CCA preservative treatment and redrying effects on the bending properties of 2 by 4 southern pine

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Abstract

Loblolly pine 2 by 4 lumber was treated with chromated copper arsenate (CCA) preservative (0.4 or 0.6 pcf) and then air-dried or kiln-dried at 240°F. For commercially graded No. 2 lumber, average bending strength was consistently reduced from 6 to 23 percent depending on the treatment and redrying level. The effect of CCA treatment and redrying throughout the rest of the bending strength distribution was shown to be a function of rank order or percentile level within the distribution. Air-drying after treatment affected strength only above the 20th to 40th percentile depending on the level of treatment. Kiln-drying after treatment at 240°F affected the entire bending strength distribution. The effects of CCA treatment and redrying were highly interactive with quality level based on strength ratio and the presence or absence of pith. Results indicated that CCA treatment and redrying reduced the strength of 2 by 4 loblolly pine lumber having higher strength ratios more than 2 by 4 lumber having lower strength ratios. The presence of pith tended to lessen the effect of CCA treatments on strength.

For engineering design, reduction is not currently required in allowable design stresses (10-yr. loading) for lumber treated with waterborne preservatives (9). Yet, chromated copper arsenate (CCA) preservative treatments reduce the strength of many treated wood products (13). This strength loss seems to be caused by both the hydrolytic chemical (pH 1.5 to 3.0) and the temperature sustained in kiln-drying after treatment (KDAT). This study is intended to address questions about the effects of using high temperatures (> 212°F) in the KDAT process; temperatures similar to those used in the initial kiln-drying. In addition, recent research results involving CCA-treated lumber have differed considerably in regard to treatment effects on specimens in the lower tails of the strength distribution. Two recent studies have found larger reductions in the lower regions of the strength distribution than in mean properties, Barnes and Mitchell (3) using No. 1 and better Southern Pine and Knuffel (6) using three machine stress-rated grades of South African pine. Conversely, Winandy and Boone (15) found less effect in the lower regions of the strength distribution than at mean or higher regions when using No. 2 Southern Pine. This study attempts to explain the differences between these earlier studies and how the distributional characteristics of lumber bending properties are affected by CCA treatments, lumber quality, size, and the presence or absence of pith.

Experimental procedures

The experimental specimens, 1,148 8-foot-long loblolly pine (*Pinus taeda* L.)2 by 4's, were sorted into 7 treatment-drying groups, each with 164 specimens (Table 1); sorting procedures are discussed later. One group was kept as a true control; two groups were treated with water; and two groups each were treated with either of two target levels of CCA retention, 0.4 or 0.6 pcf. After treatment, the CCA- and water-treated 2 by 4's were either air-dried or kiln-dried at 240°F. Target levels of CCA treatment were chosen to represent the American Wood-Preservers' Association (AWPA) specified CCA retentions (2) for structural lumber intended for use in ground contact (0.4 pcf) or in a permanent wood foundation (0.6 pcf). Drying conditions were chosen to represent two extreme industrial redrying practices.

All specimens were commercial grade No. 2. Because of certain anatomical or manufacturing limits in the national grading rules (NGR) (11), this lumber contained many pieces that would qualify for a higher grade if they had been graded for knot size or slope of grain only. Examples of these limits are those for wane, warp, and manufacturing defects in excess of those allowed in Select Structural or No. 1 graded lumber. In many cases, these limits are intended to ensure the straightness, presence of an adequate nailing edge, or appearance rather than

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TABLE 1. – *Experimental design showing the seven treatment-drying groups and the number of 2 by 4 specimens graded as No. 2 ongrade, or graded on strength-reducing characteristics only.*

		No. of specimens				
Treatment	Redrying	No. 2 ongrade (SR[a] ≥ 0.45)	SR ≥ 0.66	SR < 0.66	SR ≥ 0.55	SR < 0.55
None (control)	None	164	76	88	111	53
Water	None					
	Air-dried	164	66	98	98	66
	Kiln-dried	164	57	107	90	74
CCA	None					
0.4 pcf	Air-dried	164	68	96	105	59
	Kiln-dried	164	57	107	104	60
CCA	None					
0.6 pcf	Air-dried	164	72	92	108	56
	Kiln-dried	164	59	105	99	65

[a]SR = strength ratio.

the strength of a piece. Thus, No. 2 grade lumber may have a range of actual strength ratios from 0.45 to nearly 1.00.

Material

Loblolly pine trees from southern Arkansas were identified in the field, harvested, sawn into lumber, and kiln-dried at 180°F by a cooperating sawmill. A Southern Pine Inspection Bureau quality supervisor selected 1,148 2 by 4 8-foot specimens to be No. 2 ongrade as defined in the NGR (11). The lumber was then shipped to the Forest Products Laboratory (FPL) in Madison, Wis., and equilibrated at controlled conditions of 74°F and 65 percent relative humidity (RH). The flatwise stiffness of each 2 by 4 was determined using a Metriguard E-computer.[1] The presence of pith was noted. Finally, the two worst knots and the maximum slope of grain were measured so that for each specimen a strength ratio (SR) could be calculated based solely upon the largest strength-reducing factor that could be placed within (or nearest to) the maximum-moment zone during the bending test. This SR was then used to assign specimens to four SR classifications. The range of possible SRs for commercially graded No. 2 lumber and for each of the four experimental SR classes are shown in Figure 1.

The commercially graded No. 2 lumber and the four SR classes provided two schemes for analyzing the data. One scheme analyzed the specimens solely on the basis of the NGR (11); it was termed the No. 2 ongrade analysis. With a large number of specimens in each treatment-drying group, this scheme provided precise identification of treatment and redrying effects throughout the entire bending property distribution for No. 2 lumber. The second scheme analyzed the same specimens, but the specimens were classified exclusively on the basis of strength-reducing factors. This scheme, with multiple SR classes, provided a means of assessing the interaction between treatment- and drying-induced effects and recognized predictors of lumber quality, such as knot size and location from edge and slope of grain. Because the first scheme was deemed most important, the specimens were assigned to treatment groups solely on the basis of pretreatment stiffness to ensure similar modulus of elasticity (MOE) distributions for each of the seven No. 2 ongrade groups.

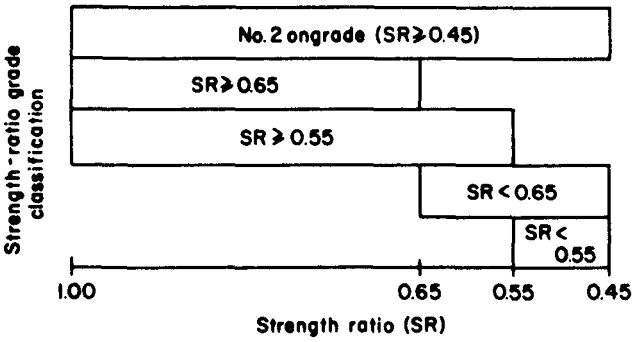

Figure 1. – Range of strength ratios in commercially graded No. 2 ongrade lumber and in each of the four strength ratio classifications.

MOE correlates with strength, therefore, this procedure helps to ensure similar strength distributions, too. Thus, for the second scheme involving the SR classes, the number of specimens in each treatment group was uncontrolled, even though sorting by pretreatment stiffness tended to balance the distributions (Table 1).

Treatment

For each retention, 2 groups each of 164 2 by 4's were treated by a local commercial treater using a CCA (Type C) oxide formulation and a modified full-cell process to target retentions of 0.4 and 0.6 pcf (2). The treater tested both charges for penetration and retention using a 20-boring sample taken from each charge. An analysis for CCA retention was performed using an Asoma x-ray spectrometer. Water treatments were performed at FPL using a modified full-cell process. Post-treatment moisture contents (MC) for both CCA- and water-treated specimens ranged from 35 to 85 percent. Before drying, the CCA-treated specimens were close-piled and covered outdoors during July 1984 for 5 to 8 days at ambient temperatures and humidities in Madison. This provided a fixation period between treatment and drying (14).

Drying

Kiln redrying of treated lumber was performed at FPL in a steam-heated dry kiln using 240°F dry-bulb and 180°F wet-bulb temperatures. Airspeed was 800 to 1,000 fpm. The lumber was dried in 4-foot-wide piles using 3/4-inch stickers on 2-foot centers. It took 6 hours to reach

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[1] The use of firm or trade names is for reader information and does not imply endorsement by the U.S. Dept. of Agriculture.

an average MC of 24 percent, with an additional 6 hours of equalizing at 168°F dry-bulb and 160°F wet-bulb temperatures for a total time in the kiln of 12 hours. The 24 percent average MC level after the drying phase was chosen to ensure that specimens equilibrated under desorbing conditions. Strength is affected by MC, and equilibrium moisture content (EMC) differs depending on whether a specimen approaches equilibrium under adsorbing or desorbing conditions. Thus, we chose a kiln-drying schedule to ensure that all specimens would subsequently approach their EMC under desorbing conditions, rather than adsorbing conditions. The target MC for individual pieces coming from the kiln after the drying and equalization phases was a minimum of 19 percent. A top load of 40 psf was used on all charges to minimize warp in the upper courses.

Specimens designated for air-drying were dried at FPL during the summer of 1984. Lumber piles were 6 feet wide using 314-inch stickers on 2-foot centers and roofed with plywood. To keep the plywood from blowing off, lead weights were placed on top of the plywood, otherwise a top load was not employed. After 4 weeks, the lumber had dried to 12 to 15 percent MC.

Environmental conditioning

Before mechanical testing, all specimens (treated and controls) were conditioned in a controlled environment of 74°F and 60 percent RH. CCA treatments can have a significant effect upon the EMC of treated small, clear specimens (4,16). A comparable effect in 2 by 6 lumber has also recently been reported (15). The MC calculated after mechanical testing was used to test for an effect on lumber MC after CCA treatment and redrying.

Mechanical testing

Static bending tests (1) were performed on edge using third-point loading and a 17:1 span-to-depth ratio. The main strength-reducing defect was placed in the maximum-moment area. If the main defect could not be placed within this area, the second most strength-reducing defect was placed within this area. When neither of these defects could be placed in this maximum-moment area, the specimen was tested so that the defect (of the two recorded) that could be placed closest to the maximum-moment area was used. Thus, the inability to always place the primary grade-limiting defect within the maximum-moment area tended to increase the number of specimens in the higher SR classes.

For each group, one-half of the specimens were tested with the chosen defect up (in the compression zone), and one-half of the specimens were tested with it down (in the tension zone). The rate of loading was 0.6 inch of head travel per minute, which was about 3.15 times faster than the standard rate (1). This faster rate induced failure in about 30 to 70 seconds and was used because earlier results for untreated southern pine indicated no difference between standard loading rates and those up to 25 times faster than standard (5). Load was measured using a calibrated load cell and deflection was measured using a linear potentiometer. The maximum load (PMAX), maximum center-span deflection (DMAX), modulus of rupture (MOR), MOE, and work to maximum load (WML) were calculated at time of test from the loads and deflection acquired during testing on an interfaced microcomputer. Because CCA treatment induces bulking (swelling), which effectively reduces MOR, we felt PMAX might be a valuable parameter to quantify the comparable load-carrying capacities of treated and untreated beams. DMAX was included because past studies (4,8,16) have shown appreciable losses in WML without corresponding losses in MOE.

Immediately after testing, a block was cut from each specimen near the zone of failure to determine MC and specific gravity (SG) at the time of the test. SG measurements were based on ovendry weight and volume at test.

Statistical analysis

An analysis of variance was performed for each mechanical property considered under each of the two grading schemes. When the analysis of variance indicated that significant differences existed between mean property estimates, a Tukey multiple comparison was used to identify where statistically significant differences existed. Depending on the property-grade combination being considered, these Tukey tests could generally discern mean differences of 7 to 15 percent as being significantly different at the 95 percent significance level. While statistical tests exist to test equality at various percentile levels away from the mean, their power decreases rapidly as one moves away from the distribution mean. For this reason, a practical difference of 10 percent allows a more uniform criterion for comparing the distributions and represents an arbitrary definition of what constitutes a practically important difference when considering the number of specimens used (i.e., 164 per treatment-drying combination). Thus, when comparing the differences at other percentiles in the lower tail of the distributions, a 10 percent difference between the untreated control and treatment-drying combination in question is used as a practical test of the importance of these differences throughout the distributions.

Results

The commercial treater reported that both charges met the specified targets for penetration and retention. For CCA retention estimates, the treater assumed a density for southern pine of 32 pcf and reported average CCA retentions of 0.49 and 0.71 pcf (target 0.4 and 0.6 pcf, respectively).

Average MC at the time of mechanical testing for the individual treatment-drying-grade groups ranged from 9.8 to 12.0 percent (Table 2) depending upon grade, treatment, and redrying level. After equilibrating at 74°F and 60 percent RH, the MC of air-dried CCA-treated lumber was significantly ($\alpha < 0.0001$) higher than that of untreated lumber, however when redried at 240°F, the MC of CCA-treated lumber was always significantly ($\alpha < 0.0001$) lower. To a lesser extent, the water-treated lumber appeared to show this same trend of an increased MC when air-dried and a decreased MC when kiln-dried. Apparently, CCA-treated lumber followed by air-drying results in a product having a greater number of water-bonding sites when compared with untreated controls, as indicated by its increased water-holding propensity (i.e., higher MC). Conversely, high-temperature KDAT results in a treated product with fewer water-bonding sites, as indicated by its decreased water-holding propensity (i.e., lower MC). The hydrophilic nature of CCA and a lack of enough thermal energy to induce significant hydrolysis of the wood cell wall might explain the higher MC found in air-dried material. The lower MC of high-temperature KDAT material might be explained by the combination of acidic CCA and high temperatures that could induce significant cell wall hydrolysis. Further supporting this theory is the fact that the MC of water-treated specimens is intermediate between untreated controls and CCA-treated specimens when followed by either air-drying or kiln-drying. Results of previous experiments also support this theory (7,15,16).

Mechanical properties

The results of this study were significantly impacted by the presence or absence of pith. This was especially true when the various SR classifications were considered separately. However, the experiment was designed to be analyzed in two ways; as graded under current grading rules in which pith is not a grade-limiting factor, and as a function of SR class (based solely on knot size and location or slope of grain) and the presence or absence of pith. Accordingly, we will first discuss the effects of CCA on 2 by 4 lumber as it is currently graded as No. 2, and then examine the SR class and pith interaction and its impact. The mean, standard deviation, and various percentile estimates of MOR for No. 2 ongrade and for the four SR classes are shown in Table 2. Percentile estimates were calculated using a nonparametric ordered-rank procedure (12). The mean and standard deviation for PMAX, DMAX, MOE, and WML are shown in Table 3.

No. 2 ongrade. – Consistent with earlier reports, the effects of CCA treatment and redrying on MOE appear negligible (Table 3). In contrast, the mean of MOR, PMAX, DMAX, and WML of every group treated with CCA was reduced when compared to untreated controls (Tables 2 and 3). When air-dried after CCA treatment, the reductions in mean MOR were 6 percent when treated to 0.4 pcf and 8 percent when treated to 0.6 pcf. However, because of the natural variability associated with lumber properties, these apparent differences were not shown to be statistically significant at the $\alpha \leq 0.05$ level. Air-drying after CCA treatment also apparently reduced the mean of PMAX, DMAX, and WML when compared to untreated

TABLE 2. – *CCA treatment and redrying effects on the modulus of rupture (MOR) of 2 by 4 southern Dine as graded for various strength and appearance factors.*

Strength ratio (SR) classifications	Treatment	Drying level	No. of specimens	MOR Mean	SD[a]	5th percentile	25th percentile	50th percentile	75th percentile	MC[b]	SG[c]
				(psi)						(%)	
No. 2 ongrade (SR > 0.45)	None	None	164	6,110	2,990	2,690	3,830	5,480	7,680	11.0	0.47
	Water	Air-dried	164	5,670	2,620	2,620	3,670	4,910	7,090	11.4	0.46
		Kiln-dried	164	5,390	2.460	2,410	3.510	4,770	6,700	10.5	0.46
	0.4[d] pcf	Air-dried	164	5,730	2,550	2,710	3,870	5,090	6,870	11.8	0.48
		Kiln-dried	164	4,700	1,930	2,240	3,310	4,150	5,710	9.9	0.47
	0.6 pcf	Air-dried	164	5,630	2,660	2,560	3,660	4,850	7,360	12.0	0.48
		Kiln-dried	164	4,730	2,110	2,330	3,400	4,090	6,070	10.1	0.47
SR $\geq$ 0.65	None	None	76	7,530	3,040	3,010	5,510	7,140	9,080	10.9	0.50
	Water	Air-dried	66	6,880	2,520	3,610	5,030	6,080	8,260	11.6	0.47
		Kiln-dried	57	7,190	2,590	3,560	4,930	6,710	9,030	10.6	0.47
	0.4 pcf	Air-dried	68	6,800	2,730	3,410	4,890	6,340	8,160	11.8	0.49
		Kiln-dried	57	5,230	1,930	2,710	3,650	4.910	6,460	9.8	0.47
	0.6 pcf	Air-dried	72	6,560	2,590	2,960	4,450	6,300	8,100	12.0	0.48
		Kiln-dried	59	6,030	2,030	3,100	4,340	5,860	7,430	10.1	0.49
SR $\geq$ 0.55	None	None	111	6,800	3,070	2,950	4,320	5,930	8,750	11.0	0.49
	Water	Air-dried	98	6,390	2,530	3,320	4,550	5,660	7,970	11.5	0.46
		Kiln-dried	90	6,240	2,570	3,090	4,140	5,500	7,920	10.5	0.46
	0.4 pcf	Air-dried	105	6,250	2,540	3,250	4,420	5,660	7,310	11.9	0.49
		Kiln-dried	104	4,990	1,980	2,750	3,580	4.430	6,320	9.8	0.47
	0.6 pcf	Air-dried	108	6,090	2,780	2,870	3,870	5,340	7,900	12.0	0.47
		Kiln-dried	99	5,230	2,120	2,570	3,540	4,750	6,560	10.2	0.48
SR < 0.65	None	None	88	4,880	2,350	2,480	3,230	4.270	5,530	11.1	0.45
	Water	Air-dried	98	4,860	2,360	2,280	3,290	4,290	5.470	11.4	0.45
		Kiln-dried	107	4,430	1,750	2,260	3,220	3,980	5,450	10.5	0.45
	0.4 pcf	Air-dried	96	4,970	2,110	2,480	3,400	4,630	6,050	11.8	0.47
		Kiln-dried	107	4,420	1,880	2,170	3,110	3,920	4,890	9.9	0.47
	0.6 pcf	Air-dried	92	4,900	2,500	2,440	3,130	4,160	5,590	12.0	0.47
		Kiln-dried	105	4,000	1,780	2,190	2,810	3.520	4,430	10.1	0.46
SR < 0.55	None	None	53	4,660	2,240	2,190	2,990	4,120	5,440	11.0	0.45
	Water	Air-dried	66	4,610	2,390	2,210	3,220	3,960	4,890	11.4	0.45
		Kiln-dried	74	4,360	1,870	2,330	3,110	3,830	5,540	10.6	0.46
	0.4 pcf	Air-dried	59	4,790	2,300	2,340	3.160	4,190	5,680	11.8	0.47
		Kiln-dried	60	4,200	1,760	2,000	3.030	3.890	4.770	9.9	0.47
	0.6 pcf	Air-dried	56	4,750	2,190	2,350	2,990	4,380	5,590	12.0	0.48
		Kiln-dried	65	3,970	1,870	2,190	2,800	3,420	4,430	10.0	0.46

[a] SD = standard deviation.
[b] MC = moisture content.
[c] SG = specific gravity.
[d] Pcf of CCA.

controls, but again, not significantly. On the other hand, CCA treatment and redrying at 240°F reduced the mean of the MOR by 23 percent, and this was significant at the $\alpha < 0.0001$ level. Redrying CCA-treated material at 240°F also significantly reduced the mean of PMAX, DMAX, and WML.

Generally, PMAX was affected in an identical manner as MOR. This infers that CCA treatments do not induce enough bulking to warrant any practical concern about differences between effects on fiber bending strength and beam load-carrying capacity.

The reduction in WML was between 1-1/2 and 2 times the effect on bending strength. This was expected, considering that a recent review of the literature (13) noted other energy-related properties, such as toughness and impact bending, are also comparably affected. The reductions in WML and DMAX may indicate that in instances where impact-type loading is expected, additional research might be needed to verify existing design stresses (currently derived from untreated static tests). In addition, the reported losses in WML and DMAX may indicate that the current duration-of-load model derived from untreated wood may not apply to treated wood. Recent work has shown that CCA-treated lumber may respond differently than untreated lumber in cases where treated members are loaded to full-design capacity for extended periods (10). FPL is also currently studying the influence of rate of load on CCA-treated lumber.

The effects of CCA treatment and redrying on bending strength are related to rank order or percentile level within the strength distribution (Figs. 2 and 3). When the specimens were air-dried after treatment, the effect of CCA treatment on the MOR of No. 2 ongrade appears negligible below the 40th percentile for the 0.4 pcf retention and below the 20th percentile for the 0.6 pcf retention (Fig. 2). This includes the 5th percentile. However, when kiln-dried after treatment at 240°F, bending strength is reduced throughout the entire distribution, with the reduction generally increasing with percentile (Fig. 3). For each redrying level, the relative difference in MOR between each group and the untreated control is plotted over the entire distribution to illustrate how specimens at the high end of the strength distribution (i.e., naturally stronger specimens) are reduced in strength by treatment to a greater extent than low-end specimens (Fig. 4). Note that the difference between the three air-dried treatments and the untreated control is practically negligible below the 20th percentile, then depending on treatment, the difference gradually increases between the 20th to 60th percentiles to about – 10 percent, eventu-

TABLE 3.–*CCA treatment and redrying effects on maximum load (PMAX), maximum deflection (DMAX), modulus of elasticity (MOE), and work to maximum load (WML).*

Strength ratio (SR) classifications	Treatment	Drying level	PMAX		DMAX		MOE		WML	
			Mean	SD[a]	Mean	SD	Mean	SD	Mean	SD
			-------- (lb.) --------		-------- (in.) --------		----- (10^6 psi) -----		------ (in./lb.) ------	
No. 2 ongrade (SR > 0.45)	None	None	1,860	910	1.140	0.620	1.320	0.360	1,490	1,540
	Water	Air-dried	1,730	790	1.100	0.570	1.300	0.350	1,310	1,380
		Kiln-dried	1,660	760	1.040	0.580	1.300	0.340	1,170	1,240
	0.4[b] pcf	Air-dried	1,760	790	1.100	0.650	1.330	0.350	1,330	1,380
		Kiln-dried	1,450	600	0.860	0.420	1.280	0.340	860	740
	0.6 pcf	Air-dried	1,740	830	1.060	0.600	1.300	0.370	1,240	1,230
		Kiln-dried	1,450	660	0.850	0.410	1.290	0.330	810	790
SR $\geq$ 0.65	None	None	2,300	930	1.370	0.700	1.410	0.380	2,100	1.790
	Water	Air-dried	2,100	770	1.340	0.650	1.360	0.350	1,870	1,660
		Kiln-dried	2,210	810	1.400	0.680	1.340	0.370	2,000	1,640
	0.4 pcf	Air-dried	2,090	850	1.380	0.760	1.330	0.440	1,900	1,690
		Kiln-dried	1,610	610	0.970	0.460	1.280	0.350	1,010	900
	0.6 pcf	Air-dried	2,020	810	1.240	0.670	1.350	0.360	1,630	1,340
		Kiln-dried	1,850	630	1.050	0.440	1.360	0.380	1,180	840
SR $\geq$ 0.55	None	None	2,070	940	1.250	0.660	1.370	0.380	1,770	1,670
	Water	Air-dried	1,950	770	1.240	0.600	1.330	0.350	1,600	1,500
		Kiln-dried	1,910	800	1.210	0.640	1.320	0.340	1,540	1,470
	0.4 pcf	Air-dried	1,920	790	1.270	0.710	1.300	0.400	1,610	1,520
		Kilndried	1,540	620	0.950	0.450	1.270	0.350	940	820
	0.6 pcf	Air-dried	1,880	870	1.090	0.610	1.360	0.370	1,370	1,260
		Kiln-dried	1,600	660	0.930	0.440	1.320	0.340	960	840
SR < 0.65	None	None	1,490	710	0.950	0.470	1.230	0.320	960	1,030
	Water	Air-dried	1,490	710	0.930	0.440	1.260	0.350	930	990
		Kiln-dried	1,360	540	0.840	0.400	1.270	0.320	730	620
	0.4 pcf	Air-dried	1,530	650	0.900	0.460	1.320	0.280	920	910
		Kilndried	1,360	580	0.810	0.380	1.280	0.330	700	620
	0.6 pcf	Air-dried	1,520	780	0.910	0.500	1.260	0.370	930	1,040
		Kiln-dried	1,230	560	0.740	0.350	1.250	0.300	610	680
SR < 0.55	None	None	1,420	680	0.920	0.460	1.200	0.280	900	1,000
	Water	Air-dried	1,410	720	0.890	0.451	1.260	0.340	860	1,040
		Kiln-dried	1,340	570	0.830	0.410	1.270	0.330	720	650
	0.4 pcf	Air-dried	1,480	710	0.790	0.360	1.370	0.240	820	880
		Kiln-dried	1,290	550	0.710	0.290	1.310	0.320	570	510
	0.6 pcf	Air-dried	1,470	680	0.980	0.570	1.200	0.350	990	1,140
		Kilndried	1.220	590	0.730	0.320	1.240	0.320	590	650

[a] SD = standard deviation.

[b] Pcf of CCA.

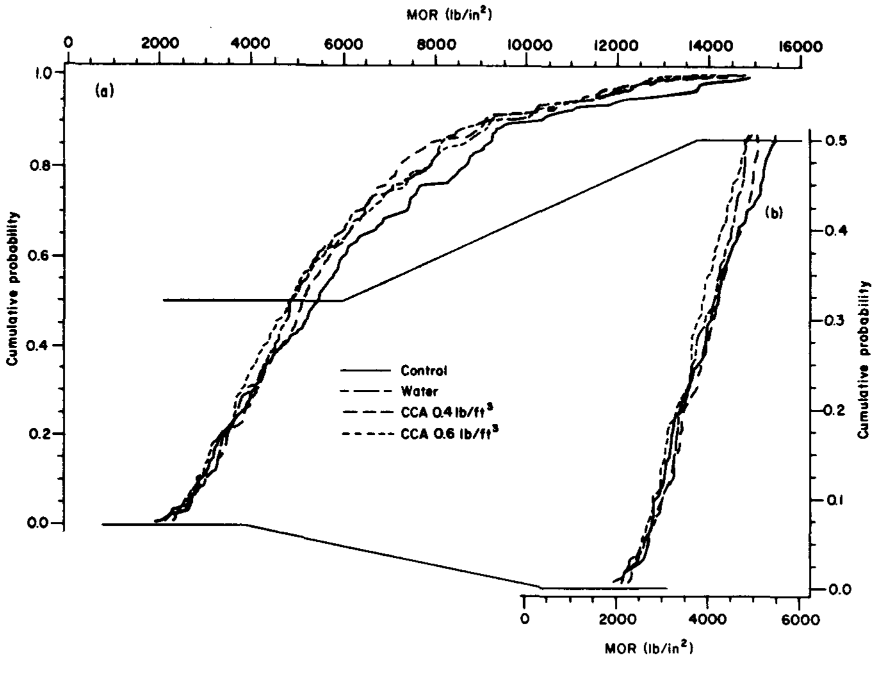

Figure 2. – Cumulative probability distribution of modulus of rupture (MOR) for the control group and for groups treated with water or two levels of CCA and then air-dried after treatment. (a) Cumulative probability (full range: 0.0 to 1.0); (b) cumulative probability (expanded lower range: 0.0 to 0.5).

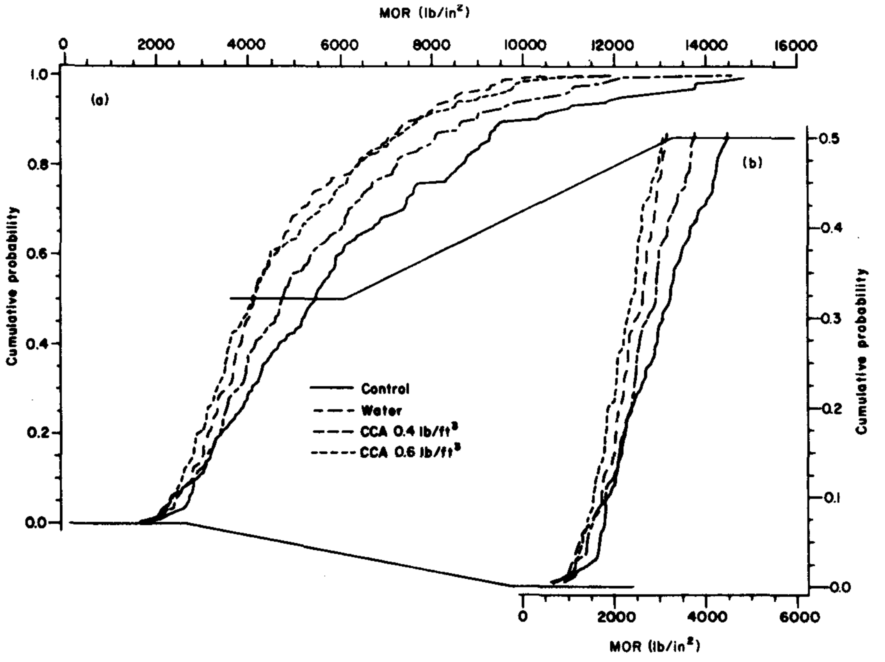

Figure 3. – Cumulative probability distribution of modulus of rupture (MOR) for the control group and for groups treated with water or two levels of CCA and then kiln-dried at 240°F after treatment. (a) Cumulative probability (full range: 0.0 to 1.0); (b) cumulative probability (expanded lower range: 0.0 to 0.5).

ally stabilizing at that - 10 percent level beyond the 60th percentile of the distribution (Fig. 4a). Note that for CCA-treated material redried at 240°F, the lower end of the distribution is reduced about 10 percent (Fig. 4b). This reduction then increases to between 20 to 30 percent above the 40th percentile. For each redrying level, it appears that few differences exist in the magnitude of the bending strength reductions between the 0.4- and 0.6-pcf CCA retention levels and that strength reductions begin at about the 40th percentile for the 0.4 pcf CCA retention and at about the 20th percentile level for the 0.6 pcf CCA retention.

The effects of water treatment were similar to those of air-dried CCA treatments, regardless of whether the water-treated material was air-dried or kiln-dried after treatment.

As previously stated, work by Barnes and Mitchell (3) and Knuffel (6) had led us to expect larger reductions in the lower tails of the strength distribution than in average values. The results using 2 by 6 lumber (15) were somewhat contrary to the results of these two previous studies in that, depending on treatment and redrying level, few effects were noted in the lower portions of the distribution. In this study, the trend exhibited by 2 by 4 No. 2 ongrade lumber suggests that the differences in results between this and these three previous studies may be more a function of grade or pith interactions, or both, rather than actual contradictions between study results.

SR classes. - For the SR classes, our ability to precisely predict distributional effects was reduced because the SR classes were subsets of the larger No. 2 ongrade lumber (Table 1). To assure that each of the seven treatment-drying groups had nearly equal numbers of specimens in each SR class, a Chi-square test was used. It showed that the numbers of specimens in the SR classes were not statistically different at a 5 percent level of significance. This assurance allowed the statistical limits of the property data, such as the mean and the various percentile estimates, to be directly compared within each SR class. However, as a secondary benefit, this assurance also validates the hypothesis that the initial sorting of specimens into groups having nearly equivalent pretreatment stiffness profiles effectively provides nearly equal SR class distributions within those groups.

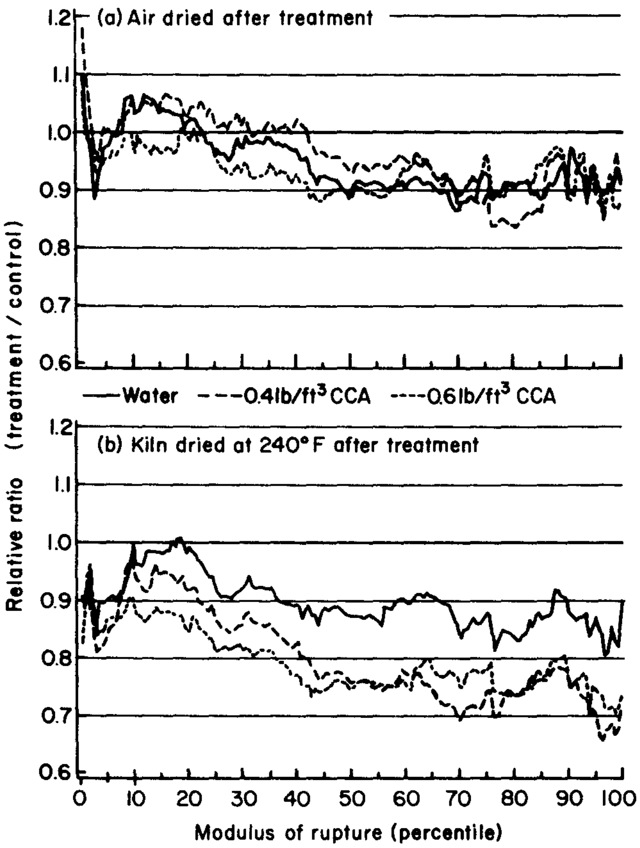

Figure 4. – Relative difference in modulus of rupture as a function of percentile level between the control group and each of the groups treated with CCA (two levels) or water. (a) Groups air-dried after treatment; (b) groups kiln-dried at 240°F after treatment.

When considering the SR classes, there exist practical and, in many cases, significant differences in the effects of CCA treatment and redrying on PMAX, DMAX, and WML at mean levels (Table 3). There are also differences related to rank order throughout the MOR distribution, depending upon the treatment-drying-grade combination under consideration (Table 2). To begin to understand the influence of CCA treatment and redrying on the various SR classes, an analysis of variance was performed. The analysis of variance included the seven treatment-drying groups, the presence or absence of pith, and the SR class as factors. It indicated significant ($a < 0.006$) interaction between SR class and pith that limited interpretation. Thus, the SR class effect cannot be independently discussed without concurrent consideration of a pith effect.

SR class and pith effects

While current lumber grades do not differentiate between pith-associated material (i.e., juvenile wood associated) and pith-free material, the presence of pith has a substantial influence on strength. In untreated controls having a SR $\geq$ 0.65, the mean MOR of pieces containing pith was 66 percent of those without pith (Table 4). Also, for a SR < 0.65, the mean MOR of control pieces containing pith was 83 percent of those without pith (Table 4). The impact of the presence of pith is obvious.

When considering the presence or absence of pith, there are important differences in how each SR class is influenced by CCA treatment and redrying. A statistical

TABLE 4. – *The bending strength of pith-associated and pith-free 2 by 4 southern pine lumber of two strength ratio (SR) classifications.*

			SR < 0.65				SR $\geq$ 0.65			
Treatment	Drying level	Pith-associated	No. of specimens	MOR[a]	Change[b]	Ratio[c]	No. of specimens	MOR	Change	Ratio
				(psi)	(%)			(psi)	(%)	
None	None	No	50	5,263		0.83	53	8,393		0.66
		Yes	38	4,381			23	5,540		
Water	Air-dried	No	57	5,194	–1	0.84	33	7,516	- 10	0.83
		Yes	41	4.387	0		33	6,242	+13	
	Kiln-dried	No	66	4,480	- 15	0.97	31	8,268	–1	0.72
		Yes	41	4,347	–1		26	5,913	+7	
CCA (0.4 pcf)	Air-dried	No	62	5,035	-4	0.96	38	7,659	-9	0.75
		Yes	34	4,840	+10		30	5,710	+3	
	Kiln-dried	No	62	4,666	–11	0.87	23	6,117	- 27	0.77
		Yes	45	4,078	-7		34	4,626	- 16	
CCA (0.6 pcf)	Air-dried	No	56	5,312	+ 1	0.80	36	7,929	-6	0.65
		Yes	36	4,268	-3		36	5,193	-6	
	Kiln-dried	No	56	3.968	-25	1.02	40	6,451	-23	0.80
		Yes	49	4,047	-8		19	5,138	-7	

[a] MOR = modulus of rupture.

[b] Percent change from the appropriate nonpith-associated or pith-associated nontreated control.

[c] Ratio of average MOR for pith-associated to nonpith-associated for each treatment-drying group.

analysis of sufficient power to adequately discern the influence of pith and its interaction with lumber grade in the tails of the MOR property distribution is not possible because of the further reduced sample sizes, but mean trends merit discussion.

The presence of pith tends to lessen the effect of CCA treatments on the mean of MOR. This can be seen by comparing the percent change in mean MOR for each treatment, drying, and SR class combination with appropriate untreated controls (Table 4). In five of the six combinations when SR < 0.65 and in all combinations when SR ≥ 0.65, the presence of pith lessened the impact of treatment and redrying upon bending strength. This is somewhat different than the grade-pith interaction noted using 2 by 6 southern pine (15), in which the inclusion of pith lessened the negative effects of CCA treatment when SR ≥ 0.65, but increased the effects when SR < 0.65.

This complex grade-pith interaction needs to be better understood before firm recommendations can be supported. When considering that between 40 to 50 percent of the southern pine lumber produced in the United States is eventually treated with CCA, the possible impact of this SR class pith-treatment effect is evident. This is especially relevant considering the large quantity of pith-associated southern pine dimension lumber produced when processing small-diameter logs.

Conclusions

This report relates the effects of CCA treatment and redrying after treatment on the bending properties of 2 by 4 southern pine lumber. Few important differences in strength properties existed between CCA retentions of 0.4 and 0.6 pcf. Overall, neither retention of CCA treatment had an effect on MOE, but each reduced the average MOR up to 11 percent when air-dried and 25 percent when kiln-dried at 240°F, depending on strength ratio and the presence or absence of pith (Table 4). When air-dried after treatment, strength reductions of about 10 percent existed at or above the 20th to 40th percentile of the bending strength distribution depending on the treatment used (Fig. 4a). When kiln-dried after CCA treatment at 240°F, strength reductions ranging from 5 to 37 percent existed throughout the bending strength distribution (Fig. 4b). In all cases, strength reductions were influenced by the presence or absence of pith and the SR class being considered. Additional research is needed before the complex SR grade-pith interaction with the effect of CCA preservative treatments on strength can be explained.

When the results of this study are considered with the results of earlier clear wood and lumber studies (3,4,8,15,16), it appears that high-temperature kiln redrying significantly reduces the bending strength of CCA-treated material.

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