Long-term strength of CCA-treated lumber

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Abstract

The effect of chromated copper arsenate (CCA) treatment on the bending duration-of-load (DOL) characteristics of 2 by 4 southern pine lumber was studied. Previous DOL studies have used untreated lumber. The effects of treatment on material properties are needed since much treated lumber is used in engineered structures, such as permanent wood foundations. We tested 200 untreated and 200 treated specimens. One-half of each group was tested for static bending strength, and the other half was tested under constant load at the 10th and 40th percentile (50 specimens at each percentile) of their respective static strengths for 12 weeks. The effect of CCA treatment on both static strength and DOL characteristics was related to the percentile level within the strength distribution. The effect on static strength was negligible below the 40th percentile, but average static strength was reduced. Changes in the DOL factor occurred at or above the 40th percentile of static strength. Since design allowable stresses are based on 5th percentile values, we conclude that preservative treatment has a negligible effect on DOL strength for a 12-week duration at this stress level.

Our objective was to determine the effect of chromated copper arsenate (CCA)[1] treatment on the duration-of-load (DOL) characteristics of lumber bending strength. The research was limited to No. 1 and No. 2 grades of southern pine 2 by 4 lumber, one level of CCA Type C preservative treatment, and one redrying temperature (160°F). Both treated and untreated (control) specimens were tested for static bending strength and for constant bending stress for 12 weeks.

[1] This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed have been registered. All uses of pesticides must be registered by appropriate state and or federal agencies before they can be recommended.

Engineered structures that use wood treated with preservatives are designed with the same allowable strength properties as those for untreated wood. Yet, research indicates that waterborne preservatives like CCA reduce the static bending strength of most treated-wood products, especially as redrying temperatures approach or exceed 190°F (7). This raises the question of how the long-term strength of wood is affected by waterborne preservatives.

A recent literature review (7) found that preservative treatment consistently reduced energy-related properties, such as work to maximum load, toughness, and impact bending 1.5 to 2 times as much as static strength properties. However, the National Forest Products Association's design specifications (6) require that allowable design stresses cannot be increased for impact-type loading for material treated with waterborne preservatives at the high retentions needed for marine applications.

Recent research on CCA-treated lumber has shown that the effects of treatment and redrying on bending strength are related to rank-order or percentile level within the strength distribution (2,5,8,9). At redrying temperatures of 190°F or below, the effect of CCA treatment on the bending strength of No. 2 southern pine appears negligible below the 20th to 40th percentile depending on retention and redrying temperature (8,9). Thus, the often-discussed 5th percentile is unaffected at redrying temperatures below 190°F. However, when lumber is dried at greater than 190°F, bending strength is reduced throughout the entire distribution, including the 5th percentile.

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Winandy and Boone (8,9) found that CCA treatment and redrying temperatures significantly interact with strength-ratio grade (a research grade based solely on knot size or slope of grain) and the presence or absence of pith. The study reported here excluded all pith material to limit one source of variability on the results.

To our knowledge, nothing is known about the DOL characteristics of preservative-treated lumber. Based on our experience with a cumulative damage model approach (4), we suspected that a loss in static bending strength could have a substantial effect on DOL factor.

Experimental procedure

Four hundred 8-foot-long southern pine 2 by 4's were obtained from a local lumber supplier. Specimens were either No. 1 KD or No. 2 KD stress grade and were selected to be free of pith and heartwood.

All specimens were equilibrated at controlled conditions of 75°F and 50 percent relative humidity (RH), and then tested for modulus of elasticity (MOE) by nondestructive two-point edgewise bending before preservative treatment. Strength ratio for each specimen was determined from measured knot or slopeof-grain data. The 400 specimens were divided into 8 matched groups of 50 specimens each. Each group had matched distributions of MOE and strength ratio. When more than eight specimens had a similar MOE, a secondary match was made on strength ratio. The objective of sorting was to obtain nearly identical static strength distributions for each group.

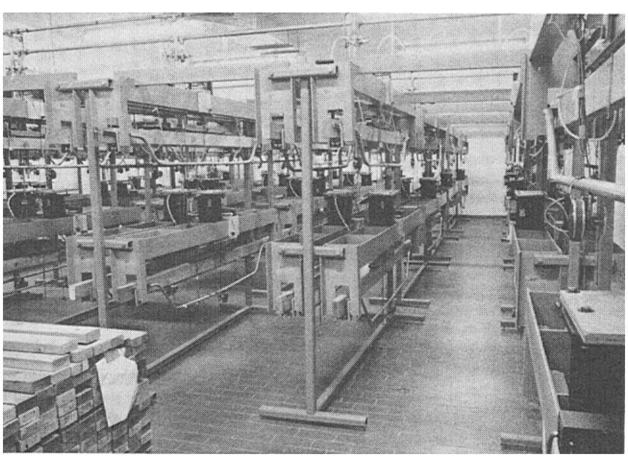

Figure 1. – Test frame setup for both static strength and constant load tests.

The 8 matched specimen groups were randomly divided into treated (200 specimens) and untreated (200 specimens) groups. Half of each group (100 specimens each) was tested for bending strength under a ramp load to failure; these were the control groups for static strength. The remaining specimens in each group were tested at two constant load levels (50 specimens at each level). The constant load levels corresponded to the 10th and 40th percentiles ofthe respective control group static strength. Thus, a total of six series of tests was conducted: a static strength test and 10th and 40th percentile constant load tests for both treated and untreated groups.

The specimens for the treated group were treated commercially with a CCA (Type C) oxide formulation and a modified full-cell process to a target retention of 0.6 pcf (1). A 20-bore sample was taken from each charge to test for penetration and retention of the preservative. An analysis for CCA retention was verified using x-ray spectroscopy.

The treated specimens were redried at the Forest Products Laboratory (FPL), Madison, Wis., in a steam-heated dry kiln using 160°F/148°F dry- and wet-bulb temperatures, respectively. Air speed was 400 to 600 ft./min. Specimens were dried for 4 days to reach an average moisture content (MC) of 15 percent, with a targeted maximum MC of 19 percent. All bending tests were done under controlled environmental conditions (73°F, 50% RH). MC was determined after each test.

Static strength tests

Static strength tests used the same test configuration as that for the MOE test. The specimens were edgewise loaded with two load points 24 inches apart and centrally located on the 84-inch span. Specimens were tested to failure at a rate of 300 pounds of load per minute, causing failure in less than 10 minutes. The median specimen failed in about 5 minutes.

The static strength and constant load tests were made with 100-frame bending test equipment (Fig. 1), in which 100 tests are conducted simultaneously. Fifty untreated and 50 treated specimens were tested simultaneously to eliminate any test procedure bias. Load and deflection values for the simultaneous tests were recorded by the computer until the specimen failed. Maximum load re-

TABLE 1. – *Physical properties of test specimens.*

Testseries	No. of specimens	MC Average	MC SD[a]	SG[b] Average	SG[b] SD	MOE Average	MOE SD	Strength ratio Average	Strength ratio SD
		(%)				(10^6 lb./in.^{2})		(%)	
Untreated									
Static strength	100	9.9	0.8	0.54	0.05	1.42	0.29	68	18
Constant load									
loth percentile	50	9.9	0.8	0.54	0.05	1.42	0.29	68	18
40th percentile	50	10.1	0.9	0.54	0.05	1.41	0.29	68	18
Treated									
Static strength	100	11.0	0.3	0.54	0.05	1.42	0.29	68	18
Constant load									
loth percentile	50	10.8	0.3	0.55	0.04	1.42	0.28	69	18
40th percentile	50	11.1	0.3	0.64	0.06	1.42	0.28	68	17

[a] SD = standard deviation.
[b] Specific gravity, based on test volume and weight.

TABLE 2. – *Static strength of treated and untreated specimens.*

Treatment	Mean	SD[a]	5	10	25	40	50	75
	Static strength (lb./in.^{2})							
			Percentile					
None	6,430	3,430	2,190	2,440	3,330	4,860	5,890	8,880
CCA[b]	5,840	3,120	2,170	2,540	3,320	4,270	5,120	7,730

[a] SD = standard deviation.
[b] Chromated copper arsenate.

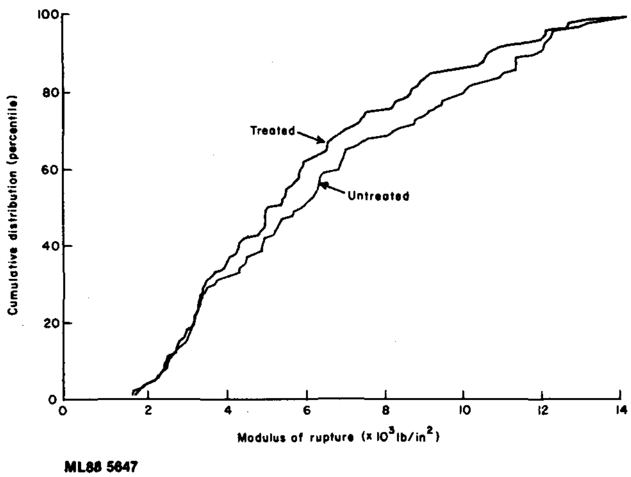

Figure 2. – Static strength distribution for treated and untreated control specimens.

sults from the static tests were used to estimate the 10th and 40th percentile static strengths used in the constant load tests.

Constant load tests

The constant load tests used the same test configuration as the static strength tests. The specimens were ramp loaded at the same rate as the static strength tests to their 10th and 40th percentile constant load levels. Loads were maintained for 12 weeks. Failure load data were recorded for those specimens failing on ramp uploading; time-to-failure data were recorded for those specimens failing under constant load. Those specimens that survived 12 weeks of constant load were then ramp loaded to failure at the same rate used in the static strength tests. As in the static strength tests, 50 untreated and 50 treated specimens were tested simultaneously.

Results and discussion

Physical properties

The lumber used for the six series of tests did not differ significantly in specific gravity, MOE, or strength ratio (Table 1). Average values for these three properties were 0.54, 1.42 × 10^6 lb./in.^{2} and 68 percent, respectively.

The MC for the untreated specimens averaged about 10 percent, whereas the MC of the treated specimens averaged about 11 percent (Table 1). This difference of about 1 percent in equilibrium MC was also noted by Winandy (8,9). No adjustments were made for strength because all the specimens were conditioned and tested under the same environmental conditions.

Static strength

When compared to untreated controls, CCA treatment followed by kiln-drying at 160°F reduced mean static bending strength by 9 percent, reduced median strength by 13 percent, and affected a broad range of the bending strength distributions (Table 2). This result is evident when comparing modulus ofrupture of the cumulative distribution of treated groups to untreated control groups; no difference exists below the 30th percentile or above the 90th percentile of the bending strength distribution (Fig. 2). This phenomenon is similar to earlier results comparing No. 2 grade 2 by 6's (9) and 2 by 4's (8) of southern pine treated with CCA. As discussed in depth in these reports, the effect of CCA on bending strength is related to rank order or percentile within the overall bending strength distribution. We believe the strength of the specimens in the lower percentiles is controlled by knot size and location. The CCA treatment has no effect on knot size or location. The specimens in the higher strength percentiles are more controlled by clear wood strength, which is affected by CCA treatment.

Recalling that pith was specifically excluded in the experimental material, the 2 by 4 material of this study represents one of the largest samples to date of CCA-

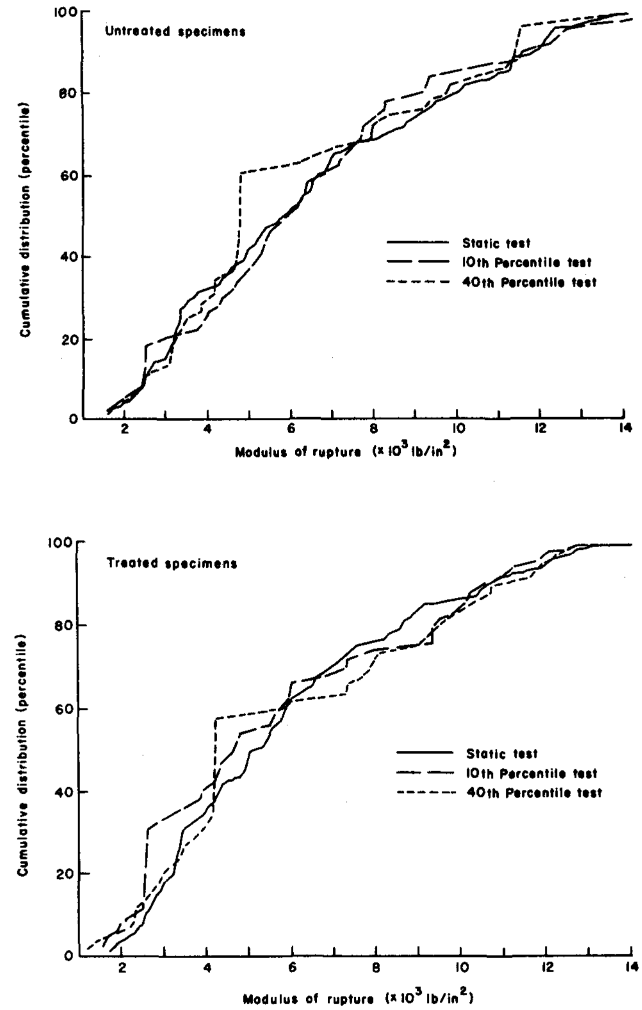

Figure 3. – Strength distributions for static strength test and constant load tests at the 10th and 40th percentiles of the static strength distribution for untreated and treated specimens.

TABLE 3. – *Number of failures during constant bending load tests.*

Constant load test series	Loading phase	Failed specimens – Untreated – Number	Untreated – Cumulative number	Treated – Number	Treated – Cumulative number
10th percentile	Ramp to 10th percentile	5	5	7	7
	Constant at 10th percentile	4	9	8	15
	Final ramp of survivors	41	50	35	50
40th percentile	Ramp to 40th percentile	22	22	19	19
	Constant at 40th percentile	8	30	10	29
	Final ramp of survivors	20	50	21	50

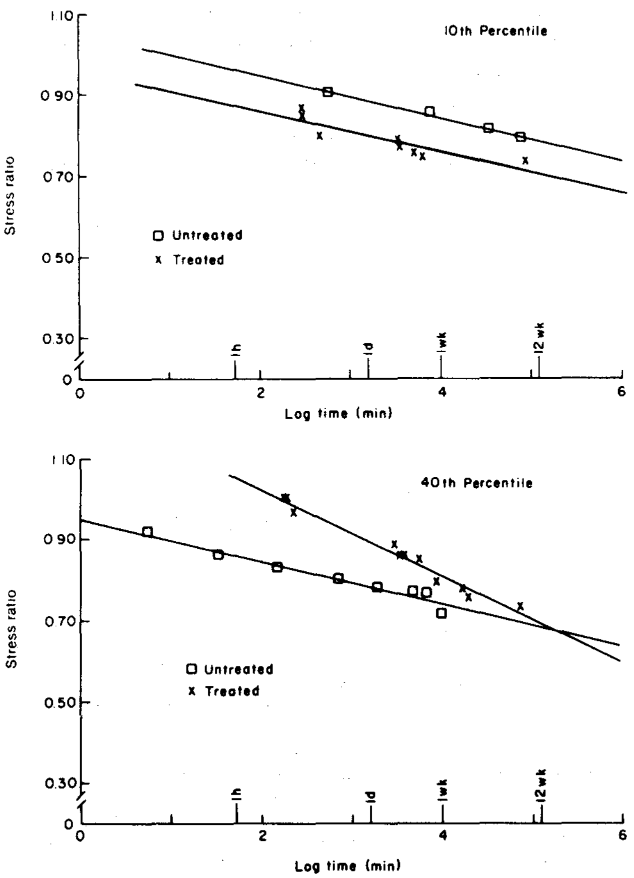

Figure 4. – Duration-of-load curves showing strength ratio on log time for constant loads at 10th and 40th percentiles of static strength.

treated, pith-free No. 2 southern pine. It is worthwhile to note that the bending strength distributions (Fig. 2) are similar to the referenced data, which included specimens with pith (8,9).

Duration of load

There were three phases in the DOL tests: 1) initial ramp load to the 10th or 40th percentile of static strength; 2) constant load at the 10th or 40th percentile; and 3) final ramp load to failure of the constant load survivors.

The initial ramp loads were comparable to the static strength tests. The constant load data determined DOL factors and time-to-failure data. The final ramp load compared to the static strength indicated how much damage occurred while the specimens were under constant load.

TABLE 4.–*Constants for Equation [1].*

Treatment	Percentile	Constants A	Constants B	95% confidence interval of B	r^2
None	10	1.056	−0.0525	−0.0678 to −0.0372	0.99
	40	0.953	−0.0523	−0.0638 to −0.0407	0.95
CCA[a]	10	0.964	−0.0497	−0.0755 to −0.0239	0.70
	40	1.233	−0.1052	−0.1211 to −0.0893	0.97

[a] CCA = chromated copper arsenate.

For both untreated and treated specimens, the initial ramp load results were, as expected, about equal to the static strength results for constant stress levels at both the 10th and 40th percentiles (Fig. 3). The number of ramp failures were also approximately equal for both untreated and treated specimens (Table 3). This indicates that specimen groups were generally well matched.

More treated than untreated specimens (8 compared to 4) failed under constant load at the 10th percentile level and about the same number (10 compared to 8) at the 40th percentile (Table 3). The difference between untreated and treated specimens under constant stress at the 10th percentile (stress level of 2,440 compared to 2,540 lb./in.^{2}) was only 4 percent compared to 12 percent at the 40th percentile (stress level of 4,860 compared to 4,270 lb./in.^{2}) (Table 2). The small number of failures and the differences in constant stress levels preclude any conclusions based on these data alone.

Figure 4 shows the times to failure for individual constant load specimens (for those specimens failing in less than 12 weeks) as plots of stress ratio as a function of log time; also included is a linear regression fit to the data. The stress ratio is the constant load stress divided by static strength. The static strength is determined from the control tests (Fig. 2) using the equal rank assumption, which assumes the same order of failure for constant load and control specimens.

The DOL factor is determined by comparing stress ratios at different times. Thus, the DOL factor is related to the slope of the linear regressions. For example, the DOL factor for a 5-minute load based on a 10-year normal load could be found from Equation [1] by taking the ratio of the stress level at t = 5 minutes divided by the stress level at t = 10 years (expressed in minutes).

The general form of the regression lines is:

$$SL = A + B \log t \qquad [1]$$

where:

SL = stress level
t = time in minutes

Table 4 gives the constants, A and B (including the 95% confidence interval for B), and square of the correlation coefficient, r^2, for both untreated and treated specimens at the 10th and 40th percentiles. For the untreated specimens, Equation [1] is comparable to the equation for clear wood given by Gerhards (3):

$$SL = 0.9809 - 0.058 \log t \qquad [2]$$

The slopes are about equal for the 10th percentile treated and untreated specimens and the 40th percentile untreated specimens (Fig. 4). However, the slope for the 40th percentile treated specimens is noticeably different (Table 4), indicating the DOL is affected. Thus, the effect of preservative treatment on the DOL factor parallels its effect on static strength as previously discussed. Recall that the effects of treatment on static bending strength are related to the percentile within the overall bending strength distribution.

Although the times to failure for the 10th percentile treated and untreated specimens were apparently equal, the regressions do not coincide (Fig. 4) because we did not know the exact static strength of a specimen tested for load duration. Small changes in static strength will move the regression of strength ratio on log time up or down. Thus, the noncoincident regressions are not significant.

At the 40th percentile, the untreated specimens had earlier times to failure than the treated specimens. This is attributed to the higher stresses applied to untreated specimens at the 40th percentile and not to CCA treatment (Table 2).

The final ramp loads were compared to the static strength (Fig. 3). The treated and untreated survivors had approximately equal distributions of strength, indicating no significant damage occurred during the 12-week constant load phase.

Conclusions

The objective of our study was to determine the effect of CCA treatment on the DOL characteristics of lumber bending strength. All previous DOL studies have been on untreated lumber. No comparisons are made with these previous studies because we felt that the 12-week load duration was too short to make DOL factor extrapolations to longer times. Our conclusions relate only to comparisons of untreated and treated specimens in this study.

The effect of CCA Type C preservative treatment and 160°F redrying temperature on static strength of southern pine lumber compared to untreated lumber was related to the percentile level within the strength distribution. Treatment apparently had a negligible effect below the 20th to 40th percentiles but reduced median strength by 13 percent. This result has also been noted in other studies (8,9).

The effect of treatment on the DOL characteristics of lumber in bending parallels its effect on static strength. Treatment apparently had a negligible effect on strength when the specimens were loaded to the 10th percentile of their static strength, but the treatment did affect the DOL factor at the 40th percentile of static strength.

Since design allowable stresses are based on 5th percentile values, and since treatment had a negligible effect on the lower percentile of strength, we conclude that for a 12-week load duration, preservative treatment has a negligible effect on the DOL factors at this stress level.

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