	- -	.113 to .265	.00 to .06	.17 to .53	.00 to .05	.05 to .31
90 min./heartwood	3.0 (0)	0.670 (.075)	0.38 (.27)	0.75 (0)	0.94 (.65)	1.75 (0)
	- -	.515 to .760	.05 to .75	- -	.09 to 1.75	- -
120 min./heartwood	2.0 (1.4)	0.539 (.262)	0.32 (.34)	0.59 (.26)	0.60 (.80)	1.30 (.75)
	0 to 3	.147 to .790	.00 to .75	.13 to .75	.00 to 1.75	.00 to 1.75

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

TABLE 10. — Percentage rating of cross section penetrated, retention (pcf CuO), penetration (in.), means, standard deviations, and ranges for red maple heartwood treated with ACQ-B.

Time and temperature	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./80°	2.5 (.7)[b]	0.171 (.027)	0.33 (.16)	0.66 (.16)	0.66 (.22)	1.21(.50)
	1 to 3[c]	.121 to .209	.05 to .58	.29 to .75	.27 to .91	.58 to 1.75
90 min./80°	2.3 (.8)	0.142 (.031)	0.24 (.31)	0.72 (.07)	0.45 (.70)	1.38(.48)
	1 to 3	.089 to .181	.03 to .75	.56 to .75	.03 to 1.75	.74 to 1.75
120 min./80°	1.5 (1.0)	0.094 (.030)	0.09 (.13)	0.62 (.18)	0.21 (.36)	1.25(.49)
	0 to 3	.033 to .142	.00 to .34	.32 to .75	.00 to 1.08	.19 to 1.75
60 min./180°	0.8 (.9)	0.088 (.032)	0.03 (.02)	0.56 (.20)	0.03 (.04)	0.86(.66)
	0 to 2	.047 to .137	.00 to .07	.34 to .75	.00 to .12	.16 to 1.75
90 min./180°	0.7 (1.2)	0.091 (.038)	0.06 (.02)	0.63 (.16)	0.08 (.08)	0.64(.68)
	0 to 3	.053 to .169	.03 to .08	.31 to .75	.00 to .27	.00 to 1.75
120 min./180°	0.6 (1.1)	0.078 (.040)	0.04 (.02)	0.44 (.27)	0.10 (.02)	.63(.62)
	0 to 3	.037 to .155	.02 to .07	.11 to .75	.08 to .14	.13 to 1.75

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

TABLE 11. — ANOVA probability level of significance for red maple heartwood penetration categories and "best" treatment(s).

		MinX	MaxX	% rating	MinY	MaxY
A[a]	Probability[b]	0.000	0.010	0.000	0.000	0.000
	Significantly best mean	1 = 2	2	2 = 1	1 = 2	2 = 1
B[c]	Probability	0.147	0.000	0.001	0.086	0.002
	Significantly best mean	NS[d]	2	2	NS	2 = 3
AB[e]	Probability	0.001	0.000	0.000	0.001	0.000
	Significantly best mean		(1,2)[f]			
			(2,2)			(1,2)[f]
		(1,2)[f]	(2,1)	(1,2)[f]	(1,2)[f]	(2,2)
		(2,1)	(3,2)	(2,1)	(2,1)	(1,3)
		(1,3)	(2,3)	(2,2)	(1,3)	(2,3)
		(2,2)	(1,3)	(1,3)	(2,2)	(2,1)
			(3,1)			

[a] 1 = CCA; 2 = ambient ACQ-B; 3 = heated ACQ-B.
[b] Probability of larger F-ratio.
[c] 1 = 60 minutes, 2 = 90 minutes, 3 = 120 minutes.
[d] NS = no significance.
[e] Interaction of preservative × time.
[f] All equally best. 1 = 60 minutes; 2 = 90 minutes; 3 = 120 minutes.

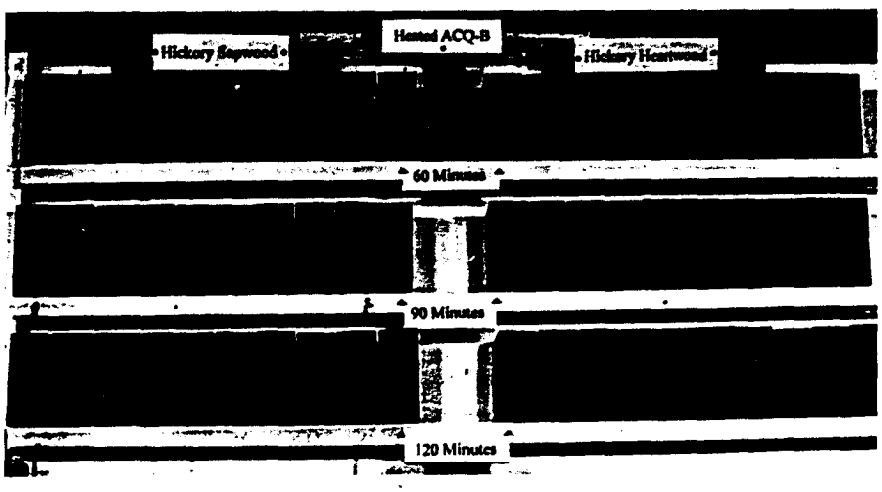

Figure 4. — Hickory sapwood and heartwood pressure treated with a heated ACQ-B solution.

tion is apparent. In the MinX, MinY, and percent cross section penetrated categories, a 90-minute pressure period was equally "best" with a 120-minute pressure period. However, there was no difference between the 60- and 120-minute pressure periods according to Fisher's LSD. In the MaxY category, the 90- and 120-minute pressure periods were statistically different from the 60-minute pressure period. All remaining 2-way and 3-way interactions were not significant except an ACQ-B ambient solution interacting with a 120-minute pressure period, which was significant in percent cross section penetrated, while the interaction of sapwood, CCA, and a 90-minute pressure period was significant for the MinY category. The statistical significance in these areas was most likely the result of random chance, was simply anomalous, or the result of difficulty in heartwood sapwood differentiation.

YELLOW-POPLAR

Tables 6 and **7** give the penetration and retention summary results for all treatments of yellow-poplar. Yellow-poplar sapwood was found to be 100 percent treatable with CCA **(Fig 2)** and would meet any criteria for treatment. As such, it was decided that sapwood would treat the same with ACQ-B and, therefore, was not included in the analysis of variance. Only the heartwood was investigated further.

Evidence for a shell treatment of heartwood, ranging from marginal to very good can be seen in the summary tables. The minimum penetration results for heartwood treated with CCA **(Table 6)** are all greater than zero. Assuming the penetration values of randomly sampled boards similarly treated would fall between the minimum and maximum penetration means, a shell of treatment of at

TABLE 12. — Percentage rating of cross section penetrated, retention (pcf CuO), penetration (in.), means, standard deviations, and ranges for hickory sapwood treated with heated ACQ-B.

Time and temperature	% rating[a]	PCF	MinX	MaxX	MinY	MaxY
60 min./180°	0.8 (.4)[b]	0.092 (.015)	0.11 (.07)	0.32 (.05)	0.10 (.07)	0.33 (.16)
	0 to 1[c]	.072 to .124	.00 to .22	.24 to .40	.00 to .23	.19 to .65
90 min./180°	0.2 (.4)	0.090 (.020)	0.10 (.06)	0.33 (.04)	0.07 (.05)	0.27 (.11)
	0 to 1	.066 to .118	.02 to .20	.31 to .42	.00 to .13	.16 to .49
120 min./180°	0.7 (.5)	0.080 (.010)	0.11 (.07)	0.36 (.05)	0.08 (.06)	0.27 (.06)
	0 to 1	.064 to .091	.00 to .21	.30 to .47	.00 to .17	.21 to .37

[a] Rating is the percent of cross section penetrated where 0 = 0 to 25 percent; 1 = 25 to 50 percent; 2 = 50 to 75 percent; and 3 = 75 to 100 percent.
[b] One standard deviation.
[c] Range.

least 0.3 inches could be reasonably expected. Treatment with the ambient solution of ACQ-B produced results **(Table 7)** similar to those from treatment with CCA. The heated solution of ACQ-B yielded the best penetration results **(Table 7)** and was statistically the best preservative solution in all penetration categories **(Table 8). Table 1** shows the frequency distribution of penetration results for heartwood (ignoring time). Desired retention levels of CCA in sapwood or heartwood would be easily achieved with a 2 percent solution. An ACQ-B solution strength of 2 percent or greater would probably be needed to reach 0.25 pcf in heartwood.

Significance in the maximum penetration categories was found for CCA. As with beech, this can be explained as long tangential "spikes" of penetration within one to several annual rings running perpendicular to the side of the sample, which accounted for large maximum penetration values, while minimum penetration values remained low. Time, when singled out, showed no significance. The two categories where interactions between the preservative and time were significant include a heated solution of ACQ-B, and CCA and all three time periods. The significance of the heated solution of ACQ-B is self explanatory, while the inclusion of CCA in the two maximum penetration categories can be explained by the previously mentioned areas of tangential penetration.

TABLE 13. — ANOVA probability level of significance for hickory penetration categories and "best" treatment(s).

		MinX	MaxX	% rating	MinY	MaxY
A[a]	Probability[b]	0.000	0.000	0.000	0.000	0.000
	Significantly best mean	2	2	2	2	2
B[c]	Probability	0.000	0.000	0.000	0.000	0.000
	Significantly best mean	3	3	3	3	3
AB[d]	Probability	0.000	0.000	0.000	0.000	0.000
	Significantly best mean	(2,3)	(2,3)	(2,3)	(2,3)	(2,3)
C[e]	Probability	0.077	0.221	0.749	0.884	0.392
	Significantly best mean	NS[f]	NS	NS	NS	NS

[a] 1 = heartwood; 2 = sapwood.
[b] Probability of larger F-ratio.
[c] 1 = CCA; 2 = ambient ACQ-B; 3 = heated ACQ-B.
[d] Interaction of heartwood/sapwood × preservative.
[e] 1 = 60 minutes; 2 = 90 minutes; 3 = 120 minutes.
[f] NS = no significance.

RED MAPLE

Tables 9 and **10** give the penetration and retention summary results for all treatments of red maple. Red maple, as with yellow-poplar, had easily treated sapwood **(Fig. 3)** with the same assumptions being made. While the percent of minimum penetration measurements that meet or exceed the hypothesized minimum penetration requirement was lower than that found for yellow-poplar, they still range from 58.6 to 62.1 percent while the lowest percentage for the maximum penetration values meeting or exceeding minimum requirements was 86.7 percent (MaxY). As such, sapwood was not included in the analysis of variance. **Table 1** shows the frequency distribution (ignoring time) of penetration results for the treatments of red maple heartwood.

Evidence of a shell treatment of red maple heartwood is similar to, yet less pronounced than, that found for yellow-poplar heartwood. While the mean minimum penetration values for CCA and Ambient ACQ-B were generally greater than those of a heated solution of ACQ-B, all three solutions had instances of zero penetration in these categories. A close visual examination of the red maple specimens indicated a tendency for the lower temperature/shorter pressure period samples to have been located further from the pith than samples in other treatment combinations and may have contained greater amounts of the more treatable sapwood or some sort of transition wood. This result indicates the difficulty in accurately distinguishing between heartwood and sapwood in red maple. It may also be an indication that red maple has relatively little heartwood, as has been indicated in the previously mentioned study done by Smith et al. Whether there are chemical reactions between copper and maple extractives that limited penetration at the higher temperature is a matter of supposition.

Statistical results **(Table 11)** for heartwood penetration show an ambient solution of ACQ-B was significantly best in the MaxX category and, along with CCA, best in the other four penetration categories when compared to a heated solution of ACQ-B. Time and the interaction between time and preservative had significance in some categories but the interpretation of these results is not readily apparent. A 90-minute pressure period was best for MaxX and percent cross section penetrated, and equally best, along with a 120-minute period, in the MaxY category. Significance was indicated in all categories for the interaction between preservative solution and time period but the interpretation of this is less than clear and may be affiliated with the previously mentioned proximity-to-pith observation.

HICKORY

Table 12 gives the penetration and retention summary results for the statistically best treatment of hickory, a heated ACQ-B solution. **Figure 4** shows the actual cross sections for this treatment. The remaining treatments are not summarized here, since they were so poor as to not warrant discussion, as the reader can judge from **Table 6** (being the best results). The probability that hickory would meet or exceed minimum penetration requirements for solid wood products is low based on these results. Hickory also had the lowest retentions of any of the species. Solution strengths of CCA might have to be doubled in order to consistently reach 0.40 pcf while ACQ-B retentions were consistently below 0.10 pcf.

Hickory was the most consistent of the species as to the factors that were statistically significant **(Table 13)** in improved penetration. While sapwood, a heated solution of .ACQ-B, and the interaction between the two were unanimously significant in improving penetration in comparison to the other treatments, this "best" treatment had penetration values well below the theoretical minimums discussed in this work.

Significance was also found in the percent cross section penetrated category for the interaction between sapwood and the 60- and 120-minute pressure periods, as well as the interaction between a heated ACQ-B solution and the 90-minute pressure period. The latter interaction was also significant in the MaxY category. As with beech, these statistical significances appear to be the result of random chance or were simply anomalous occurrences.

CONCLUSION

The treatability of hardwoods cannot be generalized and, in particular, this study further supports the difficulty in treating refractory heartwood of hardwood species. Each species must be investigated and evaluated on an individual basis. Generally, sapwood is more treatable than heartwood in the species investigated here, ranging from very good (yellow-poplar) to poor (hickory). Durability studies notwithstanding, based on these results, sawn stock of yellow-poplar and red maple could meet or exceed the referenced AWPA minimum penetration requirements for solid wood products, although incising might be required to consistently treat the heartwood. Where a shell treatment of preservative is deemed adequate, beech and the heartwood of yellow-poplar and red maple might be acceptable alternatives to the more commonly treated wood species, especially in tight of improved penetration using an ammoniacal preservative. This work may be another example of why hickory and beech are two of the least utilized of the Appalachian hardwoods. However, the potential for modest improvements in preservative penetration into the refractory wood of these species raises the possibility of a preservative treatment system for composite wood products, adhesion studies not withstanding. Whether there are reactions occurring with extractives that might explain why an ambient solution ACQ-B showed improved penetration results in red maple and beech, while the heated ACQ-B solution showed improved results for yellow-poplar and hickory, and why CCA was as good or better in some instances cannot be definitively answered here.