

THE EFFECTS OF CCA PRESERVATIVE TREATMENT AND REDRYING ON THE BENDING PROPERTIES OF 2 × 6 SOUTHERN PINE LUMBER

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ABSTRACT

Southern pine dimension lumber (commercially graded No. 2 loblolly pine 2 × 6s) was treated with chromated copper arsenate (CCA) preservative (0.4 or 0.6 pcf) and then air-dried or kiln-dried (160, 190, or 240 F). CCA treatment significantly reduced average bending strength, but no discernible differences were found between controls and CCA-treated groups in the extreme lower portions (< 10th percentile) of the bending-strength distributions. When these same specimens were then considered solely on the basis of strength-reducing characteristics, there were obvious differences in how the CCA treatments and subsequent redrying affected these various strength-ratio grades of 2 × 6 lumber; higher grades appeared to be less affected than lower grades. Similar to the trend shown when commercially graded, the middle and upper portion of each strength-ratio grade bending-strength distribution was affected more than the lower portion. In kiln drying the lumber after treatment, drying at 240 F affected a broader range of the bending-strength distribution than did drying at 160 F. The broadened range of significant effects noted after high-temperature redrying indicates that posttreatment kilndrying temperatures higher than 190 F should be avoided.

The effects of CCA treatment and redrying were highly interactive with strength-ratio grade and the presence or absence of pith. CCA treatment reduced the strength of lumber containing pith and having a strength ratio of <0.65 to a greater extent than pith-free lumber of any strength-ratio grade. Lumber having a strength ratio of 20.65 and containing pith was not affected by CCA treatment. The magnitude of this pith-related interaction demands recognition.

Keywords: Mechanical properties, bending strength, CCA, treatments, preservatives, kiln-drying, redrying, lumber, southern pine, pith.

INTRODUCTION

Although treatment with chromated copper arsenate (CCA) preservative reduces the strength of many types of wood products, the National Design Specification (NDS) does not currently require reduction in allowable design stresses (10-yr loading) for lumber treated with CCA or other waterborne preservatives (National Forest Products Association 1986). This strength loss seems to be caused by both the hydrolytic chemical (pH = 1.5–3.0) and the temperature sustained in kiln-drying after treatment (KDAT). Recent research results (Barnes and Mitchell 1984; Bendtsen et al. 1983; Knuffel 1985; Mitchell and Barnes 1986; Winandy et al. 1985) force us to question the appropriateness of unmodified allowable design stresses (ADS) for CCA-treated material. Except for work by Barnes and Mitchell (1984) and Knuffel (1985), most research on the effects of CCA has

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utilized small clear specimens and has dealt mainly with average property values, whereas ADS values are based on fifth percentile estimates.

Considering the limited lumber data available, we cannot satisfactorily estimate the effects of CCA preservative treatments and subsequent redrying on ADS values. Our study was an attempt to understand better how CCA treatment affects the distributional characteristics of lumber bending properties and ADS values. The primary objective was to define these effects throughout the entire bending strength distribution for 2×6 southern pine lumber. Secondary objectives were (1) to explore the ability of various drying temperatures to redry CCA-treated lumber without significantly reducing mechanical properties, (2) to identify relationships between strength-related characteristics (i.e., knots, slope-of-grain), CCA retention, drying temperature, and lumber strength, and (3) to identify the relationship between pith and the same characteristics.

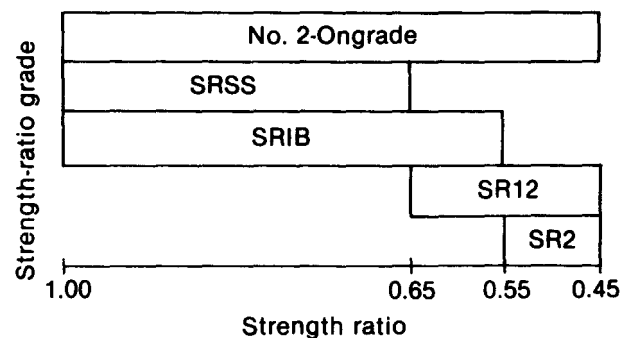
EXPERIMENTAL

The southern pine dimension lumber used in this study consisted of 1,536 loblolly pine (*Pinus taeda* L.) 2×6 s, 10 feet long. Each specimen was commercially graded as No. 2-Ongrade as defined in the national grading rule (NGR). NGR grade assignments are based on both strength-reducing characteristics (e.g., knots, slope-of-grain) and utility characteristics (e.g., warp). After all specimens had equilibrated at controlled conditions of 74 F and 65% relative humidity, the flatwise stiffness of each specimen was determined using a Metrigard² E-computer. The presence of pith was noted. Finally, the two worst knots and the maximum slope of grain of each specimen were identified, and the specimens were assigned to secondary strength-ratio grades based solely on strength-reducing characteristics (Fig. 1).

The specimens were then sorted into nine treatment-drying groups having nearly equivalent E-computer stiffness profiles (Table 1). One group of specimens remained untreated to serve as true controls. Two other groups were treated with water, and the remaining groups were treated with either of two levels of CCA retention, 0.4 or 0.6 pound per cubic foot (pcf). These levels of CCA retention were chosen to represent the American Wood-Preservers' Association (1986) specified retentions for structural lumber intended for use in Ground Contact situations (0.4 pcf CCA) or in Permanent Wood Foundations (0.6 pcf CCA). After treatment, the CCA- and water-treated 2×6 s were either air-dried or kiln-dried at 160, 190, or 240 F. These drying temperatures were chosen to represent a range of commonly used industrial redrying temperatures. The specimens were then tested to failure using ASTM D 198 static bending tests (American Society for Testing and Materials 1984).

Because of certain characteristics of the NGR, No. 2 lumber actually contains many pieces that would actually qualify as Select Structural or No. 1 if only knots or slope of grain were considered. Examples of these characteristics include limits

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ML87 5438

FIG. 1. Range of strength ratios in commercially graded No. 2-Ongrade and in each of the four strength-ratio grades. SRSS = Select Structural, SR1B = No. 1 and better, SR12 = No. 1 and No. 2, and SR2 = No. 2. (ML87 5438)

for wane, warp, and manufacturing defects in excess of those allowed in Select Structural or No. 1. In many cases these limits are intended to assure the utility rather than the strength of a piece of lumber. Possibly the most significant NGR limit is that decay in a knot automatically downgrades a piece to No. 2, regardless of the knot size, despite the fact that in most instances decay "within" a knot has only a limited influence on strength of that piece. Consequently, commercially graded No. 2 lumber has a range of strength ratios from 0.45 to nearly 1.00.

The commercial grade, which allowed for both strength-reducing factors and utility factors, and the secondary strength-ratio grade provided us with two schemes for studying the same experimental data. One scheme, with a high number of specimens in each of its treatment-drying groups, provided for precise identification of "treatment" and/or "redrying" effects throughout the entire bending property distribution for commercially graded No. 2 lumber (No. 2-Ongrade). The second scheme, with multiple strength-ratio levels, provided a method of assessing the interaction between treatment- and/or drying-induced effects and lumber quality. Because the first method of analyzing the experiment was deemed most important, the specimens were assigned to treatment groups solely on the basis of pretreatment stiffness to assure virtually identical modulus of elasticity (MOE) distributions for each of the nine No. 2-Ongrade groups (Table 1). Because MOE correlates with strength, this procedure helped assure equivalent strength distributions too. Thus, for the analysis involving the strength-ratio levels, the number of specimens in each treatment group was uncontrolled, even though sorting by pretreatment stiffness tended to balance the distributions (Table 1).

Treatment

CCA treatments were done commercially using a Type C oxide formulation (American Wood-Preservers' Association 1986) and a modified full-cell process. Target retentions were 0.4 or 0.6 pcf. For each of the two charges, a 20-boring sample was taken for subsequent analysis of CCA penetration and retention.

TABLE 1. *Experimental design showing the number of graded specimens according to treatment and drying method.*

Treatment/drying method	Graded specimens ¹				
	No. 2-Ongrade	SRSS	SR1B	SR12	SR2
No treatment (controls)	190	77	125	113	65
Watertreatment					
Air-dried	—	—	—	—	—
Kiln-dried					
160	192	109	141	83	51
190	—	—	—	—	—
240	192	99	144	93	48
CCA treatment, 0.4 pcf					
Air-dried	—	—	—	—	—
Kiln-dried					
160	128	59	91	69	37
190	—	—	—	—	—
240	128	64	88	64	40
CCA treatment, 0.6 pcf					
Air-dried	127	58	88	69	39
Kiln-dried					
160	190	89	139	101	51
190	191	90	141	101	50
240	190	100	135	90	55

¹ Specimens were graded as No. 2-Ongrade as defined by the National Grading Rule, or as Select Structural (SRSS), No. 1 and Better (SR1B), No. 1 and No. 2 (SR12), or No. 2 (SR2) according to strength ratio.

Water treatments were performed at the Forest Products Laboratory (FPL) in a 10-foot cylinder using a modified full-cell process.

Post-treatment moisture contents ranged from 35% to 85%. Before drying, the treated specimens were close piled and covered outdoors for 5 to 8 days at ambient temperatures and humidities in Madison, WI, during July 1984. This provided a fixation period between treatment and drying (Winandy et al. 1983).

Redrying

Specimens were redried after their respective treatments in conventional or high-temperature kilns or air-dried.

Kiln redrying was performed at FPL using schedules having maximum dry-bulb temperatures of either 160, 190, or 240 F (Table 2). The lumber was dried in 4-foot-wide piles using ¾-inch stickers on 2-foot centers. A top load of concrete blocks and/or iron weights (40 psf) was used on all charges to minimize warp in the upper courses. At the end of each drying regime, an equalizing cycle was employed to insure uniform moisture content within each specimen and throughout the entire lumber stack. Moisture content was determined by monitoring sample boards placed throughout the stack. The target moisture content for individual specimens from the kiln was 15% (19% maximum).

Specimens designated for air-drying were dried at FPL in the summer of 1984. Piles were 6 feet wide with ¾-inch stickers on 2-foot centers, roofed with plywood. After 4 weeks the lumber had dried to 12% to 15% moisture content.

TABLE 2. *KDAT drying schedules.*

Maximum DB temperature (F)	Estimated initial moisture content range ¹ (%)	Air speed (ft/min)	Fan reversal (h)	DB/WB settings (F)	Time (h)	Equal DB/WB settings ² (F)	Time (h)	Total time (h)
160	35-80	300-500	6	160/130	24	160/152	24	48
190	50-80	300-500	6	190/150	20	None ³		20
240	35-85	800-1,000	3	240/180	6	168/160	6	12

¹ From sample boards.

² Equalizing cycle.

³ Equalizing not needed; variation between specimens within limits.

Equilibration

Before mechanical testing, all specimens (treated and control) were placed in a controlled environment of 74 F and 65% relative humidity. After 7 months the specimens had equilibrated.

CCA treatments can have a significant effect upon the equilibrium moisture content (EMC) of treated clear specimens (Bendtsen et al. 1983; Winandy et al. 1985). However, a comparable effect has not been reported in the limited lumber data available. The moisture content data generated after subsequent mechanical testing were used to test for the effect of CCA treatment and redrying on lumber EMC.

Mechanical testing

Edgewise static bending tests (ASTM D 198) were performed 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 the maximum moment area, the second greatest strength-reducing defect was employed. Where neither of these defects could be placed in the maximum moment area, the one closest to the maximum moment area was employed. For each group, half of the specimens were tested with the chosen defect up and the remaining specimens with the defect down.

The rate of loading was 1 inch of head travel per minute, which is about 3.44 times faster than the standard rate. This faster rate was used because earlier results for untreated southern pine had indicated no difference between standard loading rates and rates up to 25 times faster than standard (DeBonis et al. 1980). Load was monitored using a calibrated load cell, and deflection was monitored using a linear potentiometer. Load and deflection data were recorded during testing on an interfaced microcomputer. The maximum load (P_{MAX}), maximum center-span deflection (D_{MAX}), modulus of rupture (MOR), MOE, and work to maximum load (WML) were calculated from these data. Since CCA treatment induces bulking (i.e., swelling), we thought that P_{MAX} would be a valuable parameter to quantify the comparable load-carrying capacities of treated versus untreated specimens. D_{MAX} was included because past studies have shown appreciable losses in WML without corresponding losses in MOE.

Immediately after testing, a moisture content/specific gravity block was cut from near the zone of failure on each specimen to determine moisture content and specific gravity at time of test.

Chemical analysis

To further verify preservative retention and to adjust specific gravity values, a 0.6-inch edge was cut from the moisture content block (edge-stressed in tension). These edges were then ground to pass 30 mesh. Randomly chosen samples of approximately 25% of the CCA-treated specimens were assayed for chromium, copper, and arsenic using X-ray spectrometry (AWPA 1986).

RESULTS AND DISCUSSION

Chemical analysis

Using an Asoma² X-ray spectrometer, the commercial treater found that both CCA charges met the AWPA specified targets for both penetration and retention. They assumed that southern pine lumber had a density of 32 pcf and reported CCA retentions of 0.49 and 0.71 pcf (target 0.4 and 0.6 pcf, respectively).

In chemical analyses performed at FPL, the 59 specimens analyzed of the 256 targeted for 0.4 pcf had a mean retention of 0.467 pcf and a standard deviation of 0.067 (assuming a density of 32 pcf); 9 of these 59 specimens (15.3%) failed to meet the specified retention. Of the 695 specimens targeted for 0.6 pcf, 183 specimens were analyzed. These specimens had a mean retention of 0.630 pcf and a standard deviation of 0.088; 73 of the 183 specimens (39.9%) failed to meet their specified retention.

When the actual density of each individual specimen was used in calculating CCA retention, the mean and the standard deviation were 0.436 pcf and 0.052, respectively, for the specimens targeted for a 0.4 pcf treatment, and 0.584 pcf and 0.065, respectively, for the specimens targeted for a 0.6 pcf treatment. Using the actual density procedure, 11 of the 59 specimens (18.6%) treated to a target of 0.4 pcf and 16 of the 183 specimens (63.0%) treated to a target of 0.6 pcf failed to meet the specified retentions.

Whereas the assumed density procedure is allowed by AWPA standards, the noncompliance of so many specimens in this study illustrates a major problem associated with assuming a density of 32 pcf for southern pine lumber. Product assurance throughout the marketplace and quality control within the industry might be better served if treating standards required that chemical retentions be reported on an actual density or weight-percent basis (weight of chemical/weight of sample) rather than on an assumed density basis.

Equilibration

After equilibration at 74 F and 65% relative humidity, average EMC of each specimen group ranged from 9.2% to 11.0% (Table 3) depending upon grade, treatment, and redrying temperature. The EMC of treated specimens was higher than that of untreated specimens. This differential effect ranged from +0.7% to +1.7% moisture content for any single CCA-treated group compared to its respective control. Little difference was found between 0.4 and 0.6 pcf CCA retention levels. Water treatment also appeared to increase EMC. Note that as KDAT temperatures increased, the eventual EMC decreased in both CCA- and water-treated specimens. However, while it is now known that EMC is increased by CCA, it is not known why.

To understand better why EMC was altered, samples were taken from five

TABLE 3. Effects of CCA-treatment and redrying on the modulus of rupture (MOR) of 2 × 6 Southern Pine as graded for various strength and appearance factors.

Grade	Treatment	Drying level	n	Mean (psi)	SD ² (psi)	MORPercentile				MC (%)	SG ³ (%)	
						5th (psi)	25th (psi)	50th (psi)	75th (psi)			
No. 2-Ongrade	None	None	190	6,049	2,731	2,296	3,906	5,897	7,696	9.3	0.47	
		Water	160	6,262	2,417	2,841	4,443	5,941	7,844	10.4	0.47	
	0.4 CCA	240	192	6,209	2,639	2,606	4,047	5,877	8,240	10.1	0.47	
		Air	160	5,629	2,480	2,087	3,755	5,292	7,028	10.7	0.47	
	0.6 CCA	Air	240	5,592	2,550	2,153	3,429	5,279	7,365	10.1	0.47	
		Air	127	5,903	2,521	2,221	3,745	5,625	7,535	10.9	0.47	
		Water	160	5,711	2,500	2,087	3,868	5,340	7,303	10.5	0.47	
		Water	190	5,784	2,405	2,574	3,863	5,360	7,376	10.2	0.47	
	SRSS	None	None	77	7,045	3,071	2,868	4,534	6,776	9,107	9.3	0.48
			Water	160	6,985	2,519	3,573	4,893	6,794	8,634	10.4	0.48
		0.4 CCA	240	99	7,306	2,617	2,943	5,269	7,227	9,289	10.0	0.48
			Air	160	5,979	2,605	2,856	4,963	6,695	9,268	10.7	0.49
0.6 CCA		Air	240	6,643	2,535	2,988	4,610	6,629	8,102	10.1	0.48	
		Air	58	6,920	2,463	2,969	5,313	7,056	8,681	10.9	0.48	
		Water	160	6,907	2,448	3,234	4,875	6,768	8,889	10.6	0.48	
		Water	190	6,740	2,342	3,132	5,120	6,651	8,136	10.3	0.48	
SR1B		None	None	125	6,547	2,857	2,863	4,200	6,515	8,619	9.3	0.47
			Water	160	6,641	2,482	3,167	4,664	6,398	8,297	10.4	0.48
		0.4 CCA	240	144	6,728	2,601	2,820	4,727	6,224	8,737	10.1	0.48
			Air	160	6,022	2,674	2,092	3,755	5,849	8,498	10.7	0.47
	0.6 CCA	Air	240	88	6,208	2,530	2,543	4,200	6,059	7,794	10.0	0.48
		Air	88	6,182	2,590	2,406	4,184	5,768	7,935	11.0	0.47	
		Water	160	6,172	2,457	2,753	4,125	5,831	7,790	10.5	0.47	
		Water	190	6,272	2,405	2,917	4,392	5,867	7,686	10.2	0.48	
	SR12	None	None	113	5,371	2,245	2,108	3,516	4,788	7,029	9.3	0.46
			Water	160	5,313	1,909	2,231	3,977	5,056	6,371	10.5	0.46
		0.4 CCA	240	93	5,041	2,120	2,331	3,312	4,774	6,234	10.1	0.45
			Air	160	4,474	1,663	2,063	3,156	4,364	5,559	10.7	0.46
0.6 CCA		Air	240	64	4,542	2,108	1,957	2,733	4,201	5,847	10.2	0.47
		Air	69	5,048	2,251	1,953	3,288	4,880	6,302	10.9	0.46	
		Water	160	4,657	2,035	1,827	3,141	4,407	5,927	10.4	0.46	
		Water	190	4,932	2,133	2,367	3,199	4,478	6,686	10.1	0.47	
SR2		None	None	90	4,211	1,722	2,224	2,812	3,686	5,429	10.0	0.46
			Water	65	5,091	2,191	1,967	3,352	4,656	6,948	9.2	0.46
		0.4 CCA	240	51	5,216	1,882	2,031	4,176	4,956	6,156	10.5	0.45
			Air	48	4,654	2,106	2,240	3,150	4,022	5,850	10.0	0.45
	0.6 CCA	Air	160	4,662	1,576	1,763	3,364	4,635	5,772	10.6	0.46	
		Air	240	40	4,239	2,041	1,933	2,616	3,489	5,191	10.3	0.46
		Water	39	5,273	2,264	1,923	3,485	5,532	6,520	10.9	0.46	
		Water	160	51	4,454	2,181	1,595	2,658	3,996	6,222	10.4	0.46
	0.6 CCA	Water	190	50	4,409	1,812	2,253	2,946	4,057	5,225	10.1	0.47
		Water	240	55	3,941	1,481	2,251	2,826	3,385	5,142	10.1	0.46

¹ KDAT temperatures of 160, 190, or 240 F, or air drying.² Standard deviation.³ Specific gravity.

TABLE 4. Effects of CCA-treatment and redrying on maximum load (P_{MAX}), maximum deflection (D_{MAX}), modulus of elasticity (MOE), and work to maximum load (WML).

Grade	Treatment	Drying level	P _{MAX} (lb)		D _{MAX} (in)		MOE (psi × 10 ⁶)		WML (in/lb)	
			Mean	SD ¹	Mean	SD	Mean	SD	Mean	SD
No. 2-Ongrade	None	None	2,910	1,307	1.534	0.624	1.362	0.273	2,796	2,344
	Water	160	3,049	1,186	1.622	0.664	1.339	0.260	3,078	2,552
		240	3,021	1,281	1.648	0.662	1.338	0.270	3,063	2,368
	0.4 CCA	160	2,749	1,208	1.482	0.710	1.314	0.261	2,587	2,445
		240	2,730	1,237	1.466	0.609	1.323	0.269	2,490	2,031
	0.6 CCA	Air	2,877	1,226	1.491	0.580	1.329	0.242	2,635	2,010
		160	2,786	1,225	1.456	0.588	1.358	0.268	2,500	2,032
		190	2,824	1,164	1.459	0.575	1.352	0.245	2,523	2,024
		240	2,641	1,181	1.373	0.501	1.346	0.249	2,220	1,844
SRSS	None	None	3,390	1,475	1.714	0.676	1.440	0.312	3,613	2,882
	Water	160	3,400	1,231	1.756	0.761	1.392	0.258	3,750	2,974
		240	3,547	1,261	1.805	0.673	1.444	0.266	3,857	2,461
	0.4 CCA	160	3,402	1,267	1.753	0.781	1.416	0.258	3,767	2,941
		240	3,242	1,224	1.694	0.656	1.350	0.256	3,279	2,315
	0.6 CCA	Air	3,384	1,198	1.607	0.559	1.399	0.240	3,283	2,173
		160	3,374	1,200	1.655	0.593	1.443	0.276	3,301	2,130
		190	3,282	1,122	1.644	0.605	1.408	0.274	3,162	2,154
		240	3,158	1,203	1.556	0.498	1.414	0.266	2,902	2,093
SR1B	None	None	3,151	1,366	1.610	0.637	1.410	0.287	3,149	2,568
	Water	160	3,240	1,217	1.707	0.722	1.368	0.256	3,474	2,784
		240	3,271	1,258	1.728	0.639	1.380	0.265	3,428	2,364
	0.4 CCA	160	2,932	1,304	1.572	0.759	1.344	0.263	2,970	2,707
		240	3,038	1,228	1.565	0.628	1.368	0.280	2,882	2,160
	0.6 CCA	Air	3,022	1,264	1.524	0.594	1.350	0.251	2,832	2,141
		160	3,013	1,207	1.529	0.575	1.396	0.260	2,786	2,085
		190	3,058	1,160	1.562	0.598	1.387	0.250	2,889	2,154
		240	2,927	1,211	1.485	0.502	1.382	0.250	2,615	1,980
SR12	None	None	2,583	1,067	1.412	0.556	1.309	0.230	2,239	1,692
	Water	160	2,588	950	1.446	0.456	1.271	0.247	2,195	1,457
		240	2,461	1,048	1.482	0.610	1.224	0.224	2,218	1,947
	0.4 CCA	160	2,190	818	1.250	0.550	1.227	0.231	1,578	1,246
		240	2,218	1,027	1.239	0.461	1.296	0.281	1,701	1,303
	0.6 CCA	Air	2,451	1,085	1.393	0.583	1.270	0.229	2,090	1,693
		160	2,267	994	1.280	0.526	1.283	0.238	1,795	1,655
		190	2,416	1,047	1.294	0.494	1.303	0.205	1,954	1,721
		240	2,066	848	1.170	0.423	1.270	0.205	1,462	1,116
SR2	None	None	2,447	1,048	1.389	0.574	1.270	0.219	2,118	1,655
	Water	160	2,520	915	1.387	0.384	1.259	0.254	1,982	1,222
		240	2,269	1,040	1.409	0.677	1.211	0.245	1,968	2,037
	0.4 CCA	160	2,298	780	1.261	0.518	1.241	0.242	1,646	1,220
		240	2,053	969	1.250	0.509	1.226	0.216	1,628	1,387
	0.6 CCA	Air	2,551	1,081	1.415	0.545	1.279	0.216	2,189	1,612
		160	2,166	1,054	1.254	0.581	1.256	0.264	1,720	1,660
		190	2,163	896	1.169	0.377	1.253	0.201	1,493	1,079
		240	1,939	736	1.099	0.382	1.256	0.226	1,249	903

¹ Standard deviation.

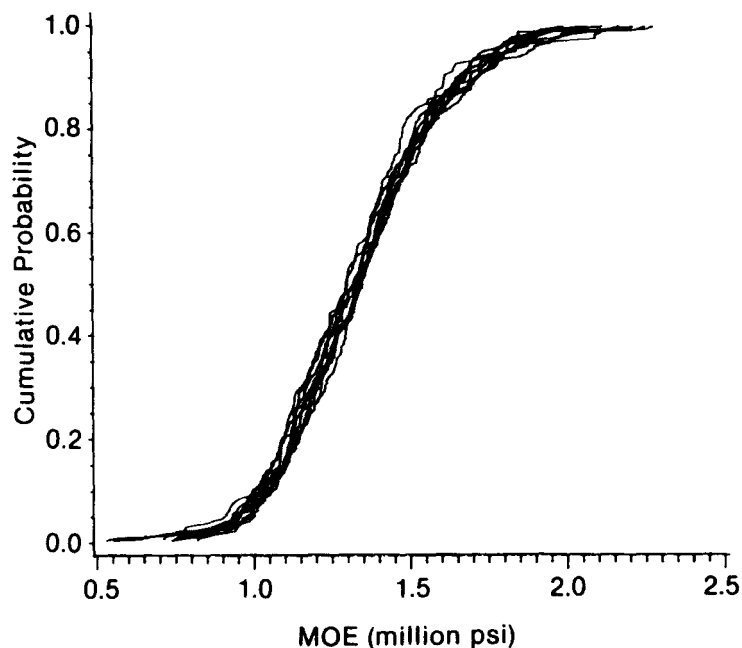
**ML87 5439**

FIG.2. Cumulative distribution of modulus of elasticity (MOE) (psi) calculated from bending data for the nine treatment-drying groups. Note the similarity of all nine of the posttreatment MOE profiles. (ML87 5439)

randomly selected specimens treated to 0.4 pcf and redried at 160 F. These samples were analyzed by scanning electron microscopy with energy dispersive spectroscopy and by X-ray photoelectron spectroscopy. Scanning electron microscopy confirmed that the chromium and copper concentrations were higher in the lignin-rich middle lamella than in the carbohydrate-rich S_2 layer of the cell wall. Photoelectron spectroscopy showed that the chromium had preferentially associated itself with the lignin rather than the carbohydrates. Both results are consistent with the reported literature (Nicholas and Preston 1984). CCA-Type C (oxide, pH = 1.5–3.0) reacts with lignin, apparently altering the hydrophobic character of lignin and thus allowing an increase in EMC.

Mechanical testing

Of the 1,536 specimens initially included in our study, 4 specimens were excluded from mechanical testing because of excessive warp after treatment. Another four specimens were excluded from the analysis because data were missing or obviously in error. This left a total of 1,528 specimens for analysis. We feel that the analysis and conclusions were not influenced by these deletions because of the large number of specimens in each group and because no single group lost more than two specimens.

The mean, standard deviation, and various percentile estimates of MOR for lumber when commercially graded as No. 2-Ongrade and when graded by strength ratio are shown in Table 3. Percentile estimates were calculated using a non-parametric ordered-rank procedure (SAS Institute 1982). The mean and standard

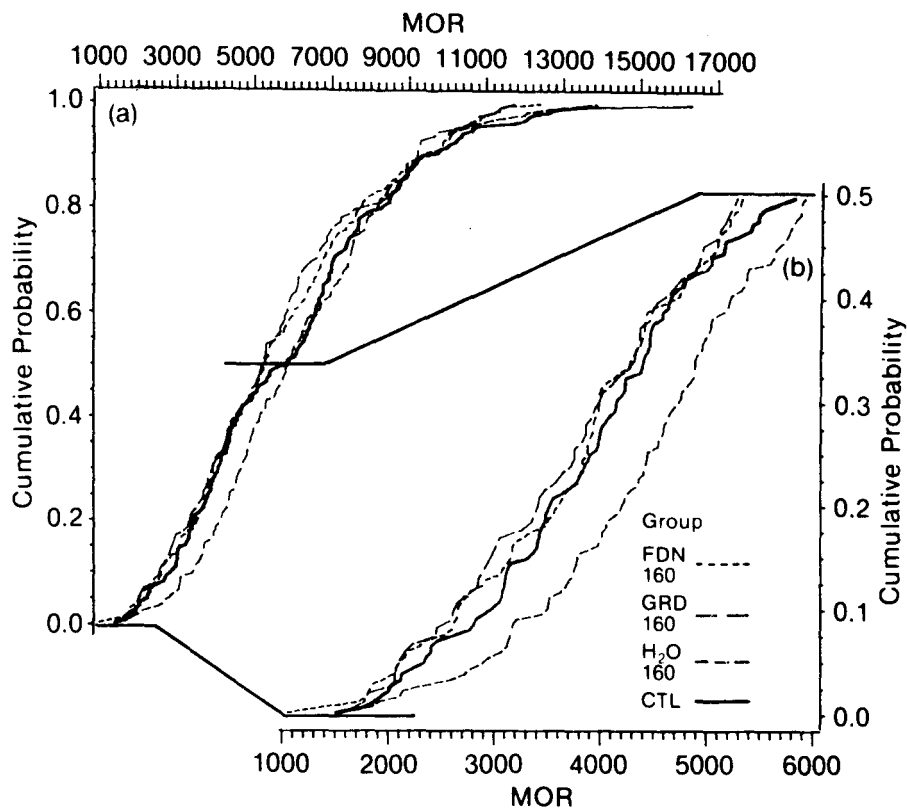
**ML87 5440**

FIG. 3. Cumulative distribution of modulus of rupture (MOR) (psi) for the three treatment groups kiln-dried after treatment at 160 F and for the control group: (a) Entire bending strength distribution; (b) magnification of lower 50th percentile of (a). FDN = 0.6 pcf CCA, GRD = 0.4 pcf; H₂O = water treated. (ML87 5440)

deviation for P_{MAX}, D_{MAX}, MOE, and WML for lumber graded as No. 2-Ongrade and for the four strength-ratio grades are shown in Table 4.

No. 2-Ongrade. – Consistent with earlier reports, the effects of CCA treatment on MOE of No. 2-Ongrade specimens were negligible (Fig. 2). The effects of CCA treatment and redrying on bending strength were related to percentile level within the distribution. In general, CCA treatment reduced the strength of all specimens at the high portion of MOR distribution (compared to untreated controls) to a greater extent than that of specimens at the low portion. Increased redrying temperatures exaggerate this effect. When specimens were redried at 160 F (Fig. 3), there was little difference between the two CCA-treated groups (0.4 and 0.6 pcf) and the untreated control group below the 40th percentile of the bending-strength distribution. However, when specimens were redried at 240 F (Fig. 4), differences between treated and untreated specimens began near the 10th percentile. Whereas all CCA treatments and KDAT temperatures reduced the strength of some CCA-treated specimens, CCA treatment followed by high-temperature KDAT affected specimens throughout a greater proportion of the bending-strength distribution when compared to low-temperature KDAT. This trend can also be seen by study-

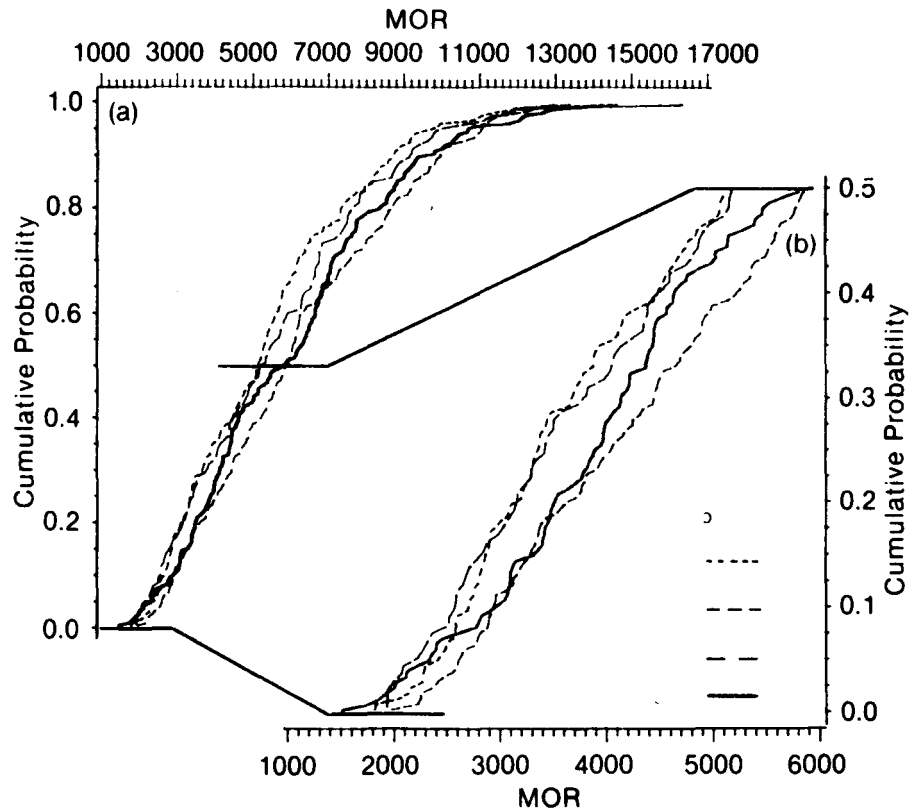
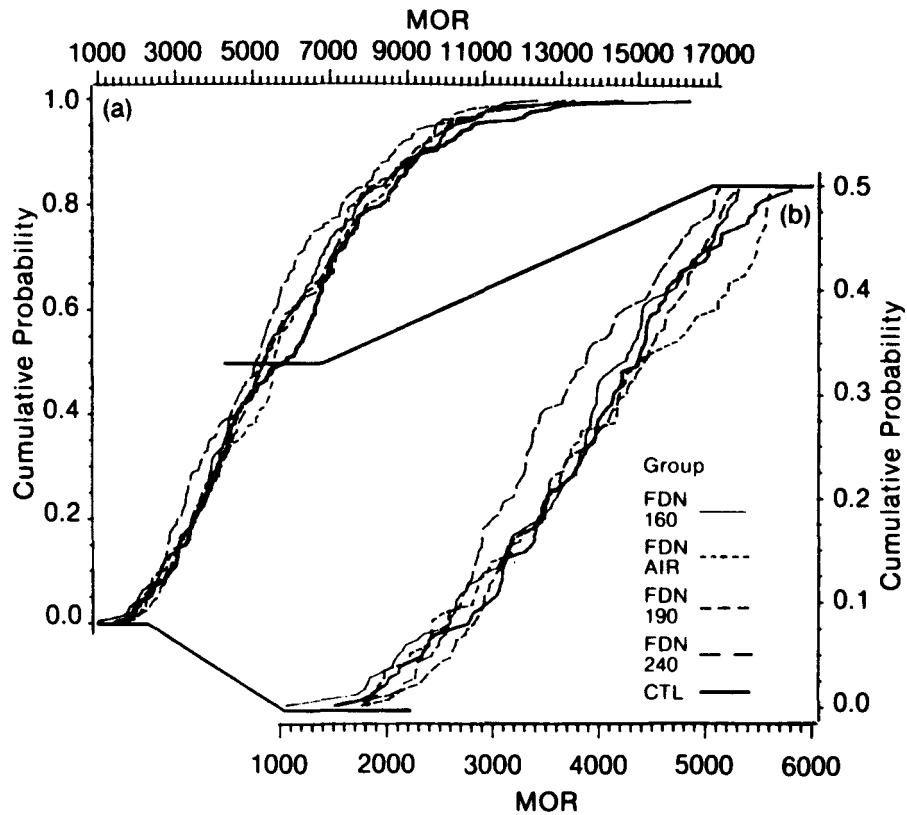
**ML87 5441**

FIG. 4. Cumulative distribution of MOR (psi) for the three treatment groups kiln-dried after treatment at 240 F and for the control group: (a) entire bending strength distribution; (b) magnification of lower 50th percentile of (a). FDN = 0.6 pcf CCA; GRD = 0.4 pcf; H₂O = water treated. (ML87 5441)

ing the effects of air-drying and three redrying temperatures on specimens treated with 0.6 pcf CCA (Fig. 5). Note how the control, air-dry, 160 F, and 190 F KDAT strength distributions are not perceptibly different, whereas the strength of specimens dried at 240 F is noticeably reduced. In most instances where CCA-treated (0.4 and 0.6 pcf) lumber was redried at a KDAT temperature of 240 F, strength reduction was significant ($\alpha < 0.05$). For No. 2-Ongrade specimens overall, CCA treatments had a negligible effect on the lower portions of the MOR distribution (i.e., < 10th percentile), including the fifth percentile.

Apparently the strength of lumber in the lower portion of the No. 2-Ongrade distribution was affected less than the average values. We were surprised by these results because previous work by Barnes and Mitchell (1984) and Knuffel (1985) had led us to expect larger reductions in the lower portions of the strength distribution than in average values. Differences in experimental details between this and earlier studies may account for the conflicting results. We used E-matched (stiffness) groups to minimize possible pretreatment differences in MOR, precise grade (defect) identification and control, and far more replications than earlier studies.



ML87 5442

FIG. 5. Cumulative distribution of MOR (psi) for the control group and for four groups treated with CCA to 0.6 pcf then dried at four different conditions: (a) entire bending strength distribution; (b) magnification of lower 50th percentile of (a). (ML87 5442)

Strength-ratio grades. – Because each strength-ratio grade is merely a subset of the larger No. 2-Ongrade set of specimens (Fig. 1), we cannot predict as precisely the effects of CCA treatment and redrying on the strength distribution of each strength-ratio grade. Still, conclusive results were noted. Similar to the previously discussed effects of CCA on No. 2-Ongrade material, CCA treatment did not have a significant grade- or quality-related effect on the MOE distribution or on the lower portions of the MOR distribution for specimens in the four strength-ratio grades. CCA treatment and redrying also appeared to affect portions of the MOR distribution at or above the 25th percentile, with the magnitude of this effect being related to a specimen's grade (Table 3). CCA treatment and redrying also had a practical and in many cases significant ($\alpha < 0.05$) effect on mean PMAX, DMAX, and WML (Table 4).

Although CCA treatment and redrying have an effect on the higher portion of the MOR distribution in all strength-ratio grades, they generally had a greater effect on the MOR of the lower strength-ratio grades than on the MOR of the higher grades. For example, the average effect of CCA treatment through the 25th to 75th percentile range was 0% for SRSS, – 7% for SR1B, – 12% for SR12, and – 13% for SR2 (Table 3). When comparing overall trends between strength-ratio

groupings, the point at which these treatment effects began to differ on a practical grade-to-grade basis occurred near a lumber strength ratio of 0.65, the lower strength-ratio boundary of the SRSS grade.

Within the individual strength-ratio distributions, the negative effects of treating and redrying tended to increase from the first quartile (25th percentile) to the third quartile (75th percentile). For example, for SRSS specimens treated to 0.6 pcf and redried at 190 F the effect on MOR was + 13% at the 25th percentile, -2% at the 50th, and finally, - 11% at the 75th; for equivalently treated and redried SR2 specimens the effect was - 12%, - 13%, and - 25% at the 25th, 50th, and 75th percentiles, respectively.

The KDAT temperature had the most consistent overall effect on strength in the strength-ratio grades. In nearly every situation as KDAT temperatures increased, strength was reduced. Note how the 240 F KDAT temperature generally had a far more deleterious effect on MOR of SRSS and SR1B specimens from 50th percentiles and above than less severe redrying conditions (air-drying or 160 F) (Table 3). For SR12 and SR2 specimens, the effect of temperature was apparent in the 25th percentile and above.

Effect of pith

Current lumber grades do not differentiate between lumber that contains pith and lumber that does not contain pith. In our study, we found that the presence or absence of pith had a significant influence on the effect of CCA treatment and redrying on each strength-ratio grade of specimens. Because the pith-strength-ratio groups were subsets of the strength-ratio grades which, in turn, were subsets of the larger commercial (NGR) grades, we were unable to analyze the influence of pith and its interaction with lumber grade over the entire MOR property distribution because of the further reduced sample sizes. Nevertheless, the mean effects are quite significant and merit discussion.

For lumber with a strength ratio of <0.65 (SR12), the reduction in bending strength of specimens with pith (Table 5) in the six CCA-treated groups ranged from - 12% to - 29% (mean = - 19%); for specimens without pith, strength was reduced by no more than - 9%, with the exception of specimens treated with 0.6 pcf CCA at 240 F. For lumber with a strength ratio 20.65 (SRSS), strength of specimens with pith was affected from + 17% to - 5% (mean = + 7%), whereas strength reduction of specimens without pith ranged from - 11% to - 15% (mean = - 13%). The complex nature of this pith-grade interaction with CCA treatments is evident (Table 5).

These data show that CCA treatments and redrying reduced the strength of lumber with pith having a strength ratio <0.65 (SR12) as well as the strength of all lumber without pith. The strength of lumber with pith having a strength ratio 20.65 was not reduced. In fact, these specimens generally showed an increase in strength. However, note that control specimens with pith with a standard ratio 20.65 were no stronger than either control group with a standard ratio <0.65. Thus, the implications of the pith-grade-treatment interaction are still open to debate. This complex pith-grade interaction needs to be investigated because between 40% to 45% of the southern pine lumber produced in the United States is eventually treated with CCA and because large quantities of southern pine dimension lumber with pith are processed from small-diameter logs that yield

TABLE 5. *The bending strength (MOR) of pith-associated and pith-free specimens of two strength-ratio groupings for 2 × 6 southern pine lumber.*

Treatment	Drying level ¹	Presence (+) or absence (-) of pith	Strength ratio						
			≥0.65 (SRSS)			<0.65 (SR12)			
			n	MOR (psi)	Change ² (%)	n	MOR (psi)	Change ² (%)	
None	None	-	39	8,504		70	5,379		
		+	38	5,547		43	5,357		
H ₂ O	160	-	57	7,518	-12	49	5,552	+3	
		+	52	6,400	+15	34	4,969	-7	
	240	-	51	7,679	-10	52	5,381	0	
		+	48	6,909	+25	41	4,611	-14	
0.4 (GRD)	160	-	40	7,393	-13	36	5,083	-6	
		+	19	6,108	+10	33	3,810	-29	
	240	-	40	7,467	-12	36	4,890	-9	
		+	24	5,269	-5	28	4,094	-24	
	0.6 (FDN)	Air	-	33	7,538	-11	43	5,240	-3
			+	25	6,103	+10	26	4,731	-12
160		-	43	7,351	-14	56	4,977	-7	
		+	46	6,491	+17	45	4,260	-20	
240	-	51	7,253	-15	63	5,142	-4		
	+	39	6,070	+9	38	4,585	-14		
			44	7,554	-11	50	4,040	-25	
			56	5,604	+1	40	4,426	-17	

¹ Post-treatment drying temperatures, F.² Percent change from the appropriate nonpith- or pith-associated untreated control.

significant amounts of material containing pith. Further investigations are underway at FPL to determine the influence of pith on strength of treated specimens of different grades and sizes.

CONCLUSIONS

CCA treatments and redrying had no effect on the average MOE, but they reduced average MOR, PMAX, DMAX, and WML up to 29% depending on level of treatment, method of redrying, strength ratio, and presence or absence of pith. Most importantly, our results show no significant reduction in the extreme lower portion (< 10th percentile) of the bending property distribution for 2 × 6 lumber.

Practical considerations such as the significant reductions of 10% to 20% in the low-to-mid portion of the MOR distribution (at or above the 10th to 40th percentile depending on treatment and drying level) and the magnitude of the influence of pith on lumber graded under current grading rules cause us to question the use of KDAT temperatures of > 190 F. Another study using 2 × 4 lumber dried at high temperatures is now underway at FPL to explore the effect of temperatures above this recommendation.

The results of our study together with the results of earlier clear wood and lumber studies (Barnes and Mitchell 1984; Bendtsen et al. 1983; Mitchell and Barnes 1986; Winandy et al. 1985) indicate that high-temperature kiln redrying reduces bending strength. Thus, we recommend that KDAT temperatures be limited to a maximum of 190 F.

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