EFFECTS OF CCA TREATMENT AND DRYING ON TENSILE STRENGTH OF LUMBER

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ABSTRACT: Approximately 50% of the southern pine lumber produced in the United States is subsequently pressure treated with chromated copper arsenate (CCA) preservative. This report discuss the influence of initial kiln-drying temperature. CCA preservative treatment, post-treatment redrying temperature, and grade on the tensile properties of southern pine dimension lumber. Tensile strength was not significantly affected by initial kiln-drying temperature, but it was reduced when CCA treatment was followed by high-temperature redrying. When comparing No. 2 and better southern pine nominal 2- by 4-in. (actual 38- by 89-mm) lumber initially kiln dried at either 91°C or 113°C, a consistent reduction in tensile strength of 7-10% was noted when initial kiln drying at 113°C was followed by CCA treatment and any level of redrying. This effect is consistent with previously reported results for bending strength.

INTRODUCTION

High-temperature kiln drying using common drying schedules (*Dry Kiln Operator's Manual* 1991) has no significant effect on the mechanical properties of southern pine lumber (Comstock 1976; Koch 1976; Yao and Taylor 1979). However, we hypothesize that an interactive relationship exists between the severity of conditions imposed during initial kiln drying and the severity of conditions during subsequent treatment with waterborne preservatives, such as chromated copper arsenate (CCA), and post-treatment redrying. This hypothesis evolved from an examination of the underlying principles behind the cumulative damage theory of strength for untreated wood (Caulfield 1985; Gerhards 1979) and the application of theoretical chemical kinetics to wood (Millett and Gerhards 1972; Stamm 1964). We believe that the effects of chemicals or chemical processing are combined functions of the chemistry of the treatment chemicals and the cumulative processing temperature to which the wood materials are exposed.

The existence or magnitude of this interactive relationship is essentially unknown; therefore, our objective was to identify the effects of initial kiln-drying temperature, CCA-preservative treatment, post-treatment redrying temperature, and grade on the tensile properties of southern pine dimension lumber. Barnes et al. (1990) showed that such a cumulative damage-type relationship does exist between initial kiln-drying temperature, CCA treatment, and redrying temperature for bending properties. In that study, when lumber was initially kiln dried at a maximum temperature of 91°C, followed by CCA treatment and redrying, even at a redrying temperature of 116°C, few reductions in bending strength were noted. When lumber was initially

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kiln dried at 113°C, small reductions in bending strength were rioted throughout the entire bending strength distribution after CCA treatment and air redrying or redrying at 71°C. When lumber was initially kiln dried at 113°C. followed by CCA treatment and redrying at 116°C, significant reductions in bending strength were noted.

This report discusses the results from nominal 2- by 4-in. (actual 38- by 89-mm) southern pine lumber tested in tension parallel to grain. These results are then compared with previously reported results from matched bending specimens.

BACKGROUND

In recent years, considerable effort has been made to quantify the effects of waterborne arsenical preservatives and post-treatment seasoning on the properties of treated wood. This work was summarized in three papers by Barnes and Winandy (1986; 1989) and Winandy (1988). They concluded as follows: (1) Mechanical property reductions for wood treated to retentions of ≤16.0 kg/m^3 and redried at temperatures less than 71°C are insignificant, although treating wood to higher retentions or redrying at higher temperatures can cause significant strength loss; (2) property reductions from waterborne arsenical preservatives seem directly linked to the chromium content of the formulation: (3) because of the importance of structural reliaibility, the results of an analysis of bending strength distributions are more informative, and thus preferable to all analysis involving only average values; (4) Mechanical properties are affected differently, with compression strength unchanged or slightly increased, stiffness generally unchanged, or if affected, reduced less than bending strength, which in turn reduced less than energy-absorbtion properties, such as toughness or work-to-maximum load; (5) Treatment with CCA and redrying temperature appear to interact significantly with stress grade, with higher lumber grades affected more than lower grades.

MATERIALS AND METHODS

Experimental Design

A factorial design was used with independent controls for each level of initial kiln drying (Table 1). Factors included two initial drying temperature levels (91°C or 113°C maximum), two treatment levels (untreated or treated with CCA-type C to 9.6 kg/m^3), and three post-treatment redrying levels (air dried, kiln dried at 71°C. or kiln dried at 116°C), with tension parallel to grain as the dependent variable.

Note that two groups (A, B) of untreated controls were evaluated at both initial kiln-drying levels (Table 1). We originally planned to treat one group at each initial kiln-drying level with water, as had been done in the Barnes et al. (1990) matched bending properties stud). This would have provided untreated and water-treated sets of controls. However, we were unable to obtain the use of a treating retort longer than 3.66 m in which to perform water treatments. Thus, we used two sets of untreated controls at each initial kiln-drying level. These combined groups of untreated controls are referred to in the text as LCTL (groups LCTL-A and LCTL-B combined) and HCTL (groups HCTL-A and HCTL-B combined). However, this change did allow us to verify whether our sorting on green dynamic modulus of elasticity (E_g) as a basis for assigning specimens to treatment groups provided an effective method of reducing variability in the experiment.

Initial kiln-drying temperature (°C)	Untreated Control[b] (Sample Size)		CCA Treated to 9.6 kg/m³ under Three Redrying Conditions (Sample Size)		
	A	B	Air dry	71°C	116°C
(1)	(2)	(3)	(4)	(5)	(6)
91	LCTL-A (98)	LCTL-B (98)	-	-	-
91	-	-	LAIR (96)	L71 (97)	L116 (95)
113	HCTL-A (103)	HCTL-B (102)	-	-	-
I13	-	-	HAIR (102)	H71 (103)	H116 (102)

Material

Approximately 1,000 green, 3.66-m southern pine two-by-fours were obtained from the green chain of a northeastern Mississippi sawmill. Based on the area from which the material was cut, the lumber was loblolly or shortleaf pine *(Pinus taeda* or *P. echinata,* respectively). We evaluated all specimens for grade in the rough, green condition according to the grading rules for southern pine dimension lumber (Southern Pine 1977), based on knot size and location. Each specimen was then nondestructively evaluated to determine E_g using an *E*-computer. Specimens were assigned to 10 experimental groups so all groups would have similar E_g distributions. We used this method because it is believed to minimize experimental variability. This method is described in detail by Winandy and Boone (1988) and Winandy (1989). The 10 groups used in this study on the effects on tensile strength (Table 1) were matched on E_g to the 10 groups used in the Barnes et al. (1990) study on the effects of initial kiln-drying temperature, CCA treatment, and post-treatment redrying effects on bending strength.

Initial Drying

Of the 10 groups of rough, green lumber designated for this study, five were commercially kiln dried at 91°C maximum dry-bulb temperature, and five were commercially kiln dried at 113°C. The five groups designated for the 91°C schedule were dried in a steam-heated kiln using a rising-temperature schedule (Table 2). Resident kiln time was 66 hours, with a target moisture content of 12% (oven-dry basis). The other five groups were dried in a direct-fired kiln, using a constant dry-bulb temperature of 113°C and an uncontrolled wet-bulb temperature ranging from 81°C to 63°C. Resident kiln time was 24 hours with fan reversal every 3 hours (Table 2).

After drying, each 3.66-m sample was graded twice, with each grade based solely on the size and location of knots or on slope of grain. One lumber grade was an evaluation of quality over the full length of the sample (termed the 12-ft grade). The other grade was an evaluation of quality over the middle 2.44 m (termed the 8-ft grade), which corresponded to the area that could be placed between the grips of the tension machine during testing. All lumber grading was performed by a quality supervisor from the Southern Pine Inspection Bureau, Pensacola, Florida.

TABLE 2. Initial and Post-Treatment Kiln-Drying Schedules

Process (1)	Drying schedule (2)	Step (3)	Temperature (Degrees C)		Time (hours) (6)	Comments
			Dry bulb (4)	Wet bulb (5)		
Initial drying	Continuously rising dry bulb	1	80	54–71	7	Initial moisture content is greater than 70%.
		2	82	72	8	
		3	87	72	7	
		4	89	72	4	
		5	91	72	16	
		6	91	60	24	
					66[a]	Average final moisture content is 12%.
	High temperature[b]	1	113	81–63	24	Dry-bulb temperature constant; floating wet-bulb temperature; initial moisture content is greater than 70%
		2	113	63	12	
					36[a]	Average final moisture content is 12%
Redrying CCA post-treatment	Conventional	1	71	54	29	Fan speed 152 m/min.
		2	71	67	24	
					53[a]	Average final moisture content is 15.1%
	High temperature[b]	1	116	82	21	Fan speed is 244 to 305 m/min.
		2	77	71	6	
					27[a]	Average final moisture content is 16.4%

[a] Total kiln residence time.

[b] Fan reversal every 3 hours.

Lumber Treatment

For each of the two initial kiln-drying temperature levels, three groups of specimens (six groups total) were treated with a 1.5% (oxide basis) solution of CCA-type C preservative *(Annual AWPA* 1989), using a Bethell (full-cell) cycle. Maximum press was 1.034 MPa and treatment was to refusal. Target retention was the AWPA wood-foundation retention level of 9.6 kg/m^3. Two groups for each of the initial kiln-drying temperature levels were maintained as untreated controls.

Post-Treatment Redrying

After preservative treatment, the lumber was stored at ambient conditions a minimum of two days prior to drying. Those groups designated for air drying were dried in 1.22-m-wide covered piles on 19-mm-thick stickers at a spacing of 610 mm. Air drying to an average 15% moisture content took three months in the late summer in northern Mississippi. Kiln redrying was done in an experimental, steam-heated masonry kiln. Drying schedules are given in Table 2. After drying, specimens were shipped by truck to the Forest Products Laboratory (FPL) in Madison, Wisconsin. At the FPL, prior to tensile testing, specimens were conditioned at 23°C and 65% relative humidity to constant weight (approximately 12% equilibrium moisture content for untreated material).

Tensile Tests

Just prior to tensile tests, the dynamic modulus of elasticity (E_d) over the 3.66-m length of each specimen was evaluated using an *E*-computer. Each specimen was then tested on a 1.11-MN tension testing machine per ASTM D-4761 *(The 1989 Book* 1989). The rate of loading was 44.5 kN/min (load control), which caused failure in about 45–300 s. For each specimen, ultimate tensile stress (UTS) was calculated from the maximum load and specimen dimensions.

After testing, a small undamaged block (25.4 mm along the grain by the full cross section of the specimen) was cut from near the failure to determine moisture content and specific gravity (oven-dry weight, volume at test basis). The size and location of the defect causing failure (for example, knot or slope of grain) were noted. Strength ratio was calculated from the defect involved in the tensile failure, whereas the 12- and 8-ft graded specimens were evaluated prior to test based on the largest strength-reducing defect in that section.

Data Analysis

A graphical analysis of the data was employed to check for trends and to interpret the data. This was followed by statistical analyses to check simple-size equivalency and then to check for normality. As appropriate, either a parametric or nonparametric analysis of variance was performed to identify significant differences between mean values for each mechanical property considered. Where analysis of variance indicated significant differences between property means, a Tukey's multiple comparison was employed to identify experimental groups that had statistically significant differences.

Although statistical analyses exist to test equality at various percentile levels away from the mean, their power decreases rapidly with increasing distance from the distribution mean. Practical criteria for comparing strength distributions are needed. When considering strength distributions of nearly

100 specimens, a 10% difference represents our definition of a practically important difference away from the mean. Thus, when comparing the differences at percentiles in the lower tail of the distribution, a 10% difference between the untreated control and the treatment-drying combination in question was used as a practical test of the importance of these differences throughout the distributions.

RESULTS AND COMMENT

We selected specimens in the rough, green condition in the sawmill. When evaluated on the entire 3.66-m length, the overall quality of the specimens varied: 97% of specimens were No. 2 and better grade, less than 2% were No. 3, and 1% were less than No. 3. However, in the tensile test, the end 0.61 m of each specimen was held in the test machine grips, and when the material was graded over the middle 2.44-m area (i,e., the 8-ft grade), all specimens were found to be No. 2 and better.

A chi-square test was used to compare the equality of group sample sizes for various uncontrolled factors in the experimental design, such as 12-ft grade, 8-ft grade, overall strength-ratio distribution, and the presence or absence of pith. The results showed that the distribution of both the 8-ft and 12-ft grades, pith, and strength ratio between groups, and the distribution of 12-ft grade, pith, and strength ratio between initial kiln-drying levels, can be considered equivalent (alpha > 0.15). However, the distribution of 8-ft grade between the initial kiln-drying levels cannot be considered equivalent (alpha < 0.0001). The impact of this finding is discussed later.

No. 2 and Better

For specimens evaluated as No. 2 and better, moisture content was significantly affected by CCA treatment (Table 3). This followed the same trend as previous work by Winandy and Boone (1988) and Winandy (1989). Moisture content is generally higher than that of untreated controls when

TABLE 3. Results of Nonparametric Analysis of Variance between Mean Values[a]

Group (1)	Mean moisture content (2)	Mean specific gravity[b] (3)	lean strength ratio (4)
LCTL-A	11.7	0.47	74.1
LCTL-B	11.4	1.47	73.2
LAIR	13.3	0.48	75.8
L71	12.8	0.48	74.3
L116	11.4	0.48	72.6
HCTL-A	11.9	0.47	71.5
HCTL-B	11.8	0.47	73.8
HAIR	13.4	0.48	75.2
H71	11.9	0.49	74.6
H116	10.0	0.48	73.1
Significance level	<0.0001[c]	0.1774	0.8521

[a] Kolomogorov-Smirnov *D*-statistic.

[b] Based on volume at test.

[c] The 10 means are significantly different.

specimens are treated with CCA and redried at 71°C or air dried after treatment, but it is lower than that of controls when specimens are redried at 116°C. This interaction is probably a result of additional CCA-induced wood hydrolysis occurring at higher redrying temperatures. Therefore, traditional procedures for adjusting tensile strength values to account for the differential influence of moisture content were inappropriate. They were not used.

No effect was shown on E_d (Table 4). This is consistent with previous results for modulus of elasticity in bending.

A chi-square test was also used to compare the median tensile strength of the two low-temperature control groups with that of the two high-temperature control groups. The test showed that tensile strength of the two control groups at each initial kiln-drying level was not statistically different, with the chi-square statistic having values of 0.234 for the low-temperature control groups and 0.433 for the high temperature control groups. Thus, the two sets of controls at each initial kiln-drying level were combined to form a single control group for each initial kiln-drying level. When comparing these combined low-temperature controls (LCTL) to the high-temperature controls (HCTL), little difference was noted between the two tensile strength distributions (Table 5, Fig. 1). This general equivalency between the two tensile strength distributions supports the concept that initial high-temperature kiln drying has little effect on tensile strength for untreated No. 2 and better southern pine lumber.

When comparing the combined LCTL and combined HCTL groups with the three low-temperature, treated, and variously redried groups (LAIR, L71, L116), using Tukey's comparison based on nonparametric analysis of variance, only the treated group redried at 116°C (L116) exhibited a significant reduction at the mean (Table 4). The L116 group also exhibited a consistent reduction from 10–30% from the controls throughout the entire tensile strength distribution (Fig. 1). We consider this 10–30% reduction in the UTS distribution to be of practical significance.

TABLE 4. Results of Nonparametric Analysis of Variance Testing Equivalency of Mean Values when Graded as No. 2 and Better

Group (1)	Number of specimens (2)	E_g^a (GPa) Mean (3)	E_g^a (GPa) Median (4)	E_d^b (GPa) Mean (5)	E_d^b (GPa) Median (6)	UTS[c] (MPa) Mean (7)	UTS[c] (MPa) Median (8)	UTS[c] (MPa) Fifth percentile (9)
LCTL-A	98	10.59	10.42	12.51	11.95	32.35	28.19	11.93
LCTL-B	98	10.36	10.09	1237	12.01	28.95	26.82	12.04
LAIR	96	10.31	10.27	12.86	13.03	29.94	26.87	12.25
L71	97	10.29	9.94	12.70	11.82	29.75	28.64	12.40
L116	95	10.49	10.14	12.66	12.23	21.47	22.90	9.79
HCTL-A	103	10.24	10.03	12.53	12.49	29.59	27.66	12.77
HCTL-B	102	10.17	10.04	12.21	12.04	32.28	27.46	13.31
HAIR	102	10.04	9.93	12.03	11.88	27.71	26.90	11.28
H71	103	10.44	10.22	12.67	12.59	28.73	25.50	11.70
H116	102	10.26	10.18	12.52	12.40	25.76	23.36	9.29
Significace level	–	0.9942		0.8558		0.0015[d]		

[a] E_g is green dynamic modulus of elasticity.

[b] Ed is dynamic modulus of elasticity, kiln dried to less than 15% mositure content.

[c] UTS is ultimate tensile stress.

[d] Both L116 and H116 are significantly lower than teh other eight groups when tested using a nonparametric analysis of varienace.

TABLE 5. Tensile Strength Means, Standard Deviations, and Nonparametric Percentile Estimates for the Three Levels of 8-ft Grade

Lumber grade and group[a] (1)	Number of specimens (2)	Mean (3)	Standard deviation (4)	Percentile Levels				
				10th (5)	25th (6)	50th (7)	75th (8)	90th (9)
(a) No. 2 and better								
L116	95	24.97	10.93	12.21	16.57	22.90	31.58	40.58
L71	97	29.75	13.52	15.30	19.29	28.64	33.14	48.59
LAIR	96	29.94	13.04	13.20	19.28	26.87	37.10	50.16
LCTL	192	30.65	15.88	13.90	18.59	27.49	38.81	54.49
HCTL	205	30.93	15.75	15.17	19.35	27.56	38.28	52.85
HAIR	102	27.71	11.36	13.63	18.64	26.90	36.24	44.27
H71	103	28.73	14.28	12.80	18.36	25.50	36.42	49.46
H116	102	25.34	11.48	11.26	16.76	23.36	31.77	39.70
(b) No. 1 and better								
L116	41	31.16	11.12	16.64	23.38	30.95	39.14	47.22
L71	42	37.74	12.59	24.84	29.51	32.55	47.04	60.93
LAIR	40	38.57	12.58	24.20	28.23	36.48	48.44	61.68
LCTL	81	38.65	15.24	22.87	28.04	35.32	48.06	60.65
HCTL	109	37.10	15.65	19.81	26.78	33.62	43.80	55.81
HAIR	53	34.01	9.73	21.75	26.90	35.17	41.73	45.73
H71	53	35.19	14.04	19.97	24.36	30.23	43.78	56.23
H116	54	29.69	11.38	15.55	21.76	29.53	35.71	43.87
(c) No. 2								
L116	54	20.28	8.16	10.27	14.59	19.41	23.99	33.02
L71	55	23.65	10.81	13.17	16.65	21.65	29.07	33.16
LAIR	56	23.78	11.63	12.34	16.55	20.42	28.92	36.86
LCTL	113	24.66	13.51	12.76	16.13	20.80	28.87	39.35
HCTL	96	23.93	12.69	13.59	15.90	20.52	27.31	38.36
HAIR	49	20.91	8.82	11.04	13.94	19.57	25.11	33.67
H71	50	21.88	11.04	11.71	13.46	18.82	26.27	40.49
H116	48	20.45	9.55	9.84	14.52	18.31	25.82	32.83

[a] Code defined in Table 1.

The low-temperature treated groups air dried after treatment and redried at 71°C showed no apparent differences from either of the combined LCTL or HCTL groups below the mean (Fig. 1). However, each group showed a consistent 4–15% reduction in tensile strength at or above the 75th percentile (Fig. 1) when compared with the controls.

When comparing the three initially high-temperature kiln-dried and treated groups (HAIR, H71, H116) to the two untreated combined control groups (LCTL, HCTL), using the nonparametric Tukey comparison, a significant difference in mean tensile strength existed between the controls and the treated H116 group (Table 4). Similar to the trend exhibited by the low-temperature initially kiln-dried group (L116), a consistent difference of 10–30% existed throughout the entire tensile strength distribution between the two combined controls and the treated group redried at 116°C (Fig. 1). Again, we considered this 10–30% effect throughout the entire tensile strength distribution to be of practical significance.

When comparing the initially high-temperature dried groups, air dried or kiln dried at 71°C after treatment, to the two combined control groups, no significant reduction in tensile strength was noted below the 25th percentile. For the treated group air dried after treatment, the reduction in tensile strength above the 25th percentile ranged from 2–19% averaging 10% (Fig.

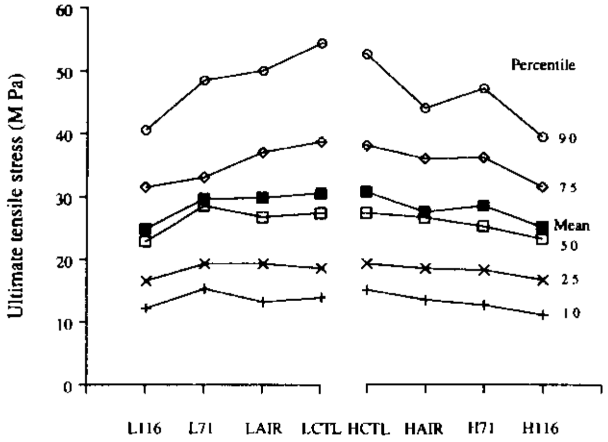

FIG. 1. Effect of Initial Kiln Drying on Subsequent Effect of CCA Treatment and Redrying on Various Percentile Levels of Tensile Strength Distribution when Graded No. 2 and Better.

1). For the treated group kiln dried at 71°C after treatment, the reduction in tensile strength above the 25th percentile ranged from 6–9% averaging 7%. This reduction in tensile strength after high-temperature initial kiln drying at all treatment and redrying levels is similar in magnitude to the high-temperature initial kiln-drying–induced reductions found with bending properties (Barnes et al. 1990).

The consistent reductions of about 20% throughout the entire tensile strength distribution for treated lumber redried at 116°C are nearly identical to the effects on bending strength (Barnes and Mitchell 1984; Barnes and Winandy 1986; Winandy 1989; Winandy and Boone 1988). This result confirms that excessive redrying temperatures significantly reduce tensile or bending strength by about 20%.

No significant reductions in tensile strength could be attributed directly to initial kiln-drying temperature. However, a consistent trend of about a 7–10% reduction in UTS was noted when comparing the initially high-temperature kiln-dried and CCA-treated groups (HAIR, H71, and H116) with the LCTL and HCTL control groups.

No. 1 and Better, and No. 2

Because of the previously discussed inequity in sample size in the initial kiln-drying groups based on the 8-ft grade, the issue of how different lumber grades are related to initial drying level cannot be definitively resolved from this data. However, we do attempt to discuss the general impact of grade on the effects on UTS in relation to initial kiln-drying temperature, CCA treatment, and redrying temperature.

Sample size and various percentile levels of the tensile strength distributions of No. 1 and better and No. 2 lumber are reported in Table 5. The general trends of tensile strength throughout these distributions are shown in Figs. 2 and 3. Note that when comparing the No. 1 and better grade at various percentile levels, the low-temperature dried controls ranged from 4–13% more tensile strength than the high-temperature dried controls (Table 5, Fig. 2). The apparent reduction in tensile strength from initial high-temperature kiln drying of No. 1 and better material averaged 7% when

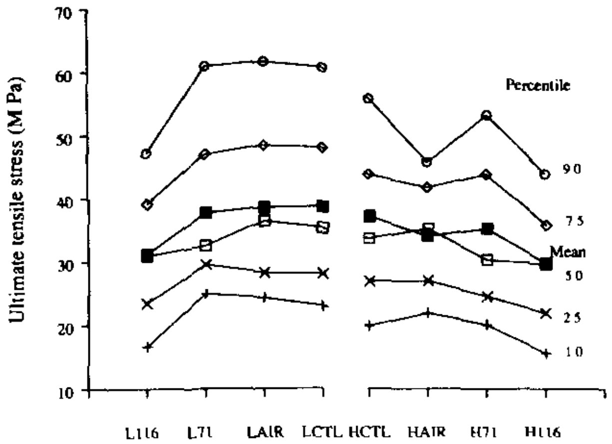

FIG. 2. Effect of Initial Kiln Drying on Subsequent Effect of CCA Treatment and Redrying on Various Percentile Levels of Tensile Strength Distribution when Graded No. 1 and Better.

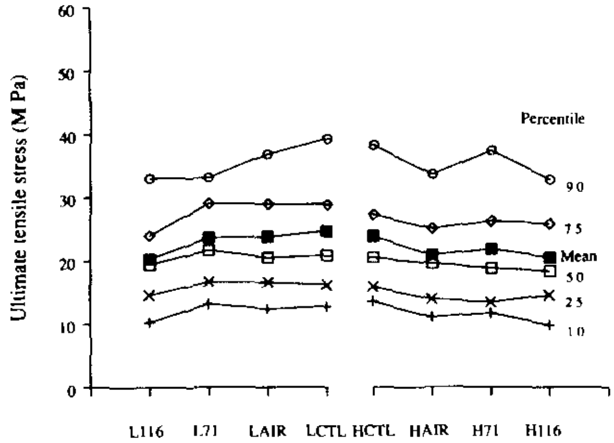

FIG. 3. Effect of Initial Kiln Drying on Subsequent Effect of CCA Treatment and Redrying on Various Percentile Levels of Tensile Strength Distribution when Graded No. 2.

compared with initial kiln drying at 91°C. The LAIR and L71 groups appeared unchanged from the low-temperature control. As expected, the reduction in tensile strength between the LCTL, control and the L116 group ranged from 12–23% and averaged 18%. All initial high-temperature kiln-dried groups appeared to be reduced in tensile strength when compared with the low-temperature dried control. The HAIR and H71 groups appeared to be reduced similarly. The reductions in tensile strength ranged from 1–14% and averaged 9% (excluding the 90th percentile of the HAIR group). This variability in a tail of the UTS distribution is not surprising, considering the limited sample size of 40–55 specimens. The reduction in tensile strength between the LCTL control and the H116 group ranged from 16–32% and averaged 24%.

When considering the No. 2 grade, few differences were apparent below the 90th percentile between the LCTL, HCTL, LAIR, and L71 groups (Table 5, Fig. 3). The reduction in tensile strength between the LCTL control and the L116 group ranged from 7–20% and averaged 15%. Both the HAIR and H71 groups appeared to be reduced similarly when compared with the low-temperature control. These reductions in tensile strength ranged from 6–17% and averaged 11% (excluding the 90th percentiles of both groups). The reduction in tensile strength between the LCTL control and the H240 group ranged from 10–23% and averaged 15%.

High-temperature redrying significantly reduced tensile strength for both grades; No. 1 and better grade material appeared to be reduced in tensile strength more than No. 2 grade material (Figs. 2 and 3). This trend is consistent with previously reported results (Winandy 1988,1989). However, as discussed, such a trend with tensile strength cannot be definitively proven with these data because of the difference in sample sizes in the initial kiln-drying temperature levels.

CONCLUSIONS

No significant differences were found in tensile strength distribution between two matched sets of untreated, 3.66-m, No. 2 and better southern pine two-by-fours kiln dried using either a continuously rising dry-bulb kiln schedule (maximum 91°C) or a high-temperature kiln-dry schedule (maximum 113°C).

Compared with either untreated control group (LCTL or HCTL), tensile strength of the specimens was not significantly reduced when either initial kiln-drying temperature level was followed by CCA treatment and then air drying after treatment (LAIR, HAIR) or redrying at a dry-bulb kiln temperature of 71°C (L71, H71). However, for the initially high-temperature kiln-dried and CCA-treated groups (HAIR, H71), a consistent, but statistically nonsignificant, tensile strength reduction of 7-10% was noted in the distribution above the 25th percentile. This consistent reduction in tensile strength with initially high-temperature kilndried and treated material should be viewed with concern by the design community.

When either initial kiln-drying level was followed by CCA treatment and then redrying at 116°C, tensile strength was significantly reduced. High-temperature redrying promotes reductions in tensile strength similar to previously reported reductions in bending strength. This result on tensile strength confirms recent changes in American Wood-Preservers' Association standards to limit excessive redrying temperatures that were intended to control reductions in bending strength.

The quality level or grade of the lumber interacts with the reduction in tensile strength caused by CCA treatment and redrying. Higher lumber grades, No. 1 and better, appear to be reduced in strength more than lower lumber grades, No. 2. This trend is consistent with previously reported results for bending strength.

APPENDIX. REFERENCES

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