THE EFFECT OF PRESSURE ON RETENTION AND BENDING PROPERTIES OF COPPER NAPHTHENATE AND CCA TYPE C TREATED HARDWOODS

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ABSTRACT

The objective of this study was to investigate the effect of the pressure level on retention and bending strength of some northern hardwood species after preservative treatment. Samples of red maple, sugar maple, beech, and red oak were pressure-treated with waterborne chromated copper arsenic (CCA) type C or with oilborne copper naphthenate (Cu-N) at four pressure levels: 0.69, 1.03, 1.38, 2.07, and 2.76 MPa. At a pressure level of 0.69 MPa (200 psi) for 2 h, retentions of 4.5 kg/m^3 elemental copper from copper naphthenate and 10 ± 2 kg/m^3 total oxides from chromated copper arsenate (CCA) were achieved for maples. The pressure level did not affect the retention of Cu-N in red maple, sugar maple, and red oak; the same observation was made for CCA in maples. A pressure level of 2.76 MPa was needed to obtain a 7.5 kg/m^3 CCA retention and 1.08 kg/m^3 copper metal in Cu-N-treated beech. Copper naphthenate treatment did not affect the bending strength, while CCA-treated samples exhibited a reduced bending strength between 0 and 33% depending on the species, pressure level, and preservative type.

Keywords: CCA, Cu-N, copper naphthenate, hardwood, retention, pressure treatment, bending.

INTRODUCTION

Increasing industrial demand for redwood timbers that are easy to treat, combined with the recent restriction of harvesting from Pacific redwood forests and the depletion of durable wood species, may lead to the utilization of nondurable, relatively underutilized species and low-grade materials. They are mostly hardwoods with decay resistance properties varying from resistant to nondurable. Most furniture plants are designed for higher grades to produce high volume of parts with little waste. Dimension grade hardwoods are widely used for furniture and paneling, while the boxed heart with defects such as excessive split, pitch, crook, and numerous large knots are underutilized. The use of low-grade hardwoods in furniture and paneling is therefore limited. The potential use of hardwoods in high decay hazard situations such as farm posts or landscaping timbers is not well explored. One alternative to hardwood utilization, at least for low grade, is for exterior application or in an environment where termites, bacteria, or decay fungi may cause a problem. The protection of hardwoods could increase their use, particularly in regions with predominantly hardwood forests, such as the Northeastern United States and regions with nondurable abundant tropical hardwood species, for instance rubberwood in Southeast Asia, South America, and Africa.

Chromate copper arsenate oxides (CCA), ammoniacal copper zinc arsenate, creosote, pentachlorophenol, copper naphthenate (Cu-N), and copper dimethyl dithiocarbamate have been used commercially to protect softwoods. Creosote is used extensively for the protection of hardwoods in the railroad and the utility pole industries. Pentachlorophenol is used mostly for pole treatment (Micklewright 1993). Environmental questions may cloud the future utilization of creosote and pentachlorophenol for the protection of hardwoods in industrial and residential applications. CCA is the most widely used preservative in the world (Richards and McNamara 1997). CCA-treated hardwoods have shown considerable variation in performance, and the effectiveness is questionable (Pizzi et al. 1986).

The performance of CCA-treated hardwood compared to softwood has been a subject of considerable research (Butcher 1979). The problems encountered with the chemical treatment of hardwoods are the inability to obtain even distribution of the chemicals and difficulty in achieving a desired level of chemical retention.

Wood species, moisture content before treatment, pretreatment method such as steaming or drying, viscosity and temperature of the treating solution, vacuum and/or pressure level applied as well as their duration, are some of the parameters that influence wood treatability.

The objective of this study is to determine the effect of treatment pressure level on retention, modulus of elasticity (MOE), and modulus of rupture (MOR) in bending of CCA or Cu-N treated hardwoods.

EXPERIMENTAL

Design of the experiment

The factorial experiment was conducted with solution absorption, modulus of elasticity (MOE), and modulus of rupture (MOR) in static bending as the dependent variables. Wood species, treating pressure, and type of wood preservatives were considered as independent variables. Wood species included red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), and northern red oak (*Quercus rubra*). Four treating pressure levels were used: 0.69 MPa (100 psi), 1.38 MPa (200 psi), 2.07 MPa (300 psi) and 2.76 MPa (400 psi). Samples of each species were treated with solutions of waterborne CCA type C or oilborne copper naphthenate diluted with toluene.

A minimum of 10 specimens were treated at each pressure level for each wood species and each preservative type. The mean retention of the 10 specimen groups was used in the analysis. The bending strength of each untreated wood species was determined by testing ten untreated specimens conditioned at 21.1°C (70°F) and 65% relative humidity and equalized at 10% equilibrium moisture content (EMC).

Wood samples

For each species, six FAS defect-free nonseasoned rough sawn sapwood boards from the same growth period of a single log measuring 5 cm by 15 cm in cross section and 2.4 meter in length were purchased from a local hardwood sawmill. The selection of boards from a single log and from the same growth period of each species was intended to control variability. However, the variability within the species will not be addressed in this study.

Boards were air-dried in the laboratory and machined into 200 specimens measuring 19 by 19 by 435 mm. About 120 specimens free of visible defects and with a grain slope of less than 1:12 were selected for each species. The selected specimens were conditioned at 21.1°C (70°F) and 65% relative humidity. The conditioned specimens were weighed and sorted by weight range into eight groups of 10 specimens. The specific gravity based on oven-dry weight of each specimen was determined. The surfaces of each specimen were sealed with a silicone-type resin in order to restrict the end penetration and reduce end checking. The specimens were weighed before and after treatment to determine the weight gain retention.

Preservative treatment

A commercial ready-to-use solution of Cu-N with 2% copper as metal was diluted to 1% copper metal with toluene and used as treating solution in this study. Specimens measuring 19 mm by 19 mm by 435 mm were placed in a steel tank containing the treating solution and placed in the pressure cylinder. An initial vacuum of 625 mm of mercury was applied for 30 min, followed by 2 h pressure. The pressure level was reached within 5 min. A final vacuum of 625 mm mercury was applied for 30 min to obtain a clean surface and to reduce dripping.

A 2% total oxide of CCA type C solution was made from a 50% stock solution containing 17.3% CuO, 45% CrO_3, and 37.7% As_2O_5 and used for treatment. The same treatment schedule used for Cu-N was applied for CCA treatment.

After treatment the stakes were removed from the tank, wiped, and weighed promptly to determine the weight gain for the chemical retention estimation using the following equation:

$$CR = \frac{C*(FW - IW)}{(L*D*W)} \quad (1)$$

where CR is the chemical retention in kg/m^3, C, the copper or total oxides content in the treating solution, FW and IW, final and initial weight, respectively, L, W, D, length, width and depth of specimen.

Mechanical properties

The bending strength was determined by method D-143 specified by the American Society of Testing and Materials (ASTM 1996) with modification as noted below. ASTM D143 specifies 50- by 50-mm or 25- by 25-mm specimens; a 19- by 19-mm specimen was used in this study. ASTM D143 specifies center-point loading and about a 14:1 span to depth ratio; third point loading with span to depth ratio of 19:1 was used in this work. Before testing, preservative-treated stakes were first stored outside at 25 ± 8°C at 90 ± 8% relative humidity during the summer for 2 weeks to allow a mild evaporation of the solvent and then placed in a conditioned room at 21°C (70°F) and 65% relative humidity to achieve an approximative equilibrium moisture content (EMC) value of 10 ± 2%. Most of the samples were tested within 3 months after treatment. Bending samples were loaded on third points with a test span of 356 mm (14 in.). The span to depth ratio was 19:1, and the rate of loading was set at 1.25 mm per minute of constant displacement head travel.

Preservative distribution analysis

The retention of copper, chromium, and arsenic in the treating solution and in treated wood was determined by using atomic absorption spectroscopy (AAS) technique following AWPA A11-93 (AWPA 1997). A 19-mm cube was cut from the center points equidistant to extremities of treated stakes and was used to determine the preservative retention. The cube was cross-cut in halves, one half for the overall retention and the other half sectioned in two parts: the first outer 5 mm was called shell and the remainder 9 mm was labeled core. The average retention in shell, core, and the overall cube was analyzed to evaluate the macro-distribution of the treating solution and the impact of the pressure.

RESULTS AND DISCUSSION

Effect of pressure on retention

The average copper content in the shell, core, and samples treated with copper naphthenate and CCA is listed in Table 1 and Table 2, respectively. The copper and total oxides retention expressed in kg/m^3 was calculated by multiplying the concentration in percentage by the specific gravity of each sample at 12% moisture content. The values of the specific gravity calculated from the dry weight and the volume at 12% moisture content of sample

TABLE 1. *Gradient of copper retention (kg/m³) in Cu-N-treated wood vs. pressure level.*

Pressure, MPA	Description	Red Maple (RM)	Sugar Maple (SM)	Red Oak (RO)	Beech
0.69	Shell*	4.80	4.40	2.67	0.89
	Core**	3.40	2.11	1.01	0.17
	Core/shell	0.71	0.48	0.38	0.19
	Total mean	4.47	3.17	2.35	0.42
	SD***	1.42	0.65	0.77	0.82
1.03	Shell*	5.48	5.49	2.72	1.21
	Core**	3.88	2.61	1.63	0.27
	Core/shell	0.71	0.48	0.60	0.22
	Total mean	4.80	3.80	2.40	0.89
	SD***	1.2	0.60	0.75	1.0
1.38	Shell	5.35	4.95	2.6	1.41
	Core**	3.74	2.5	1.74	0.56
	Core/shell	0.70	0.51	0.67	0.40
	Total mean	4.76	3.78	2.60	1.05
	SD***	0.38	0.35	0.50	0.90
2.07	Shell*	5.38	4.80	2.41	1.80
	Core**	4.14	3.33	1.70	0.59
	Core/shell	0.78	0.69	0.70	0.32
	Total mean	4.80	3.64	2.56	1.11
	SD***	0.38	0.31	0.46	0.72
2.76	Shell*	4.76	4.25	2.99	1.97
	Core**	4.17	3.37	2.00	0.65
	Core/shell	0.87	0.80	0.67	0.33
	Total mean	4.62	3.60	2.50	1.08
	SD***	0.40	0.30	0.50	0.65

* The shell is the outer 5 mm of the sample. ** The core is the portion of the sample remaining after the shell has been removed. *** SD: standard deviation.

TABLE 2. *Gradient of total oxides retention (kg/m³) in CCA-treated wood vs. pressure level.*

Pressure, MPA	Description	Red Maple (RM)	Sugar Maple (SM)	Red Oak	Beech
0.69	Shell*	13.25	13.98	11.3	5.7
	Core**	6.59	5.83	5.93	1
	Core/shell	0.50	0.42	0.52	0.18
	Total mean	11.8	10.8	8.53	2.07
	SD***	4.67	2.91	3.51	3.82
1.03	Shell*	13.79	13.87	11.98	8.4
	Core**	8.39	10.56	6	3.07
	Core/shell	0.61	0.76	0.55	0.37
	Total mean	12.2	11.2	9.44	5.5
	SD***	3	2.7	3.12	3.42
1.38	Shell*	14.25	13.9	12.29	7.5
	Core**	11.39	11.0	8.17	3.2
	Core/shell	0.80	0.79	0.66	0.43
	Total mean	12.43	11.37	10.49	4.77
	SD***	2.55	2.48	2.80	3.43
2.07	Shell*	13.58	13.35	13.0	7.5
	Core**	11.38	9.87	8.1	4.56
	Core/shell	0.84	0.74	0.62	0.61
	Total mean	12.4	10.86	10.46	6.2
	SD***	2.47	1.81	2.95	1.82
2.76	Shell*	14.09	14.2	12.0	9.07
	Core**	11.25	10.9	7.89	4.50
	Core/shell	0.80	0.77	0.66	0.50
	Total mean	12.74	11.02	10.26	7.5
	SD***	1.82	1.37	2.59	2.01

* The shell is the outer 5 mm of the sample. ** The core is the portion of the sample remaining after the shell has been removed. *** SD: standard deviation.

used in this study were within the 10% coefficient of variation similar to data available in the literature (Forest Products Laboratory 1987).

Copper naphthenate (Cu-N)

Red maple (RM) absorbed more copper than sugar maple (SM), red oak (RO), and beech (B) from Cu-N treatment. The maximum retention of copper naphthenate by both maples was achieved at 1.03 MPa (150 psi), although no significant difference ($P = 0.05$) was found with retention at 0.69 MPa. A retention of 2.50 ± 0.50 kg/m³ was achieved by RO. The effect of pressure was not significant for red oak within the pressure level range used in this study (Table 3). The pressure level was important for the absorption of Cu-N in

TABLE 3. *Statistical analysis on the retention of preservative as function of the pressure level.*

Species	Pressure, MPa 0.69	1.03	1.38	2.07	2.76
			Cu-N		
RM	A	A	A	A	A
RO	A	A	A	A	A
SM	A	A	A	A	A
B	A	AB	B	B	B
			CCA type C		
RM	A	A	A	A	A
RO	A	AB	B	B	B
SM	A	A	A	A	A
B	A	AB	AB	AB	B

(Different letters within a row are significantly different at $\alpha = 0.05$).

beech with an increase of retention to 1.05 kg/m^3 at 1.38 MPa pressure level.

The standard deviation of the retention of Cu-N by red maple decreased from 1.42 to 0.40 with increased pressure. The same trend was noticed with sugar maple (0.65 to 0.30), red oak (0.77 to 0.50), and beech (0.86 to 0.65). Standard deviation characterizes the dispersion of individuals from the mean value, i.e., the closer the individuals are to the mean, the smaller the standard deviation. The increase of pressure level during the Cu-N treatment of hardwoods helps in reducing the variability of retention. It is long established that the increase of the pressure level and the period of time over which it is applied result in an increase of retention and penetration (Hunt and Garratt 1938). The penetrations obtained under insufficient pressure level and short treating periods conditions are reported to be very erratic and unsatisfactory (Hunt and Garratt 1938). After the absorption of preservatives has practically ceased at a given pressure level, there is little or nothing to be gained by increasing or maintaining the pressure. This may explain the reduction in the variability of retention with the increase of the pressure level. The retention level was more uniform between shell and core samples at 2.76 MPa pressure level than at 0.69 MPa.

During a treatment with pressure level at 0.69 MPa (100 psi) applied for 2 h, a copper metal retention of 4.4 ± 1.4 kg/m^3 is obtained on red maple and 3.2 ± 0.6 kg/m^3 on sugar maple, with a relatively low shell to core ratio.

A retention of 3.2 kg/m^3 copper from copper naphthenate was reported to be adequate for the protection of northern red oak and maple in a laboratory soil block test (Kamdem et al. 1995) and against termites (Grace et al. 1993). De Groot et al. (1988) reported data on the field performance of pine, Douglas-fir, and red oak stakes pressure-treated with Cu-N and exposed in Mississippi, Louisiana, and Wisconsin. A copper retention between 0.06 and 0.117 pcf (0.96 and 1.87 kg/m^3) was sufficient to protect for more than 28 years' exposure in Mississippi and Wisconsin. Specimens treated at 0.05 pcf (0.85 kg/m^3) copper and exposed in Florida suffered from deterioration.

CCA type C

Retention of CCA as a function of pressure level applied during the treatment is listed in Table 2. Red maple and sugar maple, the two diffuse porous species without tyloses, absorbed more CCA than red oak and beech at 0.69 MPa and 1.03 MPa. The pressure level in this range (0.69–2.76 MPa) did not significantly affect the CCA retention in red maple and sugar maple (Table 3). The same trend was noticed with Cu-N treatment. A CCA retention of 11.8 ± 4.6 kg/m^3 was achieved with red maple and 10.8 ± 2.9 kg/m^3 with sugar maple at 0.69 MPa (100 psi). Butcher (1979) reported that at least 0.3% copper is needed to protect *Tilia vulgaris, Betula alba, Fagus sylvatica,* and *Eucalyptus sp.* against soft rot decay in unsterile soil. The 0.3% minimum requirement of copper from CCA type C corresponds to a minimum CCA retention of 10 kg/m^3 for hardwood species with 0.60 specific gravity. At 0.69 MPa pressure level for 2 h, red maple and sugar maple satisfied the 10 kg/m^3 CCA retention requirement.

The pressure level had a positive effect on the CCA retention in beech and red oak. A minimum pressure level of 1.03 MPa applied for 2 h was needed for red oak to achieve a CCA retention of 9.44 ± 3.12 kg/m^3, and 2.76 MPa for 7.5 ± 2.01 kg/m^3 in beech. Acceptable retention levels in beech were not achieved. Behr (1967) reported that beech sapwood can be treated by short-time soaking in solvent-borne preservatives and that penetrations at moisture contents of 10 to 20% are superior to beech wood of 30% moisture or higher. However, soaking in waterborne preservatives did not give satisfactory penetrations. Behr et al. (1969) found oil in vessels containing tyloses in beech and suggested that rays in the red heart of beech wood were often clogged by brown gum capable of limiting the penetration of preservatives.

TABLE 4. *Summary of the MOR (MPa) of Cu-N and CCA-treated hardwoods as function of the pressure applied during treatment.*

Wood species		Control		0.69		1.03		1.38		2.07		2.76	
		Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
						Cu-N							
RM	MOR, MPa	80	21	70	10	60	10	70	20	80	10	80	20
RO	MOR, MPa	100	20	110	20	100	10	100	20	100	20	100	20
SM	MOR, MPa	110	21	120	20	110	30	110	20	100	30	120	10
B	MOR, MPa	120	20	110	20	120	30	120	20	110	20	110	20
						CCA-C							
RM	MOR, MPa	80	21	80	10	80	10	70	10	70	10	60	10
RO	MOR, MPa	100	20	80	20	80	20	80	10	80	10	80	20
SM	MOR, MPa	110	22	100	10	100	20	100	20	100	10	90	10
B	MOR, MPa	120	30	100	20	110	10	100	40	80	20	80	10

(Pressure level MPa)

Retention in shell and core

Tables 1 and 2 contain the retention values of copper metal and total oxides of the outer 5-mm shell and the remaining core portion, as well as the ratio of core to shell values. The higher retention value of shell compared to core was predictable. The core to shell ratio was used as an indicator of penetration. A ratio value close to 1 corresponds to a uniform retention in both core and shell.

Unlike beech, the core to shell ratio for Cu-N-treated samples increases with the pressure level from 0.70 to 0.87 for red maple, 0.48 to 0.80 for sugar maple, and 0.38 to 0.70 for red oak. The pressure level can be used as a means to increase the penetration of Cu-N in some hardwood species. The same pressure effect was observed with CCA treatment. The core to shell ratio of red maple varied from 0.50 to 0.80, 0.42 to 0.77 for sugar maple, and 0.52 to 0.66 for red oak. The high core to shell ratio values of Cu-N-treated wood compared to CCA-treated hardwood suggest that a better penetration is achieved with oilborne Cu-N. The solubility of gum or deposits in the rays and vessels with oilborne preservatives may partially explain the penetration level achieved with Cu-N compared to CCA.

Effect of pressure on MOE and MOR

Tables 4 and 5 summarize the average value and the standard deviation of MOR and MOE for each species at each pressure level and for each preservative, respectively. The values of MOR and MOE of untreated samples are comparable to values of bending strength available in the literature (FPL 1987).

The MOE and MOR of hardwood after Cu-N treatment were similar to those of untreated samples. No statistically significant reduction was detectable at a 5% level (Table 7). This suggests that after 2 h at these pressure levels, no deleterious effects on bending strength and stiffness occur with Cu-N-treated wood. The pressure level and the Cu-N preservative have a negligible effect on the bending strength of hardwood. This is in agreement with results reported on creosote treatment by Walters (1967), although a more comprehensive study with more representative sampling is needed to confirm this finding.

The effect of CCA treatment and redrying on the mechanical strength of southern yellow pine has been widely covered in the literature. The mechanical strength was significantly reduced after the CCA treatment and this was attributed to the hydrolysis of wood carbohydrate by the low pH of CCA (Winandy 1995). Values in Tables 4 and 5 indicate that the MOE and MOR were reduced after CCA treatment. MOE and MOR of red maple were reduced over a range of 0 to 25% (Table 6). The reduction of MOE and MOR in sugar maple ranged from 4 to 21%, about 15 to 25% for

TABLE 5. *Summary of the MOE (GPa) of Cu-N arid CCA- treated hardwoods as function of the pressure applied during treatment.*

Wood species		Pressure level MPa											
		Control		0.69		1.03		1.38		2.07		2.76	
		Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
							Cu-N						
RM	MOE, Gpa	9.00	1.89	8.68	1.57	8.94	3.35	8.42	1.50	8.23	4.80	8.58	1.57
RO	MOE, Gpa	11.71	2.23	12.07	2.60	11.79	2.31	11.16	2.51	11.85	2.58	11.20	1.74
SM	MOE, Gpa	12.39	2.50	12.95	1.95	12.82	2.44	12.05	2.81	12.65	3.04	13.36	1.05
B	MOE, Gpa	13.43	2.14	11.96	3.33	11.88	2.80	11.96	2.17	11.73	2.56	10.31	2.14
							CCA-C						
RM	MOE, Gpa	9.00	1.89	8.00	1.22	8.05	1.54	7.94	1.52	7.80	0.97	6.84	1.28
RO	MOE, Gpa	11.71	2.23	9.98	1.63	9.70	1.92	9.39	2.39	8.76	1.72	8.77	2.14
SM	MOE, Gpa	12.39	2.50	12.38	0.94	12.10	1.49	11.85	2.34	11.19	1.05	10.13	0.90
B	MOE, GPa	12.92	2.14	11.60	1.66	11.30	1.52	11.16	2.68	9.65	1.54	8.96	1.47

red oak, and 8 to 33% for beech (Table 6). The MOE seems more sensitive to the effect of CCA treatment than the MOR.

A linear regression was run to determine if any significant relationship exists between the bending strength and the pressure applied during CCA type C treatment. The coefficient of correlation (C2) varied from 0.79 to 0.96 for MOE and from 0.43 to 0.85 for MOR. Beech exhibits the highest coefficient of correlation for both MOE (0.96) and MOR (0.85), followed by sugar maple with 0.79 for MOE and 0.74 for MOR, and red maple with 0.84 for MOE and 0.84 for MOR. Northern red oak coefficient of correlation was 0.82 for MOE and 0.43 for MOR. Data supporting correlation between MOE or MOR and the wood species were obtained from a single log for each species. Accordingly, this protocol controlled variability between species and ignored variability within species. Further studies, including representative sampling of each species, are needed before any major implications on the treatability or mechanical properties of CCA-treated hardwood species can be made.

A Pearson product moment correlation was also run to determine the effect of pressure on mechanical property at a 5% level. All correlation coefficients were negative with P values below 0.05. This clearly indicates that MOE or MOR tend to decrease as the pressure level increases for CCA treatment. The strength reduction after treatment has been attributed to the damage caused by the pressure treatment (Hunt and Garratt 1938) or/and temperature of the subsequent drying (Winandy 1995). However, data from copper naphthenate treated

TABLE 6. *Change (%) in MOR and MOE after CCA treatment compared to mean value.*

Species	Pressure, MPa	0.69	1.03	1.38	2.07	2.76
		Change, %				
RM	MOR	0	0	−12	−12	−25
RO	MOR	−20	−20	−20	−20	−20
SM	MOR	−9	−9	−9	−9	−18
B	MOR	−17	−8	−17	−33	−33
RM	MOE	−11	−11	−12	−13	−24
RO	MOE	−15	−17	−20	−25	−25
SM	MOE	−4	−6	−8	−13	−21
B	MOE	−10	−13	−14	−25	−31

TABLE 7. *Statistical Analysis of MOE and MOR of CCA treated-hardwoods as affected by pressure level.*

Species		CCA type C Pressure, kPa					
		None	0.69	1.03	1.38	2.07	2.76
RM	MOE	A	AB	AB	AB	AB	B
RO	MOE	A	AB	AB	B	B	B
SM	MOE	A	AB	AB	AB	AB	B
B	MOE	A	AB	AB	B	BC	C
RM	MOR	A	A	A	A	A	A
RO	MOR	A	B	B	B	B	B
SM	MOR	A	AB	AB	AB	B	B
B	MOR	A	AB	AB	AB	B	B

(Different letters within a row are significantly different at α = 0.05).

samples did not indicate any bending strength reduction. The relation between pressure level and bending strength applies only to CCA type C treatment. The bending strength reduction may be explained by a chemical degradation caused by CCA and the pressure treatment.

CONCLUSIONS

This study shows that a copper retention of 4.4 ± 1.4 kg/m^3 in red maple, 3.2 ± 0.6 kg/m^3 in sugar maple, and 2.3 ± 0.8 kg/m^3 in red oak can be achieved by an oilborne Cu-N treatment with 0.69 MPa (100 psi) applied pressure level for 2 h. The retention level was not significantly affected by the increase of the pressure level up to 2.76 MPa (400 psi). The copper retention was affected by pressure only in beech. MOE and MOR from bending strength were not affected either by the copper naphthenate treatment nor the pressure level applied during the Cu-N treatment.

A CCA retention of 11.8 ± 4.6 kg/m^3 was achieved with RM and 10.8 ± 2.9 kg/m^3 with SM at 0.69 MPa (100 psi). Bending strength of CCA-treated wood at this retention target was negatively affected. MOE and MOR were reduced over a range of 4 to 33% depending on the species.

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