EFFECT OF INITIAL AND POST-TREATMENT DRYING TEMPERATURES ON THE BENDING PROPERTIES OF CCA-TREATED SOUTHERN PINE

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Abstract

This study identifies the interaction of four processing or material characteristics on the bending properties of southern pine (*Pinus taeda* or *P. echinata*) dimension lumber. The four characteristics studied were (1) initial kiln-drying temperature, (2) chromated copper arsenate (CCA) preservative treatment, (3) subsequent post-treatment kiln-drying temperature, and (4) grade (based solely on strength-reducing characteristics such as knots and slope-of-grain). Understanding these relationships are important to US consumers and treaters because approximately 40-50 percent of the southern pine lumber produced in the USA is subsequently pressure treated with CCA preservative.

When initially kiln-dried using a continuously-rising kiln temperature (maximum 91°C), few reductions in bending strength were noted from CCA treatment when redried at temperatures of up to 71°C. When initially kiln-dried at temperatures above the boiling point of water (maximum 113°C), consistent reductions in mean bending strength were noted after CCA treatment at all redrying temperatures. Overall, initial kiln-drying at temperatures of 113°C resulted in consistently greater reductions in bending strength after CCA treatment and redrying than did initial drying at 91°C. Yet, this reduction was only significant for the high temperature initial/ high temperature redry combination. In general, treatment and subsequent redrying reduced the strength of lower grade (strength ratio <0·65) material more than that of the higher grade material (SR>0·65).

Keywords: Mechanical properties, engineering properties, CCA preservatives, pressure treatment, kiln-drying, redrying, lumber, southern pine, Pinus.

Introduction

High temperature kiln-drying (HTD) has little negative effect on the mechanical properties of southern pine lumber (Comstock, 1976; Koch, 1976; Yao and Taylor, 1979). However, an interactive relationship may exist between the severity of the initial kiln-drying (IKD), the subsequent treatment with waterborne preservatives (e.g., chromated copper arsenate [CCA]), and post-treatment redrying (i.e., kiln drying after treatment [KDAT]). This assumption is based on the cumulative damage theory of Gerhards (1979) and on the theoretical chemical-kinetics work of Stamm (1964) which acknowledges that the effects of chemicals and/or chemical processing are functions of the chemistry and thermodynamics of the wood materials and processes involved.

Because the existence or possible magnitude of this interactive relationship is essentially unknown, the objective of this study was to identify the effects of IKD temperature, CCA preservative retention, subsequent KDAT temperature, and grade on the tensile and bending properties of southern pine dimension lumber. A collateral objective was to recommend maximum initial and post-treatment drying temperatures for CCA-treated dimension lumber. This paper discusses our results with bending properties. The tension properties will be discussed in a second report.

Background

For engineering design in the United States, the allowable design stresses for untreated lumber are not modified when the lumber is treated with waterborne preservatives and subjected to “normal” (10-yr duration) loading (NFPA, 1986). However, the practice of increasing “normal” design stresses when considering impact loading is not allowed for material treated to marine retentions (>16 kg/m^3). American Society for Testing and Materials (ASTM) Standard D245 (ASTM, 1984) provides a general warping of strength reductions as high as 25 per cent for preservative-treated wood, but offers the design engineer or architect little guidance in setting design stresses.

Considerable research effort has been made in recent years to quantify the effect of arsenical preservatives and post-treatment seasoning on the properties of wood treated with arsenical preservatives. In the United States, the work has centred at the US Forest Products Lab (Bendtsen, *et al.,* 1983; Winandy, 1988; Winandy, *et al.,* 1983; Winandy and Boone, 1988; Winandy, *et al.,* 1985) and at the Mississippi Forest Products Lab (Barnes, 1985; Barnes and Moore, 1987; Barnes and Mitchell, 1984; Mitchell and Barnes, 1986; Wood, *et al.,* 1980). Internationally, studies with South African woods performed at the National Timber Research Institute, CSIR, Pretoria, South Africa are especially germane (Conradie and Pizzi, 1987; Knuffel, 1985). The results from these and other studies have been summarised in two recent articles (Barnes and Winandy, 1986; Winandy , 1988). Conclusions from these studies can be summarised generally ais follows: (1) with waterborne arsenical preservatives, mechanical property reduction seems directly linked to the chromium content of the formulation; (2) mechnical property reductions for wood treated to terrestrial retentions and redried at temperatures less than 70°C are insignificant, while treating to higher retentions and/or redrying at higher

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temperatures can cause significant strength loss; (3) because of the importance of structural reliability, an analysis of bending strength distributions is preferable to an analysis involving only average values; (4) mechanical properties are affected differently, with stiffness generally less affected than strength properties, which, in turn, are less affected than are mechanical properties related to energy-absorption such as toughness or work-to-maximum load; and (5) CCA treatment and KDAT temperature appear to interact significantly with stress-grade and the presence or absence of pith (used as an indication of juvenile wood).

Overall, it seems apparent that the effect of CCA on strength is a multiple function of the lumber grade, the pith location, the initial drying, the treatment, the chemical fixation, and the post-treatment drying process.

Materials and Methods

Experimental Design

This study was designed as an incomplete factorial with independent controls for each level of initial kiln-drying. Factors included two properties (bending to be discussed in this report and tension to be discussed in a subsequent report), two initial drying temperatures (91°C or 113°C max), three treatments (none, water-treated or 9.6 kg/m^3 of CCA-Type C), three post-treatment drying temperatures (air-dried or kiln-dried at 71°C or 116°C), and two strength-ratio grades (SR <0·65 and SR ⩾0·65).

Material

Approximately 2,000 pieces of rough-sawn, green southern pine (*Pinus taeda* or *P. echinata*) lumber, nominally 100- × 50-mm × 3·66-m long, were obtained from the green chain of a local sawmill. All pieces were cursorily evaluated by the author$ in the green condition to be No. 2 and better under the grading rules for southern pine dimension lumber (SPIB, 1977) based on knot size and location from edge. Another important aspect of this cursory evaluation was to select only pieces which were free of knots or excessive slope-of-grain within 610 mm of either end. These criteria reduced the likelihood of grip-associated failures in the tension tests. For consistency these same criteria were also applied to the bending specimens.

Each piece was then non-destructively evaluated to determine its green modulus of elasticity (E_g) using a Metrigard E-computer. Specimens were assigned to 20 experimental groups such that all groups would have similar E, distributions. This technique was used to minimise the random differences between the experimental groups. The process is described in detail elsewhere (Winandy 1988b; Winandy and Boone, 1988). Ten groups were randomly chosen from the lot of 20 groups for evaluation of tensile strength and the remaining 10 groups for bending strength.

Initial Drying

For the 10 groups of rough, green lumber designated for this study, five groups were randomly selected and commercially kiln-dried at 92°C maximum dry-bulb temperature (Table 1). The other five groups 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 1).

TABLE 1 **Initial and post-treatment kiln schedules**

Step	Temperature ("C) Dry-bulb	 Wet-bulb	Time (h)	Comments
INITIAL DRYING SCHEDULES				
Conventional Schedule				
1	80	54-70	7	Continuously-rising DBT
2	82	72	8	
3	87	72	7	
4	89	72	4	
5	92	72	16	
6	92	60	24	
Total kiln residence time			66	
High-Temperature Schedule (fan reversal every 3 h)				
1	113	81-63	24	DBT constant; floating WBT
2	113	63		
Total kiln residence time			2	
POST-TREATMENT DRYING SCHEDULES				
Conventional Schedule (Initial Avg. MC = 54-119% fan reversal every 6 h; 3 kiln charges)				
1	71	54	29	Fan speed = 152 m/min
2	71	67	24	
Total kiln residence time Avg. Final MC = 15.1%			53(avg)	
High-Temperature Schedule (Initial Avg. MC = 95-105%; fan reversal every 3 h; 3 kiln charges)				
1	116	82	21	Fan speed = 244-305 m/min
2	76	71	6	Equalization
Total kiln residence time Avg. Final MC = 16·4%			27 (avg)	

TABLE 2 **Data summary for bending tests of CCA-treated southern pine dimension stock**

Treatment/Redrying Group		Ring Count No./25mm	Latewood (%)	SpGr[1]	MC (%)	Eg	E	R	r	WPL	WML
						(GPa)		(MPa)		(J)	
LowTemperatureInitialDryingSchedule(92°C)											
CONTROL/NONE-	Mean	6.1	24	0·48	11·9	10·4	10.4	50·7	35·6	68·9	224·0
	Maximum			0·62	18·7	17·8	17·6	105·8	72·4	135·2	519·0
	Minimum			0·35	10·3	4·4	5·2	16·6	10·3	16·7	32·9
	StdDev			0·06	0·9	2·9	2·9	21·5	13·6	33.0	141.0
	CV(%)			14	8	28	28	42	38	48	63
Reps = 92											
WATER/71°C–	Mean	6·4	21	0·48	12·1	10·6	10·6	50·5	35·7	71·2	230·2
	Maximum			0·65	13·5	18·2	17·8	111·3	68·7	135·2	519·0
	Minimum			0·34	8·9	4·3	5·0	12·1	9·6	16·7	32·9
	StdDev			0·06	0·6	3·0	2·9	21·9	13·2	33·0	140·2
	CV(%)			13	5	28	27	43	37	46	61
Reps = 92											
CCA/Air-dried–	Mean	6.6	29	0·50	12·4	10·4	10·4	51·4	34·5	68·5	230·8
	Maximum			0·68	13·7	17·3	16·7	105·9	70·3	135·2	519·0
	Minimum			0·36	9·8	3·8	5·1	14·1	9·9	16·7	32·9
	StdDev			0·07	0·7	2·7	2·8	23·6	13·7	32·4	141·1
	CV(%)			13	6	26	27	46	40	47	61
Reps = 94											
CCA/71°C–	Mean	6·6	27	0·49	12·2	10·4	10·1	47·0	33·5	69·9	227·9
	Maximum			0·65	18·5	19·2	18·3	102·1	69·5	135·2	519·0
	Minimum			0·35	7·4	3·1	4·1	12·7	8·4	16·7	32·9
	StdDev			0·06	1·2	3·0	2·9	21·7	13·8	33·8	142·7
	CV(%)			13	10	29	29	46	41	48	63
Reps = 92											
CCA/116°C–	Mean	6·6	25	0.49	11·7	10·6	11·0	47·9	36·6	69·1	218·8
	Maximum			0.64	13·3	18·3	18·5	99·5	70·7	135·2	519·0
	Minimum			0.34	8·9	4·6	4·3	8·2	7·9	16·7	32·9
	StdDev			0.07	0·9	2·9	3·0	19·8	13·5	33·8	135·4
	CV(%)			13	8	28	28	41	37	49	62
Reps = 91											
High Temperature Initial Drying Schedule (113°C)											
		7·0	27	0·49	12·3	10·4	10·3	54·7	37·0	73·5	235·2
	Maximum			0·65	13·3	18·5	17·0	104·7	66·2	135·2	519·0
	Minimum			0·36	10·7	3·1	3·2	18·3	9·7	16·7	32·9
	StdDev			0·06	0·5	3·0	3·1	22.5	13·5	32·4	135·6
	CV(%)			13	4	41	29	41	36	44	58
Reps = 98											
WATER/71°C–	Mean	7·1	20	0·49	11·8	10.3	10.1	51·3	35·7	74·4	245·8
	Maximum			0·72	12·8	18.3	17.9	97·7	65·5	135·2	519·0
	Minimum			0·32	10·6	4.5	4.8	15·1	8·7	16·7	32·9
	StdDev			0·07	0·6	3.0	3.0	21·6	13·5	32·9	140·9
	CV(%)			15	5	42	29	42	38	44	57
Reps = 100											
CCA/Airdried–	Mean	6.8	27	0·48	12·9	10.0	9.9	48·5	34·2	74·3	236·9
	Maximum			0·65	21·7	17.3	18.9	102·4	66·5	135·2	519·0
	Minimum			0·37	11·0	3.6	4.9	14·5	10·1	16·7	32·9
	StdDev			0·06	1·1	2.9	2.8	20·9	13·2	32·8	136·0
	CV(%)			13	8	43	29	43	39	44	57
Reps = 99											
CCA/71°C–	Mean	6·7	27	0·50	12·8	10·3	10·2	51·0	35·1	74·1	236·4
	Maximum			0·66	14·1	17·0	17·2	109·9	70·4	135·2	519·0
	Minimum			0·36	10·9	4·5	4·5	11·3	10·7	16·7	32·9
	StdDev			0·06	0·6	2·9	3·1	21·8	13·5	33·2	135·6
	CV(%)			13	5	43	28	43	38	45	57
Reps = 101											
CCA/116°C–	Mean	6·5	24	0·50	9·5	10·2	11·0	44.8	36·5	73.3	239.4
	Maximum			0·67	12·9	17·5	19·0	101·5	83·1	135·2	519.0
	Minimum			0·37	6·3	3·8	4·5	9·3	8·2	16.7	32.9
	Std Dev			0·06	1·0	2·9	3·3	20·3	16·1	32.9	137.5
	CV (%)			13	10	45	29	45	44	45	57
Reps = 101											

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[1] Specific gravity based on oven-dry weight, volume at test.

After drying, each piece was surfaced, then graded based on strength reducing characteristics only by a quality supervisor of the Southern Pine Inspection Bureau (SPIB). This SR grade was based solely on the size and location of knots or on slope-of-grain which could be placed in the maximum moment area during subsequent third-point bending tests.

Treating of Lumber

For each of the two initial kiln-drying levels, three groups of specimens (six groups total) were treated with a 1.5 per cent (oxide basis) solution of chromated copper arsenate (CAA)-Type C preservative (AWPA, 1984) using a Bethall (full-cell) cycle. Maximum pressure was 1034 kPa and treatment was to refusal. Target retention was 9.6 kg/m^3. In addition, for each of the two initial kiln-drying levels, a fourth group was treated solely with water using an identical cycle, and a fifth group was left as an untreated control.

Post-Treatment Drying

After treatment, the treated lumber was stored at ambient conditions a minimum of two days prior to drying. After this two-day storage for each initial drying level, one CCA-treated group was randomly designated for air drying after treatment, one CCA-treated group for KDAT at 116°C, and the remaining CCA-treated group and the water-treated group for KDAT at 71°C. The untreated groups were not redried.

Those groups designated for air-drying were dried in 1.2-m wide covered piles on 20-mm thick stickers at a spacing of 610 mm. Air-drying to an average moisture content of 15 per cent took three months in the late summer of 1985 in ,northern Mississippi (located at 34" latitude in the southern US).

All KDAT drying was done in a 2000 bfm steam-heated masonry kiln. KDAT schedules are given in Table 1. After drying, all samples were cut to 2.4 m in length with the grade controlling knot centred as closely as possible to mid-length. Samples were conditioned to 12 per cent equilibrium moisture content at 24°C and 65 per cent relative humidity prior to testing.

Bending Tests

Samples were tested in edgewise bending on a Tinius-Olsen universal testing machine using third-point loading as described in ASTM D198 (1984). The span-to-depth ratio was 17 to 1. The rate of loading was adjusted to 19 mm/min which was four times that specified in the ASTM standards, but which correlates with the rate of loading used in earlier US studies. For each of the 10 groups, half the specimens in that group were tested with the grade controlling defect oriented toward the compression edge and half oriented toward the tension edge. During testing, measurements of load and center-span deflection were recorded on an interfaced X-Y plotter and microcomputer. For each specimen, modulus of rupture (MOR), modulus of elasticity (MOE), fiber stress at proportional limit (r), and work-to-proportional limit (WPL) were calculated from the load-deflection data and specimen dimensions. Work-to-maximum load (WML) was determined from the load-deflection curve using a computersised digitising device.

After testing, a small undamaged block (25 mm along the grain by the full cross-section of the specimen) was cut from near the failure for determination of moisture content and specific gravity (oven-dry weight, volume at test basis). Failures were described using the descriptions in ASTM D-198 either singly (e.g., pure tension) or in combination (e.g., combined tension/shear). The presence or absence of pith and the size and location of the grade-controlling defect (i.e., knot, slope of grain, etc.) were noted.

Data Analysis

The data were analysed in two ways. First, a graphical analysis of the data was performed by plotting, then interpreting, the cumulative frequency distributions of each property. This was then followed by statistical analyses using commercially-available computerised software (SAS Institute, 1982). Analysis of variance was performed for each mechanical property considered under each of the two evaluation (i.e., grading) schemes utilised:

1) as initially chosen in the sawmill in the rough, green condition by the authors (basically No. 2 and better); and
2) as graded after IKD and surfacing by the SPIB inspector based solely on strength-reducing characteristics (i.e., an SR grade).

Where the analysis of variance indicated that significant differences existed between mean property estimates, a Tukey's multiple comparison was employed to identify where statistically significant differences existed. Depending on the variability of the property/grade combination being considered and the sample sizes involved, these Tukey's tests could generally discern mean differences of 8-18 per cent as being significantly different at the 95 per cent significance level. While statistical tests exists 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 per cent allows a more uniform criterion for comparing the distributions and represents the personal definition of the authors as to what constitutes a practically important difference. Thus, in comparing the differences at other percentiles in the lower tail of the distributions, a 10 per cent 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 and Discussion

Effect of Drying Schedule

A summary of the bending test data for all specimens initially selected by the authors in the rough and green condition in the sawmill is shown in Table 2. A plot of cumulative frequency distribution for MOR is shown in Figure 1 for the various treatment groups which were initially dried at 91°C. These data indicate that below about the 20th percentile of the initially dried at 91°C. These data indicate that below about the 20th percentile of the initially low-temperature dried groups, no consistent effect is noted. However, above the 20th-40th percentile the CCA treated and subsequently kiln-dried (71° or 116°C) groups are generally reduced in strength as indicated by the leftward shift of these treatment groups compared to the control values.

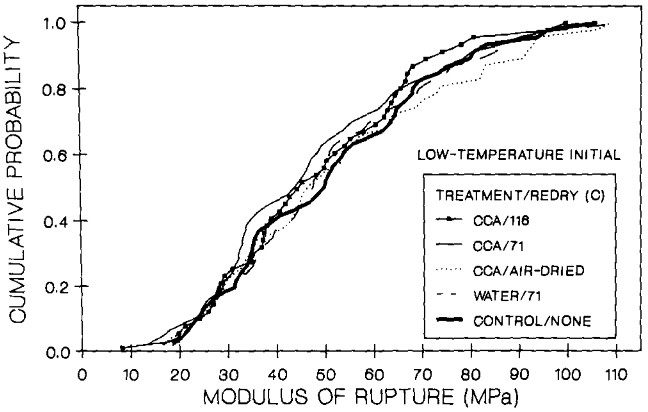

Fig 1. Cumulative frequency diagram of MOR for samples initially dried at low temperature compared with the low temperature control.

A similar plot is shown in Figure 2 for the samples which were initially high-temperature dried. This plot indicates that the strength for all levels of treatment and redrying was lower than those for the high-temperature controls throughout the strength distributions. From Figures 1 and 2, one might conclude that if wood is initially high-temperature dried and subsequently treated and redried, then any subsequent redrying temperatures will cause a substantial loss of strength. However, if one plots the distributions for the low-temperature controls vs the initial high-temperature treatment groups (Figure 3), the bending strength distributions from each group can then be directly compared because Figures 1 and 3 each use the same control data. In the important lower regions of the bending strength distribution, the low temperature initial drying groups (Figure 1) are indistinguishable from the control data, whereas, the high-temperature initial drying groups are generally reduced in strength compared to the control (Figure 3). This leads us to believe that high-temperature initial kiln-drying at 113°C exaggerates the negative effects of CCA treatment and redrying when compared to initial kiln-drying at 91°C. These trends can also be seen studying the distributional percentile estimates derived using weighted average rank-order statistics for MOR which are shown in Table 3 and Figure 4.

Statistical analyses were performed to determine the possible covariates which significantly affect the mean values for the various mechanical properties. Strength ratio grade, pretreatment green modulus of elasticity, and percent latewood were all tested. Specific gravity and moisture content were not evaluated because they are not independent of CCA treatment (CCA treatments induce bulking and generally increase equilibrium moisture content). E, was chosen as the best covariate because it provides the best correlation coefficient and because it is a non-destructive parameter which correlates with the current practice of machine stress rating of lumber. Therefore, an analysis of covariance employing E_g as the covariate was used to identify differences in treatment/redrying groups. The fact that mean MOR of the high-temperature initial/high-temperature redry combination was the only group mean which was significantly lower than untreated controls (Table 4) further supports the results reported in our discussion of the graphical analysis of Figures 1-3.

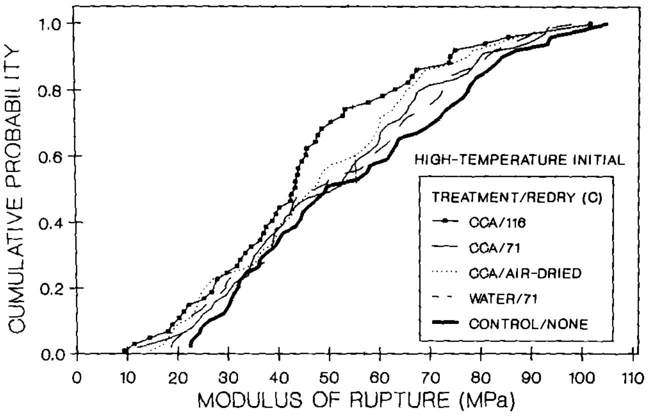

Fig 2. Cumulative frequency diagram of MOR for samples initially high temperature dried compared with the high temperature control.

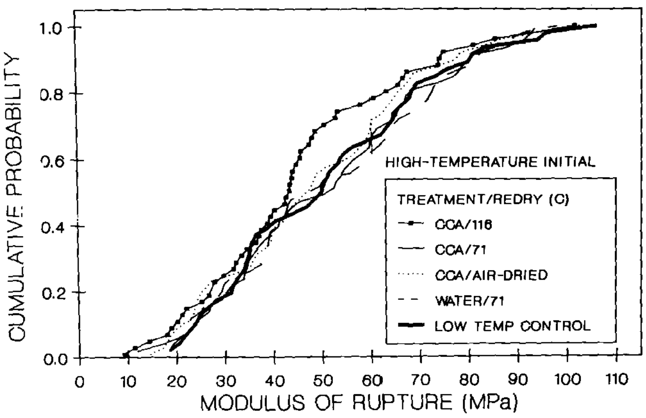

Fig 3. Cumulative frequency diagram of MOR for samples initially high temperature dried compared with the low temperature control.

Analysis of other mechanical properties showed that MOE for the high-temperature initial drying/high-temperature redrying combination was significantly higher than other combinations (Table 4). Other mechanical properties (r, WPL, WML) evaluated indicated no differences among the various combinations. This increased stiffness (as evidenced by increased MOE) and decreased strength (as evidenced by decreased MOR) represent a classic example of embrittlement.

Treatment Group	Reps	Mean	Standard Deviation	Percentile Estimates				
				5th	10th	25th	50th	75th
High Temperature Initial Drying Schedule (113°C)						(MPa)		
CONTROL	98	54·7	22·6	23·5	26·1	33·5	49·3	74·6
WATER	100	51·0	21·9	19·5	21·5	31·8	47·8	70·3
CCA/AD	99	48·5	21·0	18·0	21·9	31·7	46·7	63·5
CCA/71°C	101	51·0	21·9	19·0	23·1	34·1	51·2	66·4
CCA/116°C	101	44·7	20·4	14·6	19·9	30·0	43·1	55·4
CONTROL	92	50·7	21·6	20·7	24·1	33·9	50·0	65.9
WATER	92	50·4	22·0	20·0	23·2	35·0	47·6	66·6
CCA/AD	94	52·2	24·3	20·1	23·7	32·5	46·9	70·2
CCA/71°C	92	47·0	21·9	16·4	22·9	30·8	44·2	62·3
CCA/116°C	91	47·9	19·9	19·7	24·2	31·2	44·3	63·9

Previous studies utilising lumber initially dried at lower temperatures have not exhibited similar embrittlement. From this it would seem that increased temperatures in the initial kiln-drying process exaggerates the effect of subsequent CCA treatment and redrying.

Effect of Strength-Ratio Grades

For the two SR grades, our ability to precisely predict distributional effects is reduced because they are subsets of the larger groups. To assure that each of the 10 groups had nearly equal numbers of specimens in each SR grade ($SR \geqslant 0{\cdot}65$ and $SR < 0{\cdot}65$), a chi-square test was used. It showed that the relative number of specimens in each SR grade were not statistically different at a five per cent level of significance. This assurance that the various sample sizes of the SR grades can be considered as equivalent allows the descriptive statistics of the property data (the mean and the various percentile estimates) to be directly compared within each SR grade. As a secondary benefit, these assurances of equivalent sample sizes also validate the hypothesis that the initial sorting of specimens into groups having nearly equivalent pre-treatment stiffness (E_g) profiles effectively distributes a nearly equal number of specimens in each SR grade between the experimental groups. Finally, since some of the SR grade-treatment-drying groups have a reduced sample size with $SR \geqslant 0.65$, the lower distributional estimates (Table 5, Figure 5) and some mean values (Table 6) are not reported.

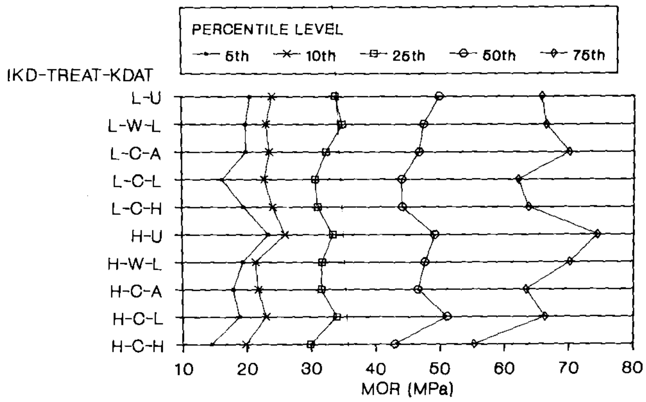

Fig 4 Percentile estimates derived from weighted average rank order statistics of MOR for the various combinations of initial drying temperature (IKD), treatment (TREAT), and final drying schedule (KDAT) [L = low temperature drying schedule, H = high temperature drying schedule, W = water treatment, C = CCA treatment, U = untreated, A = air-dried]

In previous studies No. 1 and No. 2 grade materials have been affected by treatment in a similar manner. Accordingly we have combined these two grades in this report. The reason for combining No. 1 ($SR \geqslant 0{\cdot}55$, but $< 0{\cdot}65$) and No. 2 ($SR \geqslant 0{\cdot}45$, but $< 0{\cdot}55$) is that both grades are bounded on both boundaries, whereas, Select Structural ($SR \geqslant 0{\cdot}65$) is unbounded on its upper end. In addition, earlier studies have found that the No. 1 grade material is effected by treatment and redrying more like No. 2 rather than like Select Structural (Winandy and Boone, 1988; Winandy, 1988b).

TABLE 4 **Comparison of mean values using analysis of covariance with Eg as the co-variate**

Modulus of Elasticity[1] IKD/TREAT/KDAT			Modulus of Rupture[1] IKD/TREAT/KDAT	
113/CCA/116	A	Highest	113/NONE/NONE	A
92/CCA/116	B		92/CCA/AD	AB
92/WATER/71	BC		113/WATER/71	ABC
92/CCA/AD	BC		113/CCA/71	ABCD
92/NONE/NONE	BC		92/NONE/NONE	ABCD
113/NONE/NONE	BC		113/CCA/AD	ABCD
113/CCA/71	C		92/WATER/71	BCDE
113/CCA/AD	C		92/CCA/71	CDE
113/WATER/71	C		92/CCA/116	DE
92/CCA/71	C	Lowest	113/CCA/116	E

[1] Groups not followed by a common letter are significantly different one from another at $p=0{\cdot}05$; IKD = kiln-drying temperature for initial drying; KDAT = temperature for post-treatment kiln-schedules.

Data for the two combined SR grades (SR⩾0·65 and SR<0·65) showed no significant differences in how the various combinations of treatment and redrying were affected. However, careful inspection of mean bending strength values in Table 5 and Figure 5 reveals that the SR<0·65 specimens tended to be generally reduced in strength compared to the low temperature control, whereas, the SR⩾0·65 specimens tended to fluctate above and below the mean bending strength value of the low temperature control. Finally, similar to the previously discussed graphical analysis, both SR grades showed very definite reductions in strength when initially high-temperature dried specimens were subsequently treated with CCA and then redried at high-temperatures (Table 5).

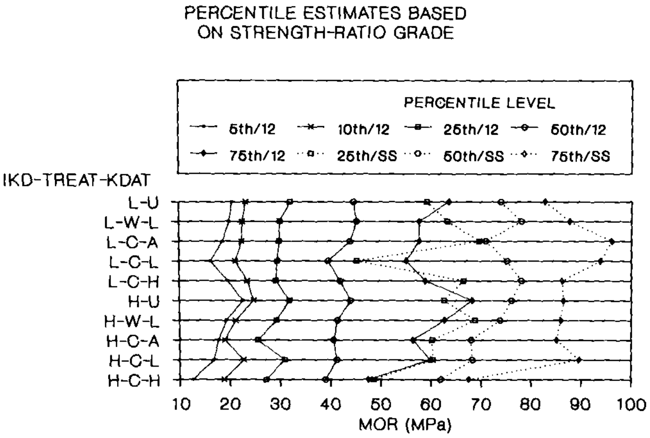

Fig 5. Percentile estimates based on strength-ratio grade (12 = SR<0·65, SS = SR≥0.65) for the various combinations [L = low temperature drying schedule, H = high temperature drying schedule, W = water treatment, C = CCA treatment, U = untreated, A = air-dried].

Grade-Related and Pith-Associated Effects

While current lumber grades do not differentiate between pith-associated (i.e., juvenile wood associated) and pith-free material, the presence of pith has a substantial influence on strength. In material having a SR≥0·65, the effect of treatment and redrying on pith-associated pieces could not be identified because few pith-associated pieces having a SR≥0·65 were included in our sample (Table 6). However, for a SR<0·65 the mean MOR of low temperature control pieces containing pith was 79 per cent of those without pith (Table 6). For every SR<0·65 grade-treatment combination, the pith-associated material is lower in strength than the pith-free material as indicated by the ratios in Table 6. The impact of the presence, of pith is obvious. More important in regard to our objectives, there appears to be no practical difference in the extent to which pith-associated vs pith-free material is influenced by CCA-treatment and re-drying. This is different from the Pith/Grade interaction noted with 2 × 6 southern pine 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 (Winandy and Boone, 1988). It is also different from the trends previously found with 2 × 4 southern pine in which the presence of pith always tended to lessen the effect of CCA treatments on mean MOR (Winandy, 1988). However, because in this study so few pith-associated specimens existed at SR<0·65 and because virtually none existed at SR≥0·65, the pertinence of this data to previous data is questionable. Thus, in our opinion the entire question of a complex Pith/Grade interaction needs to be better understood before firm recommendations can be supported. Considering that 40-50 per cent of the southern pine lumber

TABLE 5 **Strength ratio (SR) grade related effects on bending strength**

Group (IKD/TREATMENT/KDAT)	SR Grade	Rep	MOR			MOR Percentile Estimates[1]									
			Mean[1] (MPa)	(%)	StdDev (MPa)	5th (MPa)	(%)	10th (MPa)	(%)	25th (MPa)	(%)	50th (MPa)	(%)	75th (MPa)	(%)
LT/CONTROL	⩾0·65	11	73·5		13·7	[2]		[2]		59·3		74·1		82·9	
LT/WATER/71	⩾0·65	12	75·7	(+ 3)	15·2					63·4	(+ 7)	78·2	(+ 6)	87·8	(+ 6)
LT/CCA/AD	⩾0·65	14	83.5	(+14)	18·2					69·8	(+18)	71·1	(+13)	96·2	(+16)
LT/CCA/71	⩾0·65	13	70·1	(− 5)	24·6					45·3	(−24)	75·3	(+ 2)	94·0	(+13)
LT/CCA/116	⩾0·65	10	78·3	(+ 6)	12·4					66·6	(+12)	78·2	(+ 5)	86·3	(+ 4)
HT/CONTROL	⩾0·65	20	76·6	(+ 4)	16.0					62·7	(+ 6)	76·2	(+ 3)	86·6	(+ 5)
HT/WATER/71	⩾0·65	19	73·5	(0)	16.5					68·9	(+16)	73·9	(0)	86·0	(+ 4)
HT/CCA/AD	⩾0·65	21	72·2	(− 2)	16·2					60·3	(+ 2)	68·1	(− 8)	85·2	(+ 3)
HT/CCA/71	⩾0·65	20	74·5	(+ 1)	15·8					60·5	(+ 2)	68·3	(− 8)	89·7	(+ 8)
HT/CCA/116	⩾0·65	20	61·0	(−17)	18·1					48·6	(−18)	62·0	(−16)	67·6	(−18)
LT/CONTROL	<0·65	81	47·8		20·8	20·6		23·3		32·1		44·7		63·7	
LT/WATER/71	<0·65	80	46·9	(− 2)	20·5	20·0	(− 3)	22·6	(− 3)	30.0	(− 6)	45·3	(+ 1)	57·8	(− 9)
LT/CCA/AD	<0·65	80	47·0	(− 2)	21·1	18·7	(− 9)	22·5	(− 4)	29.9	(− 7)	44·0	(− 2)	57·8	(− 9)
LT/CCA/71	<0·65	79	43·5	(− 9)	19·2	16·3	(−21)	21·2	(− 9)	29.5	(− 8)	39·6	(−12)	55·2	(−13)
LT/CCA/116	<0·65	81	44·4	(− 7)	17·4	19·7	(− 4)	23·6	(+ 2)	29.2	(− 9)	42·0	(− 6)	59·0	(− 7)
HT/CONTROL	<0·65	78	49·4	(+ 3)	20·9	22·7	(+10)	24·8	(+ 7)	31.9	(− 1)	44·1	(− 1)	68·3	(+ 7)
HT/WATER/71	<0·65	81	46·0	(− 4)	19·8	19·4	(− 6)	21·2	(− 9)	29.3	(− 9)	41·4	(− 7)	62·8	(− 1)
HT/CCA/AD	<0·65	78	42·4	(−11)	17·5	17·8	(−14)	19·1	(−18)	25.6	(−20)	40·7	(− 9)	56·5	(−11)
HT/CCA/71	<0·65	81	45·5	(− 5)	19·4	16·9	(−18)	22·8	(− 2)	30.9	(− 4)	41·3	(− 8)	60·0	(− 6)
HT/CCA/116	<0·65	81	40·9	(−14)	19·2	12·7	(−38)	18·9	(−19)	27.3	(−15)	39·1	(−12)	47·6	(−25)

[1] Values in ( ) are % difference from LT/Controls at each SR grade.
[2] Not reported because of the small sample size.

produced in the US is eventually treated with CCA, the possible impact of this SR Grade/Pith/Treatment effect is evident. This is especially relevant considering the large quantity of pith-associated southern pine dimension lumber produced when processing smaller diameter logs.

Conclusions

When wood that has been kiln-dried under a continuously rising temperature schedule (91°C maximum) is used, few reductions in bending strength were noted from CCA treatment and redrying at temperatures of up to 116°C. On the other hand, when wood that has been kiln-dried at temperatures above the boiling point of water (113°C maximum), small reductions in mean bending strength were noted after CCA treatment at all redrying temperatures. Overall, initial kiln drying at temperatures of 113°C resulted in greater and more consistent reductions in bending strength after CCA treatment and redrying than did initial drying at 91°C.

Material having a strength ratio of <0·65 tended to be reduced in strength by CCA treatment and redrying more than material having a strength ratio ⩾0·65, but no significant differences attributable to the initial kiln-drying temperature were found between the two SR grades.

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TABLE 6 Pith associated effects on bending strength

Group (IKD/TREATMENT/ KDAT)	Pith Associated	Strength Ratio ⩾0·65				Strength Ratio <0·65			
		Reps	MOR[1] (MPa)	Difference from LT Control (%)	Ratio (Yes/ No)	Reps	MOR (MPa)	Difference from LT Control (%)	Ratio (Yes/ No)
LT/CONTROL	Yes	10	75·3			65	49·9		0·79
	No	1				16	39·2		
LT/Water/71	Yes	12	75·7	0		64	50·4	+ 1	0·66
	No	0				16	33·0	−16	
LT/CCA/AD	Yes	13	86·4	+15		56	51·2	+ 2	0·73
	No	1				24	37·2	− 5	
LT/CCA/71	Yes	13	70·1	− 7		64	43·6	−13	0·98
	No	0				15	42·8	+ 9	
LT/CCA/116	Yes	10	78·3	+ 4		60	47·5	− 5	0·75
	No	0				21	35·5	− 9	
HT/CONTROL	Yes	20	76·6	+ 2		59	52·7	+ 5	0·75
	No	0				19	39·3	0	
HT/WATER/71	Yes	16	75·1	0		59	46·6	− 7	0·95
	No	3				22	44·3	+13	
HT/CCA/AD	Yes	18	74·6	− 1		56	44·5	−11	0·83
	No	3				22	37·0	− 6	
HT/CCA/71	Yes	20	74·5	− 1		61	48·8	− 2	0·73
	No	0				20	35·5	−10	
HT/CCA/116	Yes	20	61·0	−19		61	42·0	−16	0·89
	No	0				20	37·6	− 4	

[1] Mean value is unreported where sample size is less than 10 specimens.