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Influence of Initial Kiln-Drying Temperature on CCA-Treatment Effects on Strength

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This report interprets recent research that quantified the influence of pretreatment kiln-drying temperature on the effects of chromated copper arsenate (CCA) treatment and redrying on mechanical properties of wood. Using data from previous research, we compared matched specimens of Southern Pine No. 2 & better lumber initially kiln-dried at either 196°F (91°C) or 235°F (113°C). Initial kiln-drying at the higher temperature generally resulted in greater strength reductions in the lower tails of the strength distribution.

Because most Southern Pine lumber is initially kiln-dried at high temperatures, the implications of these results are significant. The current redrying temperature limit of 190°F (88°C) in Standards C-2 and C-22 of the American Wood Preservers' Association is based on research results for CCA-treated lumber initially kiln-dried at 180°F (82°C). Our results imply that the 190°F (88°C) redrying temperature limit may be too high for Southem Pine initially dried at high temperatures. Our results also suggest that setting a redrying limit of ≤ 160°F (≤ 71°C) may preclude the need for a reduction in allowable design stresses for CCA-treated lumber.

Keywords: Mechanical properties, CCA, preservatives, treatments, kiln-drying, redrying, lumber, Southern Pine, chromated copper arsenate, tensile strength, bending strength.

INTRODUCTION

The initial kiln-drying of Southern Pine lumber is often performed using dry-kiln schedules that employ high temperatures (above the boiling point of water). The benefits of high-temperature kiln-drying include reduced kiln time and reduced drying-induced warp. The effects of this processing on the mechanical properties of untreated Southern Pine lumber have been shown to be negligible after normal kiln durations (Koch 1976, Yao and Taylor 1979). However, over half the Southern Pine lumber currently produced in the United States is treated with chromated copper arsenate (CCA) preservative after initial kiln-drying. Previous research showed that initial kiln-drying temperature can interact with the effects of CCA-Type-C treatment and redrying on bending and tensile strength properties (Barnes et al. 1990, Winandy et al. in press). The objective of this report is to integrate the results of these previous reports and to discuss the implications of those results on American Wood-Preservers' Association (AWPA) Standards and allowable design stresses (NFPA 1986).

METHODS

Two-thousand 12-ft- (3.7-m-) long Southern Pine (*Pinus taeda* or *P. echinata*) nominal 2 by 4's (standard 50 by 100 mm) were selected in the green condition from a sawmill in Northern Mississippi. All specimens were graded as No. 2 & better, a quality level based on knot size and location. The specimens were then sorted by green stiffness into E-matched groups of approximately 100 specimens. Half the groups were randomly chosen for initial kiln-drying with a continuously rising kiln schedule with a maximum dry-bulb temperature of 196°F (91°C). After initial kiln-drying at 196°F (91°C), these groups were treated with CCA and air redried (**Lo-AIR**) or kiln dried at either 160°F (71°C) (**Lo-160**) or 240°F (116°C) (**Lo-240**). The other groups were initially kiln-dried at a constant dry-bulb temperature of 235°F (113°C). After the initial kiln-drying, these groups were treated with CCA and air redried (**Hi-AIR**) or kiln dried at 160°F (71°C) (**Hi-160**) or 240°F (116°C) (**Hi-240**). All specimens were treated to target retentions of 0.6 lb/ft^3 (9.6 kg/m^3) CCA, using a full-cell cycle and CCA-Type-C oxide. The two initial kiln-drying regimes (196°F (91°C) and 235°F (113°C)) and the air-redrying and 160°F- (71°C-) kiln-redrying regimes represent common industry practice. The 240°F- (116°C) kiln-redrying regime represents a known excessive temperature, which was included to assure significant strength reductions. For both initial kiln-drying schedules, untreated and unredried groups were maintained as controls.

Matched groups of specimens were tested in bending at Mississippi Forest Products Laboratory or tested in tension at the USDA Forest Service Forest Products Laboratory (ASTM 1989). For each group of approximately 100 specimens, a nonparametric rank-order procedure was used to estimate the 5th, 10th, 25th, 50th, 75th, and 90th percentiles of both the bending and tensile strength distributions. Because grade was found to be a significant covariable in previous studies (Winandy and Boone 1988, Winandy 1989), the groups were further analyzed by grade. Two subsets of No. 2 & better grade were considered: No. 1 & better and No. 2 on-grade (that is, no No. 1 & better material included). The subgroups based on grade were not E-matched; thus, strong inferences from the tails of the strength distribution should be limited. Sample size varied from 38 to 57; therefore, nonparametric percentile estimates were derived for only the 10th, 25th, 50th, 75th, and 90th percentiles of the bending and tension distributions.

The experimental methods employed were described in detail in two previous reports (Barnes et al. 1990, Winandy et al. in press).

RESULTS

Bending Strength

The effects of various initial and posttreatment kiln-drying combinations on the bending properties of No. 2 & better CCA-treated 2 by 4 Southern Pine lumber are reported in Table 1 and shown in Figure 1. In this figure, nonparametric estimates of bending strength between the 10th and 90th percentiles for each treated and redried group are compared to that of untreated controls by a ratio. For example, the ratio of 0.80 for the 10th percentile of the Hi-240 group indicates that estimated bending strength was reduced 20 percent compared to the 10th percentile estimate for the untreated control. For the Lo-AIR group, the within-group variability across the bending strength distribution varied from −5 to + 12 percent. For other groups, the within-group variability across the bending strength distribution ranged less than 12 percent. Overall bending strength for CCA-treated lumber was generally reduced less than 10 percent, except for the Hi-240 group, in which bending strength tended to be reduced by 10 to 20 percent (Fig. 1).

Note that when a low temperature was used for initial kiln-drying prior to CCA treatment and redrying, the reduction in bending strength for the $\leq$ 50th percentile of the distribution was stable or decreased. In contrast, when a high temperature was used for initial kiln-drying, the reduction in bending strength for the $\leq$ 50th percentile of the distribution increased. This difference in the effects of CCA treatment and redrying on the lower tail of the strength distribution may partially explain the differing results of our previous work, which involved both high and low initial kiln-drying temperatures (Barnes and .Mitchell 1984; Winandy and Boone 1988, Winandy 1989, respectively).

Tensile Strength

The effects of various combinations of initial and posttreatment kiln-drying methods on the tensile strength of No. 2 & better CCA-treated 2 by 4 Southern Pine lumber are reported in Table 2 and shown in Figure 2. For each group, the within-group variability across the tensile strength distribution ranged less than 10 percent. For specimens air redried or kiln redried at 160°F (71°C), the overall reduction in tensile strength across the entire strength distribution was less than 13 percent when compared to that of matched untreated controls. When specimens were redried at 240°F (116°C), the reduction in strength tended to be 10 to 25 percent (Fig. 2).

When either initial kiln-drying schedule was used before CCA treatment and air redrying or high-temperature (240°F (116°C)) kiln-redrying, few practical reductions at or above the 25th percentile of the tensile strength distribution could be attributed to the initial kilndrying temperature. However, when the Lo-160 group was compared to the Hi-160 group, we noticed a differential trend in tensile strength below the 25th percentile of the distribution. This differential trend is similar to that noted for bending strength at all three levels of redrying. The differential trend in tensile strength suggests that some undefined cumulative thermal threshold was exceeded for the Hi-160, Lo-240, and Hi-240 groups, but not for the Lo-AIR, Hi-AIR, and Lo-160 groups.

Effect of Grade

When the No. 2 &better specimens were grouped into two subgroups (No. 1 & better and No. 2), the subgroups were no longer E-matched. Thus, caution must be taken when interpreting the data from tests on the subgroups. Nevertheless, few grade-related effects were apparent (Tables 1 and 2). Note that for

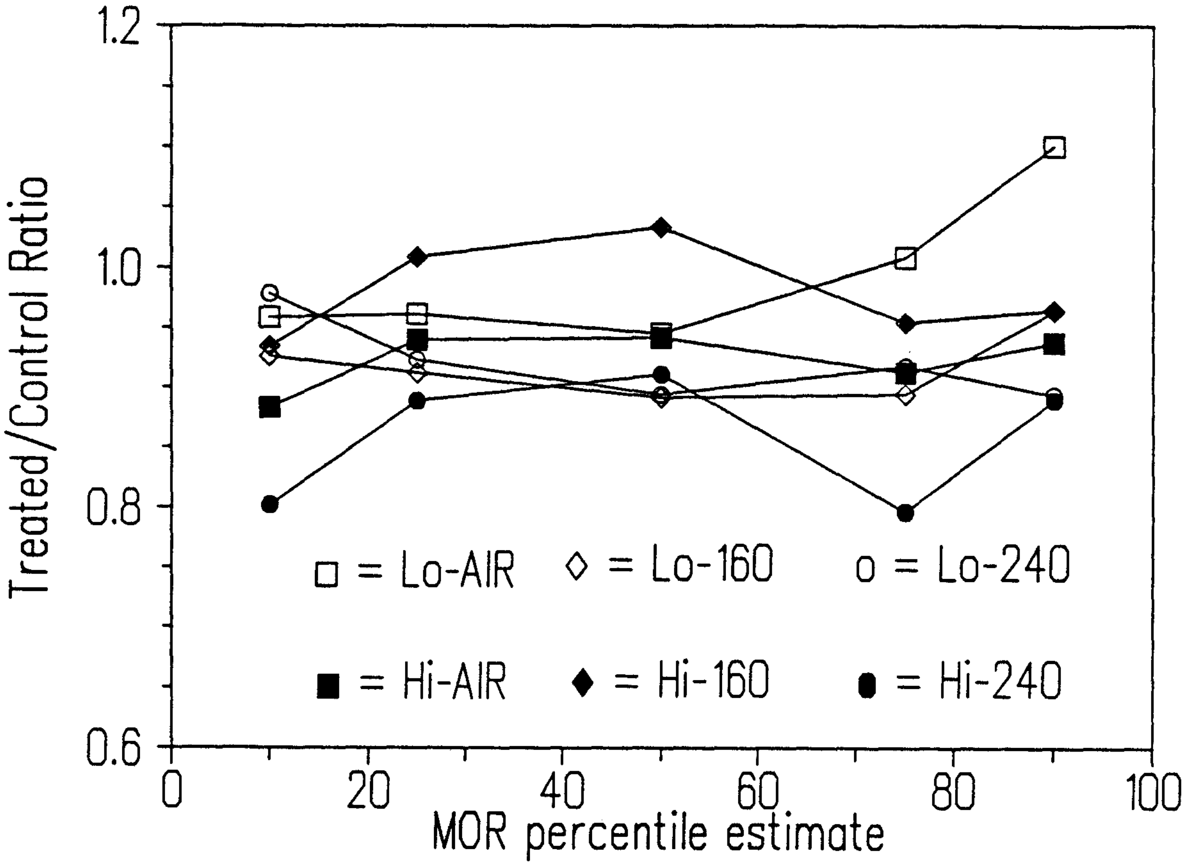

Figure 1–Effect of various drying regimes on bending strength (MOR) ratio of CCA-treated to untreated No. 2 & better Southern Pine lumber. Lo, initial kiln-drying at 196°F (91°C) and redrying by air or kiln (160°F (71°C) or 240°F (116°C)). Hi, initial kiln-drying at 235°F (113°C) and same redrying regimes as those designated for Lo groups.

both grades, the lumber initially kiln-dried at the high temperature generally had lower bending and tensile strength than the matched lumber initially kiln-dried at the low temperature. This supports the trends noted with the No. 2 & better specimens. It also suggests that regardless of grade, high-temperature initial kiln-drying interacts with the CCA-treatment and redrying effect to promote larger reductions in strength throughout a greater range of the strength distribution than does initial kiln-drying at lower temperatures. As expected, redrying at 240°F (116°C) appeared to significantly reduce the tensile strength of either grade. Finally, the entire bending strength distribution of the No. 2 Lo-240 group appeared unaffected whereas that of the No. 2 Hi-240 group and No. 1 & better Lo-240 and Hi-240 groups appeared to be reduced. This supports the concept that lower grade materials tend to be less affected by the cumulative effects of treatment and drying than are higher grade materials.

DISCUSSION

Wood is susceptible to accumulated mechanical property damage (Stamm 1964). Our results suggest that for lumber specimens comparably treated with CCA and redried, initial kiln-drying at 235°F (113°C) generally results in larger reductions in both bending and tensile strength than does initial kiln-drying at 196°F (91°C). Because most Southern Pine lumber is initially kiln-dried at high temperatures, the implications of these results are significant. If initial kiln-drying temperatures remain unlimited and if redrying temperatures as high as 190°F (88°C) are maintained in AWPA Standards, adjustments may be required in allowable design values (NFPA 1986). Based on the results between the 25th and 75th percentiles (Figs. 1 and 2), this adjustment factor might range from a 5- to 10-percent reduction, depending on the temperatures allowed in pretreatment, treatment, and posttreatment processing. However, our data and the combined results of previous work (Barnes and Mitchell 1984, Winandy and Boone

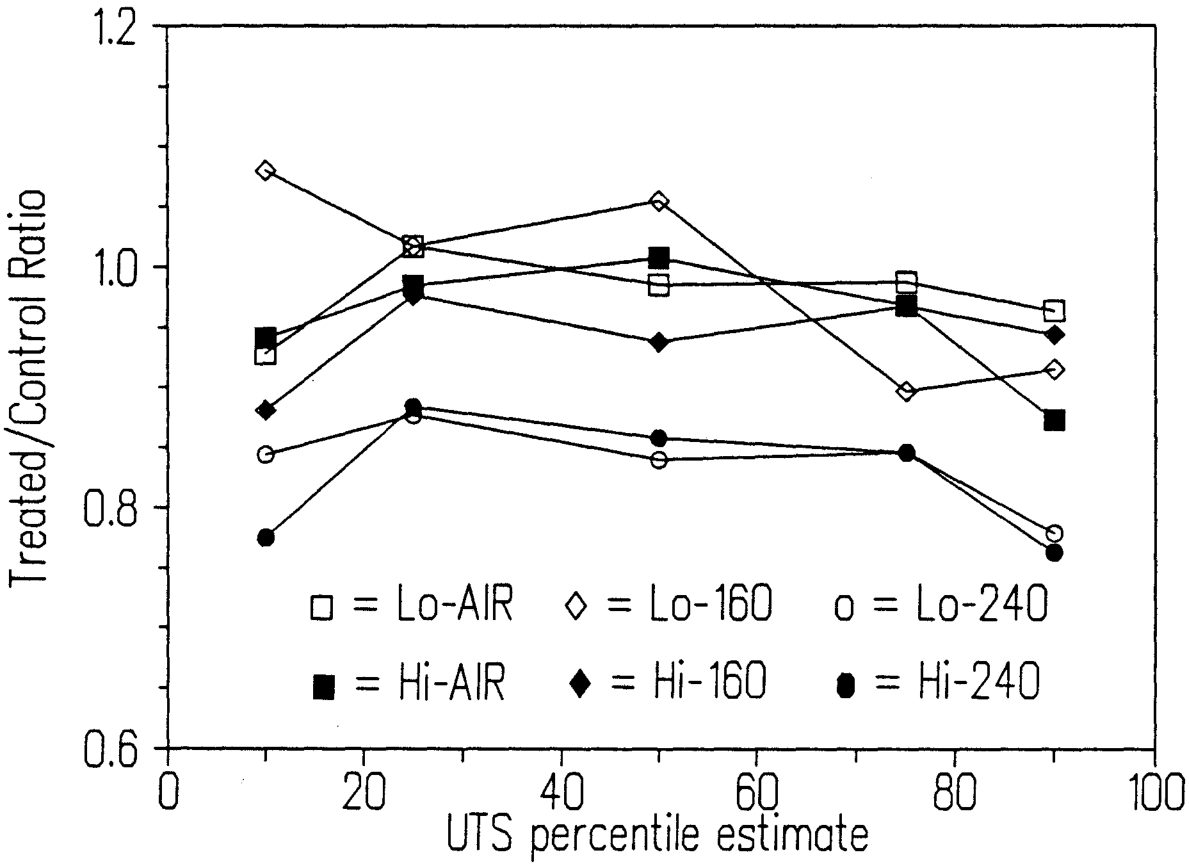

Figure 2–Effect of various drying regimes on tensile strength (UTS) ratio of CCA-treated to untreated No. 2 & better Southern Pine lumber. Groups are defined in legend to Figure 1.

1988, Winandy 1989) also suggest that if redrying temperatures in AWPA Standards C-2 and C-22 (AWPA 1990) are limited to $\leq$160°F ($\leq$71°C), then allowable design stresses for bending and tensile strength may not require adjustment.

CONCLUSIONS

Initial kiln-drying of nominal 2 by 4 Southern Pine No. 2 & better lumber at 235°F (113°C) generally resulted in larger reductions in bending and tensile strength when compared to that of matched lumber initially kilndried at 196°F (91°C). Because most Southern Pine lumber is initially kiln-dried at high temperatures, the implications of these results are significant. The current AWPA redrying temperature limit of 190°F (88°C) in Standards C-2 and C-22 is based on research results for CCA-treated lumber initially kiln-dried at 180°F (82°C). These results suggest that the 190°F (88°C) redrying limit for initially high-temperaturedried Southern Pine may be too high. These results also suggest that setting a 160°F (71°C) redrying limit in AWPA Standards may preclude the need to adjust allowable design stresses for bending and tension.

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Table 1--Modulus of rupture (MOR) of 2 by 4 Southern Pine lumber for different drying regimes[a]

Drying regime[b]	Sample size	Mean MOR (lb/in^2)	SD[c] (lb/in^2)	MOR for various percentiles (lb/in^2) 5th	10th	25th	50th	75th	90th
				No. 2 & better					
Lo-240	91	6,947	2,884	2,856	3,515	4,522	6,428	9,270	10,783
Lo-160	92	6,824	3,170	2,384	3,326	4,469	6,408	9,033	11,633
Lo-AIR	94	7,570	3,523	2,911	3,444	4,711	6,796	10,187	13,285
Control	190	7,654	3,219	3,264	3,592	4,900	7,190	10,103	12,072
Hi-AIR	99	7,038	3,047	2,610	3,172	4,604	6,769	9,214	11,312
Hi-160	101	7,398	3,175	2,750	3,357	4,942	7,431	9,636	11,640
Hi-240	101	6,487	2,964	2,113	2,880	4,355	6,549	8,042	10,728
				No. 1 & better					
Lo-240	38	8,580	2,479	--	5,141	6,882	8,817	9,776	11,690
Lo-160	39	9,152	3,010	--	4,885	6,775	9,104	11,428	13,221
Lo-AIR	41	9,558	3,494	--	4,823	6,441	9,635	12,237	13,633
Control	89	9,508	3,755	5,097	5,263	7,507	9,380	11,514	13,442
Hi-AIR	53	8,810	2,441	--	5,661	6,818	8,677	9,895	12,451
Hi-160	53	8,876	2,873	--	4,668	7,097	8,728	11,271	12,877
Hi-240	51	7,720	2,881	--	3,964	6,071	7,094	9,666	12,107
				No. 2					
Lo-240	53	5,777	2,584	--	2,898	3,949	5,408	7,164	9,803
Lo-160	53	5,110	1,978	--	2,497	3,691	4,787	6,609	7,648
Lo-AIR	53	6,033	2,699	--	3,161	3,884	5,456	7,700	9,770
Control	101	6,021	2,675	2,980	3,269	4,082	5,092	7,183	9,991
Hi-AIR	46	4,996	2,316	--	2,598	3,343	3,986	6,387	8,532
Hi-160	48	5,767	2,672	--	2,698	3,679	5,121	7,610	9,488
Hi-240	50	5,230	2,503	--	2,113	3,465	5,164	6,466	8,276

[a] 1 lb/in^2 = 6.89 kPa.

[b] Lo-240, Lo-160, Lo-AIR: initial kiln-drying at 196°F (91°C) and redrying by kiln (240°F (116°C) or 160 F (71°C)) or air.
Hi-240, Hi-160. Hi-AIR: initial kiln-drying at 235°F (113°C) and same redrying regimes as those designated for the "Lo" groups.

[c] Standard deviation.

Table 2--Tensile strength (UTS) of 2 by 4 Southern Pine lumber for different drying regimes[a]

Drying regime[b]	Sample size	Mean UTS (lb/in^2)	SD[c] (lb/in^2)	UTS for various percentiles (lb/in^2) 5th	10th	25th	50th	75th	90th
				No. 2 & better					
Lo-240	98	3,639	1,578	1,434	1,779	2,410	3,320	4,609	5,883
Lo-160	103	4,331	1,934	1,857	2,276	2,796	4,168	4,884	6,904
Lo-AIR	96	4,343	2,036	1,777	1,951	2,797	3,898	5,382	7,276
Control	408	4,452	2,277	1,828	2,108	2,749	3,952	5,447	7,549
Hi-AIR	107	4,105	1,660	1,692	1,983	2,707	3,983	5,277	6,592
Hi-160	107	4,174	2,041	1,699	1,858	2,686	3,705	5,274	7,129
Hi-240	102	3,676	1,665	1,348	1,633	2,431	3,389	4,609	5,759
				No. 1 & better					
Lo-240	42	4,552	1,607	--	2,424	3,396	4,522	5,738	6,842
Lo-160	46	5,483	1,746	--	3,664	4,310	4,807	6,192	8,821
Lo-AIR	40	5,595	1,825	--	3,511	4,095	5,291	7,026	8,947
Control	194	5,472	2,243	2,617	3,005	3,949	4,957	6,589	8,555
Hi-AIR	54	4,939	1,400	--	3,162	3,938	5,115	6,051	6,630
Hi-160	54	5,092	2,019	--	2,902	3,542	4,385	6,302	8,147
Hi-240	54	4,306	1,651	--	2,256	3,157	4,284	5,180	6,364
				No. 2					
Lo-240	56	2,954	1,164	--	1,493	2,158	2,943	3,445	4,750
Lo-160	57	3,401	1,548	--	1,936	2,499	3,104	4,192	4,785
Lo-AIR	56	3,449	1,687	--	1,790	2,401	2,962	4,200	5,346
Control	214	3,528	1,883	1,697	1,906	2,340	3,032	4,062	5,444
Hi-AIR	53	3,255	1,471	--	1,692	2,085	2,895	4,090	5,277
Hi-160	53	3,238	1,602	--	1,699	2,005	2,773	4,218	5,622
Hi-240	48	2,967	1,385	--	1,427	2,106	2,656	3,746	4,762

[a] 1 lb/in^2 = 6.89 kPa.

[b] Lo-240, Lo-160, Lo-AIR: initial kiln-drying at 196°F (91°C) and redrying by kiln (240°F (116°C) or 160°F (71°C)) or air.
Hi-240, Hi-160, Hi-AIR: initial kiln-drying at 235°F (113°C) and same redrying regimes as those designated for the "Lo" groups.

[c] Standard deviation.

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