INFLUENCE OF TIME-TO-FAILURE ON STRENGTH OF CCA-TREATED LUMBER

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ABSTRACT

Recent studies on the effects of chromated copper arsenate (CCA) treatment on lumber design properties have primarily evaluated the effects of such treatment at times to failure of 1 to 10 minutes and at 12 percent moisture content (MC). The influence of faster loading rates and different MCs on treated lumber is unknown. This report discusses the influence of time-to-failure under ramp loading conditions and at various MC levels on the bending strength of CCA-treated (6.4 kg/m^3 (0.4 lb/in.^{3})) lumber. The factors studied were failure times in bending of 3 to 6, 30 to 60, and 300 to 600 seconds and MC levels of 10, 15, and 23 percent (green lumber). Results show important differences in bending strength related to time-to-failure between untreated and CCA-treated southern pine lumber. The bending strength of CCA-treated lumber did not increase at faster loading rates compared to untreated lumber. Most importantly, specimens in the lower quarter of the CCA-treated strength distribution did not show any time-dependent strength increases compared with matched untreated material. These results imply that existing North American design guidelines for short-term duration-of-load adjustments for CCA-treated lumber, which are based on untreated lumber, should not be applied. Accordingly, this paper offers a revised adjustment model.

Recent studies on the effects of waterborne-preservative treatment on lumber design stresses have evaluated the effects of such treatment at near static loading conditions (time-to-failure of 30 to 300 sec.) and at a 12 to 15 percent equilibrium moisture content (MC) (8). It was found that post-treatment redrying and lumber quality (i.e., grade) are critical in determining the effects of chromated copper arsenate (CCA) preservative treatment on lumber. Waterborne-preservative-treated lumber has not, however, been tested at rates faster than the static loading rate or at MC levels other than 12 to 15 percent MC. Therefore, our understanding of the influence of load duration and MC on the allowable design properties of preservative-treated lumber is limited. In addition, the modification factors for treated wood for duration-of-load application and in-service MC are currently the same as those for untreated wood.

The lack of a treated wood MC-adjustment model is of concern because preservative-treated materials are (by design) subjected to high-moisture environments. To address this concern, a revised MC-adjustment model was recently reported (9). The lack of a treated wood load-duration model is of concern because energy-related properties, which indicate dynamic performance, are most affected by treatment. As a result, the National Design Specification (1) does not allow the application of the traditional load-duration modification factor for impact-loading to CCA material treated to 40.0 kg/m^3 (2.5 lb./ft.^{3}). During the development of the most recent National Design Specification (1), the consensus was that specific engineering design guidance was needed as to whether the traditional load-duration factor for untreated wood could be applied to wood treated to terrestrial CCA-retention levels (≤ 9.6 kg/m^3 (≤ 0.6 pcf) under dynamic and impact load situations. For untreated lumber, these load-duration adjustment factors are currently 1.6 for wind and earthquake (≤ 10 min.) and 2.0 for impact loads (≤ 2 sec.) (1).

The limited data for CCA-treated lumber indicated that long-term duration-of-load response at the expected 10th percentile stress level was similar to that of untreated lumber (9. Accordingly, traditional long-term duration-of-load adjustment factors for untreated wood could be applied to CCA-treated lumber because allowable stress design values were developed for a 5th percentile stress level. However, the time-dependent creep-rupture failure rate of CCA-treated material at the 40th percentile stress level was significantly greater than that of untreated material.

The lack of a short-term load-duration model for dynamic loading conditions for waterborne-preservative-treated wood is of concern because most treated wood failure occurs under dynamic loading conditions. The lack of specific engineering design guidelines may restrict expanded markets for waterborne-preservative-treated lumber, laminated veneer lumber, or glulam in highly engineered wood components or structures. Some examples of these po-

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tential markets are waterborne-preservative-treated parallel-chord trusses over insufficiently vented crawl spaces, improperly vented or unventilated flat-roof or floor truss systems, structural all-weather composite panel or lumber systems, and permanent wood foundations in areas of high seismic activity.

This study had two objectives. The first objective was to examine the influence of loading rate on the bending strength distributions of waterborne-preservative-treated No. 1 & Better southern pine nominal 2- by 4-inch (38- by 89-mm) lumber at three MC levels. The second objective was to develop a load-duration model for CCA-treated lumber that incorporated these results.

METHODS

The test material was 2.3-m (8-ft.) long, southern pine nominal 2- by 4-inch (38- by 89-mm) lumber (2 by 4's). The experiment used a 3 x 3 x 2 factorial design. The factors were time-to-failure, MC at test, and CCA treatment. The design had approximately 110 specimens per treatment/load rate/MC combination (Table 1). The lumber designated for preservative treatment was commercially treated using a modified full-cell process with a 2.8 percent solution of CCA-Type C to aretention of 6.4 kg/m^3 (0.4 pcf) (3). The untreated material designated for testing green was water-treated to refusal. The treated lumber designated for testing at either 10 or 15 percent MC was kiln-dried after treatment at 66°C (150°F) with an 8°C (15°F) wet-bulb depression for the first 24 hours, followed by a 17°C (30°F) wet-bulb depression for the final 14 hours to a target MC of 22 percent. The treated and untreated material designated for testing at 10 percent MC was equilibrated at 23°C (73°F) and 50 percent relative humidity. The treated and untreated material designated for testing at 15 percent MC was equilibrated at 27°C (80°F) and 80 percent relative humidity.

Edgewise third-point bending tests were performed according to ASTM D 198 (2), except that ramp rate-of-loading was varied at rates of 4.8, 48, or 480 mm/minute (0.19,1.90, or 19.0 in./min.) of constant-displacement head travel. Span-to-depth ratio was 17:1. Test span was 1,524 mm (60 in.), with 508 mm (20 in.) between loading points. The grade-limiting knot was placed in the maximum-moment area of the beam and randomly placed up or down for location in the tension or compression zone. Data were collected digitally via an interfaced data-logger and a microcomputer. Details of the experimental design and methodology are given by Winandy (9).

RESULTS AND DISCUSSION

The nonparametric estimates of the bending strength distribution for each MC/load rate/treatment combination are given in Table 2. For untreated material, the effect of time-to-failure on the bending strength distribution is shown in Figure 1 for 10, 15, and 23 percent (green) MC. For CCA-treated material, the effect of time-to-failure on the bend-

TABLE 1. —Experimental design.

	No. of specimens in each time-to-failure group					
	Untreated[a]			CCA treated[b]		
MC at test	300 to 600 sec.	30 to 60 sec.	3 to 6 sec.	300 to 600 sec.	30 to 60 sec.	3 to 6 sec.
(%)						
10	111	111	110	111	111	112
15	109	111	37[c]	112	111	33[c]
Green[d]	111	111	110	112	111	111

[a] The untreated specimens designated for testing green were treated with water at a pressure less than 05 Mpa (75 psi) and broken immediately after treatment.
[b] CCA-C treated to 6.4 kg/m^3 (0.4 pcf). Specimens designated for test at 10 and 15 percent equilibrium MC were kiln-dried after treatment at 66°C, and those designated to be tested green were broken immediately after treatment.
[c] Approximately 75 specimens per group were eliminated from the design because they were inadvertently equilibrated and tested at 10 percent MC conditions.
[d] Assumed to be 23 percent (4).

TABLE 2. — ***Properties of untreated and CCA-treated No. 1 & Better southern pine 2 by 4's.[a]***

Treatment	Time-to-failure	Claimed MC	Test MC	MOE	SGOD	MOR at specified percentiles 5	10	25	50	75	90	95
	(sec.)	----- (%) -----		(× 10^6 psi)[b]		----------	----------	----------	(× 10^3psi)[b]	----------	----------	----------
Untreated	300 to 600	10	9.8	2.190	0.57	6.16	7.48	9.02	11.25	13.57	14.76	15.84
		15	13.6	1.930	0.57	6.42	7.76	9.36	10.43	12.08	12.93	13.37
		23	65.6	1.370	0.57	4.12	4.39	5.48	6.23	7.12	7.59	7.71
	30 to 60	10	9.8	2.170	0.59	7.33	8.71	10.94	13.16	14.81	17.08	17.66
		15	14.2	1.950	0.57	7.36	7.78	8.95	10.84	11.98	13.58	14.25
		23	68.1	1.370	0.57	4.62	5.17	5.99	6.73	7.36	7.97	8.32
	3 to 6	10	9.8	1.970	0.57	6.75	7.54	9.80	12.19	14.34	16.50	18.01
		15	13.7	1.900	0.57	7.85	9.57	11.14	11.72	13.16	14.36	14.90
		23	48.1	1.670	0.58	5.01	5.45	6.36	7.23	8.10	8.76	9.04
CCA	300 to 600	10	10.8	2.130	0.58	5.88	6.71	8.73	10.52	12.51	13.65	14.45
		15	15.7	1.910	0.57	6.72	7.33	8.49	9.84	10.83	12.27	12.90
		23	56.6	1.350	0.57	4.44	4.65	5.26	6.03	6.93	7.44	7.90
	30 to 60	10	10.8	2.090	0.59	5.87	6.50	9.42	11.09	12.85	14.14	14.97
		15	16.6	1.940	0.58	6.24	7.30	8.56	10.20	11.36	12.63	13.43
		23	56.6	1.360	0.58	4.38	5.05	5.78	6.69	7.66	8.10	8.38
	3 to 6	10	11.0	1.890	0.57	6.02	7.14	8.63	11.50	13.34	15.30	15.96
		15	16.1	1.970	0.58	5.96	7.85	9.09	11.22	12.71	13.97	14.25
		23	66.1	1.170	0.58	4.43	4.91	6.17	7.25	8.19	8.91	9.18

[a] MC =moisture content; MOE =modulus of elasticity; SGOD =specific gravity at ovendry weight/volume; MOR = modulus of rupture.
[b] 103 psi =6.89 MPa.

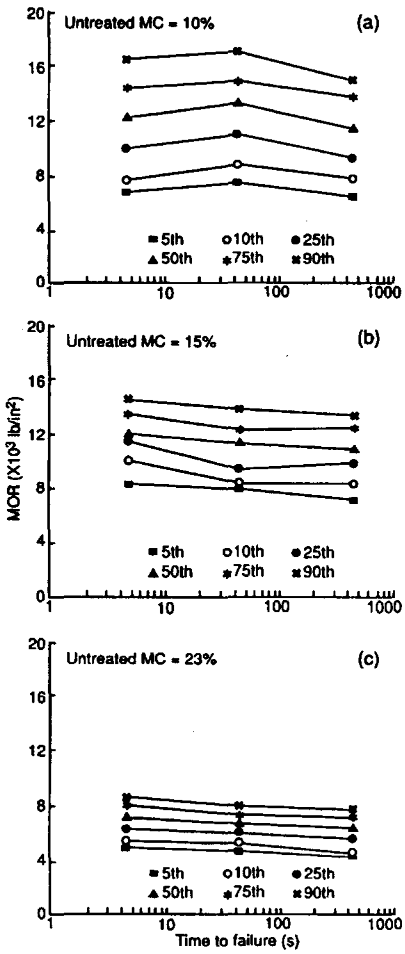

Figure 1. — The effect of time-to-failure on the bending strength (MOR) distribution of untreated lumber.

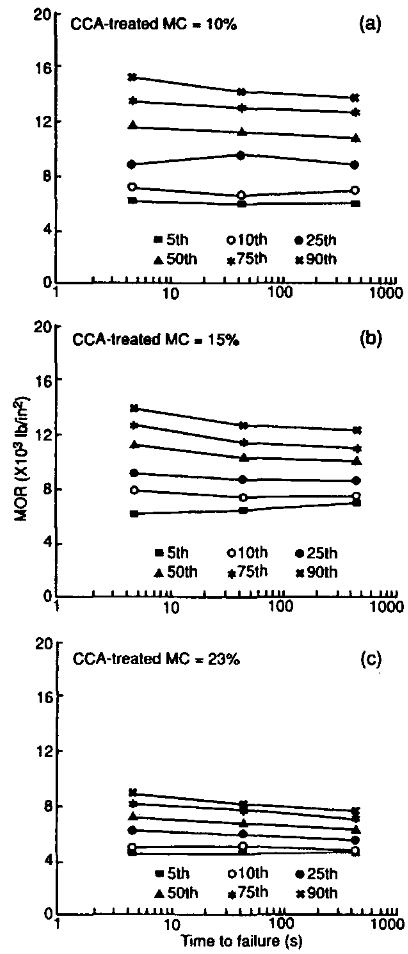

Figure 2. — The effect of time-to-failure on the bending strength (MOR) distribution of CCA-treated lumber.

ing strength distribution is shown in **Figure 2** for 10, 15, and 23 percent (green) MC. Analysis of variance indicated that the treatment effect and load-duration effect were not independent of the MC effect due to significant interactions with MC. This interactive effect of MC is evident from the differential trends noted when comparing the bending strength results at 10, 15, and 23 percent (green) MC between untreated and CCA-treated material **(Figs. 1 and 2).** With green lumber, the three load durations were significantly different ($\alpha \leq 0.05$), but there was no difference in strength between untreated and CCA-treated lumber. At 15 percent MC, the three load durations were significantly different, but the mean strength of CCA-treated material was significantly less than that of untreated material. At 10 percent MC, the 300 to 600 seconds load duration was significantly less than the other two load durations, but no difference existed between mean bending strength evaluated at time-to-failure of 30 to 60 seconds and 3 to 6 seconds. At 10 percent MC, the mean bending strength of CCA-treated material was significantly less than that of untreated material.

For untreated material, as time-to-failure decreased from 300 to 600 seconds to 30 to 60 seconds, bending strength generally increased uniformly across the entire bending strength distribution at all MC levels (Fig. 1). As time-to-failure decreased from 30 to 60 seconds to 3 to 6 seconds, bending strength again generally increased, with the exception of time-to-failure at 3 to 6 seconds and 10 percent MC. As untreated lumber dried from 15 to 10 percent MC, it apparently lost its ability to absorb impact-type loads (Fig. la). Moreover, there was a uniform loss of strength across the entire modulus of rupture (MOR) distribution for untreated lumber at 10 percent MC and fast loading rates **(Fig. 1a).** Accordingly, applying the load-duration factor for impact loads to untreated lumber at MCs below 10 to 12 percent might require further examination. Noting the uniformity in the effect of loading rate across the bending strength distribution for untreated material, it would seem that future studies using higher quality lumber, such as No. 1 and Better, need only address mean effects. Madsen (5) showed a similar uniformity in the short-term duration-of-load effect for clear material. These findings would greatly reduce the number of specimens required or increase the number of ancillary factors studied using the same number of specimens. Previous results with No. 2 grade Douglas-fir (7) and No. 2 grade Hem-Fir (5), however, would imply that the strength of lower grade material is not uniformly affected across the strength distribution by time-to-failure.

The effect of load-duration as indicated by time-to-failure on the bending strength distribution for CCA-treated material is shown in **Figure 2** for10, 15, and 23 percent (green) MC. From these data **(Fig. 2, Table 2)** and the previously mentioned results of analysis of variance, it is evident that CCA treatments significantly ($\alpha \leq 0.05$) changed the basic relationship between short-term load duration and bending strength when compared to that same relationship for untreated materials **(Fig. 1, Table 2).** As time-to-failure decreases, bending strength was no longer uniformly affected across the entire bending strength distribution as it was with untreated material. In the lower quarter of the bending strength distribution, there was no apparent increase in strength as time-to-failure decreases. In the upper three-quarters to half of the bending strength distribution, as time-to-failure decreased, bending strength also increased. In general, when evaluated across comparable percentile levels, the time-to-failure-related increase in strength for CCA-treated southern pine 2 by 4's (Fig. 2) was consistently less

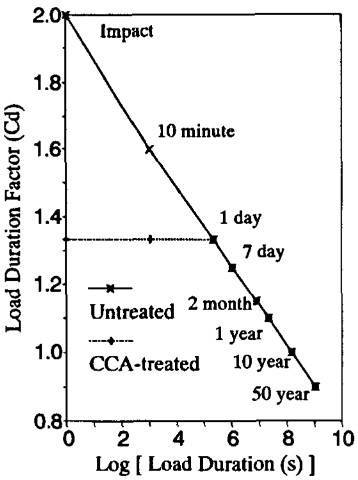

Figure 3. — Proposed load-duration factors (C_d) for various load durations of CCA-treated lumber.

than that for untreated material **(Fig. 1),** especially at lower MCs.

As CCA-treated lumber dried from green to 10 percent MC, a larger percentage of material experienced this lack of time-to-failure-related increase in strength. It seemed that very dry CCA-treated wood was somehow embrittled. Dynamic performance was changed because the wood apparently lost its ability to rapidly disseminate internal stress away from the localized area adjacent to the point of load application. For green material, only the lower 10 percent of the MOR distribution failed to exhibit increased strength as time-to-failure decreased. By the time CCA-treated material was dried to 10 percent MC, however, well over 25 percent of the bending strength distribution failed to exhibit any time-dependent increase in strength.

The consistent lack of time-to-failure-related strength increases through the lower 10 to 25 percent of the MOR distribution as time-to-failure decreases shows that the impact-load-duration factor for CCA-treated lumber at any treatment level and MC must be questioned. In addition, applicability of the load-duration factor for wind/earthquake loads, which in North America are assumed to last for ≤ 600 seconds (1), to CCA- treated material appears questionable. This is due to the consistent lack of strength increase exhibited in the lower tails of the bending strength distribution between time-to-failure of 300 to 600 seconds and 30 to 60 seconds and the fact that short-term loads of this nature are dynamic. Accordingly, the classic load- duration curve (1) for untreated lumber might be modified when load-duration factors are applied to CCA-treated lumber, as proposed in Figure 3. Additional justification for this approach may be found in Winandy's thesis (9).

CONCLUSIONS

The bending strength of lumber treated with CCA and tested at 10 percent MC was significantly ($\alpha \leq 0.05$) lower than that of matched untreated lumber by 10 to 15 percent. At 15 percent MC, the treated lumber was significantly lower in strength by 5 to 12 percent. In green lumber, few differences were found between CCA-treated and untreated lumber.

A modified load-duration factor for short-term dynamic loads is necessary to adjust design stresses for waterborne-preservative-treated lumber treated to a retention of 6.4 kg/m^3 (0.4 pcf). This modified short-term load-duration factor for CCA-treated material is needed because the existing factor derived for untreated lumber does not accurately predict the impact-load performance of waterborne-preservative-treated lumber at MC ≤ 19 percent. Applying the existing load-duration factor to waterborne-preservative-treated material exposed to wind/earthquake loads (≤ 10 min.) also seems questionable.

The bending strength of untreated No. 1 and Better 2- by 4-inch southern pine lumber tested at 10 percent MC did not exhibit any time-dependent increase in strength when tested under either static or impact loads.

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