

Effects of long-term elevated temperature on CCA-treated southern pine lumber

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Abstract

The objective of this study was to determine the influence of extended high temperatures on the mechanical properties and chemical composition of southern pine treated with chromated copper arsenate (CCA). Different treatment processing factors were evaluated to determine their effect on the rate of thermal degradation for CCA-treated lumber. When compared to untreated lumber, CCA-treated lumber (9.6 kg/m^3 (0.6 pcf)) exhibited accelerated thermal degradation on extended exposure to temperatures near 65°C (150°F) and 75 percent relative humidity. Both modulus of rupture and work to maximum load were significantly reduced, but modulus of elasticity was not affected. The effect of CCA retention levels less than 9.6 kg/m^3 (0.6 pcf) is unknown. Chemical analysis indicated that arabinose and galactose contents were reduced more than 50 and 25 percent, respectively, after the 160-day high-temperature exposure. The rate of change in arabinose and galactose content seemed directly related to the rate of strength loss. Results indicate a possible need to develop an independent temperature modification factor for design stresses of preservative-treated material intended for use in high-temperature environments.

The influence of elevated in-service temperatures on the engineering properties of waterborne preservative-treated lumber is unknown. To preclude decay problems from condensation within roof-mounted solar collectors, preservative-treated wood has been used (15). Recently, some lumber treated with chromated copper arsenate (CCA) to 6.4 kg/m^3 (0.4 pcf) failed when it was used as framing material in roof-mounted solar collectors. This CCA-treated material had the same general characteristics of medium-to-dark brown discoloration and cross-grain fracture patterns that are often found in fire-retardant material that has undergone thermal degradation. Considering

recent problems with fire-retardant-treated wood exposed to elevated in-service temperatures (11), this lack of conclusive (or even comparative) engineering data might lead to serious design deficiencies. Current design modification factors for treated wood exposed to elevated in-service temperature are based on data derived from untreated wood (1). Lack of knowledge about the thermal stability of the mechanical properties of treated lumber could present future difficulties in structures, such as solar-collectors, roof structures over machinery that emits hot, moist, air or steam, and foundation piles under hot tankage.

Objective

The objective of this exploratory study was to determine the influence of extended high-temperature exposure (65°C (150°F)) on the mechanical properties and chemical composition of CCA-treated southern pine lumber (actual 38 by 89 mm (nominal 2 by 4 in.)). Different treatment processing factors were evaluated to determine their relative effect on the rate of thermal degradation for CCA-treated lumber. The information obtained will be used to plan additional research to assess the need for an independent temperature modification factor (C) for CCA-treated material used in high-temperature environments.

Materials and methods

Design

The experiment was of limited scale because of the number of specimens used. A fractional factorial design was used with the following three factors:

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TABLE 1. — *Experimental design.*

Initial kiln-drying temperature	Treatment	Redrying temperature	Number of specimens per exposure ^b		
			0 days	60 days	160 days
(°C) ^a		(°C)			
91	None	--	8 ^c	8	8
	Water ^d	--	10	10	10
	CCA	20	12	11	11
113	CCA	71	9	9	10
	None	--	10	10	11
	Water ^d	--	10	10	8
	CCA	20	12	11	11
	CCA	71	8	8	7

^a °C = (°F - 32) / 1.8.

^b Exposed at 65°C (150°F) and 75 percent relative humidity.

^c Odd number of specimens/group/exposure combinations was dictated by number of undamaged 1-m (40-in.) lengths cut from destructively tested 3.65-m (12-ft.) tensile specimens from previous study.

^d Treated with water to refusal without post-treatment redrying and exposed green.

1. Initial kiln-drying temperature (91°C and 113°C (196°F and 235°F)).

2. Untreated, water treated with no redrying, or CCA treated with specific post-treatment redrying (air dry at 20°C (68°F) or kiln dry at 71°C (160°F)).

3. Three durations of high-temperature laboratory exposure at 65°C and 75 percent relative humidity (0, 60, and 160 days).

There were approximately 10 specimens per initial kiln-drying/treatment-exposure group (Table 1). Initial kiln-drying temperatures were selected to represent two common industrial practices. Post-treatment redrying temperatures were also selected to represent the two most common industrial practices. The CCA retention was selected to represent a worst-case scenario, because the 9.6 kg/m³ (0.6 lb/ft.³) retention is the highest used in decay-prone terrestrial situations. The laboratory exposure temperature was selected because 65°C represents the current limit for wood use (2).

Material

Two hundred and thirty-two pieces of 1-m-(40-in.-) long knot-free southern pine 2 by 4's were cut from undamaged sections of 3.65-m (12-ft.) specimens used in a previous study (18). In that study, the specimens had been sorted into study groups in a manner intended to achieve equal modulus of elasticity (MOE) rated groups. Because lumber strength is related to MOE, matching of experimental groups based on MOE is expected to yield nearly equal distributions of low-, medium-, and high-level strength specimens in each group. In an attempt to maintain MOE matching between groups, each 1-m clear piece cut from a 3.65-m tensile specimen was selected to represent an even sampling between the first-to-third quartiles (25th to 75th percentile) of previously reported tensile strength distributions (18).

Treatment

The 1-m specimens designated for CCA Type C treatment had previously been treated (18) as 3.65-m specimens to a target retention of 9.6 kg/m³ using a modified full-cell treatment process as outlined in AWPA Standards C-22 (4). Specimens had been either

air-dried or kiln-dried after treatment at 71°C dry-bulb temperature and 54°C (130°F) wet-bulb temperature (Table 1). In this study, specimens designated for water treatment were treated as 1-m specimens to refusal using a full-cell treatment process. To simulate a differential high-temperature performance between green and dry lumber, water-treated specimens were not redried prior to extended high-temperature exposure.

Nondestructive evaluation

The MOE of each 1-m specimen was nondestructively measured before and after extended exposure to elevated temperature using the stress-wave procedure (13). This was done to determine if nondestructive evaluations (NDE) of thermal-induced degradation of CCA-treated and untreated materials could be used to predict thermal degradation. The initial pre- and post-exposure MOE values were determined for each specimen based on its density and stress-wave transit time after equilibration to constant weight at 20°C and 65 percent relative humidity.

Mechanical testing

After the designated treatment and high-temperature exposure, flatwise bending tests, loaded at third-points, were performed (2). Test span was 900 mm (36 in.) with 300 mm (12 in.) between loading points. The resulting span-to-depth ratio was 24:1. Rate of loading was 12.5 mm/min. (0.5 in./min.) of constant displacement head travel. Data were collected digitally with a microcomputer.

Chemical analysis

After mechanical testing, a 25-mm (1-in.) CCA chemical analysis block and a 25-mm moisture content/specific gravity block were cut from each specimen. Each moisture content/specific gravity block was weighed and measured at its test moisture content, then oven-dried at 103°C for 48 hours and reweighed (3). Each analysis block was ground to 30 mesh. Material from each initial kiln-drying-treatment-exposure group was combined and a portion was analyzed for chromium (Cr), copper (Cu), and arsenic (As), using an ASOMA Model 200 x-ray fluorescence spectrometer. The remaining portion of the

ground material from each group was divided. Half was analyzed for carbohydrates using high pressure liquid chromatography (12), and the remainder was analyzed for Klason lignin (7).

Results

Measured CCA retention averaged 9.0 kg/m³ (0.56 pcf). No practical trend in the retention of the overall CCA complex or the three chemical components (Cr, Cu, and As) was noted as duration of high-temperature exposure increased (Table 2). This indicated that the quantity of Cr, Cu, and As in the treated wood was unchanged. It does not indicate that the overall CCA system on the individual complexes formed during the preservative fixation process was unaltered during extended exposure at 65°C.

Mechanical properties

No significant ($p < 0.05$) difference was noted between the two initial kiln-drying temperatures in their effects on MOE and modulus of rupture (MOR). To a lesser extent, no significant difference ($p < 0.10$) between the two initial kiln-drying temperatures was noted in their effects on work to maximum load (WML) (Table 3). Thus, the two initial kiln-drying temperatures for each treatment-redry-exposure combination were later combined in statistical analyses. These results are consistent with previously reported results that show no discernible difference in how much CCA treatment affects MOE, MOR, and tensile strength, with energy-related properties such as WML exhibiting slightly more effect, when specimens were initially kiln-dried using either low- or high-temperatures (5,18).

TABLE 2. — Results of x-ray fluorescence spectroscopy.

Initial kiln-drying temperature	Redrying temperature	Exposure	Chemical content				Estimated retention
			Chromium	Copper	Arsenic	Total	
(°C) ^a		(days)	(%)				(kg/m ³) ^a
91	20	0	0.814	0.288	0.632	1.73	8.9
	20	60	0.986	0.354	0.787	2.13	10.9
	20	160	0.780	0.275	0.628	1.68	8.6
	71	0	0.675	0.244	0.539	1.46	7.5
	71	60	0.782	0.278	0.624	1.68	8.6
	71	160	0.806	0.281	0.634	1.72	8.8
113	20	0	0.807	0.290	0.646	1.74	8.9
	20	60	0.804	0.279	0.631	1.71	8.8
	20	160	0.854	0.297	0.672	1.82	9.3
	71	0	0.954	0.331	0.740	2.03	10.4
	71	60	0.830	0.300	0.667	1.80	9.2
	71	160	0.840	0.294	0.662	1.80	9.2

^a °C = (°F - 32)/1.8; 16.01 kg/m³ = 1 pcf.

TABLE 3. — Mechanical properties of untreated, water-treated, and CCA-treated lumber exposed to 65°C for up to 160 days.

Initial kiln-drying temp	Treatment	Redrying temp	Duration of exp	Moisture content	MOE		NDE ^b			MOR			WML						
					Mean	SD ^d	Pre-exp	Post-exp	Ratio ^c	Mean	SD	Ratio ^c	Mean	SD	Ratio ^c				
(°C) ^a		(°C)	(days)	(%)	(GPa)									(MPa)			(kJ/m ³)		
91	Untreated	none	0	11.9	13.4	4.0	13.0	13.3	1.02	69.1	17.3	1.00	51.92	22.13	1.00				
		none	60	11.2	11.9	3.2	12.7	12.0	0.92	59.4	18.4	0.86	42.51	20.79	0.82				
		none	160	11.5	11.9	3.1	13.0	13.0	1.00	55.3	20.9	0.80	33.41	26.58	0.64				
	Water	none	0	12.8	13.9	4.6	12.3	11.9	0.92	74.6	16.1	1.08	61.12	17.17	1.18				
		none	60	11.5	13.4	2.2	12.1	11.1	0.85	69.6	14.4	1.01	62.16	35.47	1.20				
		none	160	11.5	14.6	3.3	12.0	11.0	0.85	72.5	18.6	1.05	49.13	20.37	0.95				
	CCA	20	0	12.8	13.1	3.0	12.9	11.8	0.91	63.4	20.7	0.92	42.30	25.34	0.81				
		20	60	11.7	12.8	2.9	13.1	10.9	0.84	50.5	16.8	0.73	30.30	23.37	0.58				
		20	160	10.7	12.5	4.0	12.9	11.6	0.89	37.2	15.4	0.54	15.62	13.34	0.30				
		71	0	12.5	13.2	3.8	12.6	11.7	0.90	69.3	16.8	1.00	67.74	33.20	1.30				
		71	60	11.5	12.9	3.0	12.3	11.3	0.87	49.9	14.6	0.72	22.05	11.17	0.42				
		71	160	10.8	11.8	3.0	12.3	10.8	0.83	30.4	8.2	0.44	7.81	3.23	0.15				
113	Untreated	none	0	12.1	12.4	3.2	11.1	11.1	0.85	70.7	17.4	1.02	65.26	33.20	1.26				
		none	60	11.3	11.4	3.6	11.2	11.2	0.86	53.2	18.6	0.77	36.30	23.79	0.70				
		none	160	11.2	12.6	4.1	11.7	11.7	0.90	63.3	17.6	0.92	39.72	17.38	0.77				
	Water	none	0	12.9	11.1	3.5	11.5	11.3	0.87	60.1	19.1	0.87	59.70	8.82	1.15				
		none	60	11.5	11.9	2.8	11.4	10.9	0.84	54.6	18.5	0.79	32.48	20.37	0.63				
		none	160	11.6	13.2	2.8	11.7	11.5	0.88	69.7	13.3	1.01	59.57	29.68	1.15				
	CCA	20	0	12.8	11.4	3.2	11.5	10.8	0.83	61.5	23.7	0.89	46.85	32.58	0.90				
		20	60	11.7	12.2	4.3	11.6	11.3	0.87	52.2	18.1	0.76	26.06	9.86	0.50				
		20	160	10.6	11.2	3.3	11.2	10.3	0.79	34.3	12.6	0.50	19.75	7.55	0.38				
		71	0	12.4	12.6	4.1	12.1	11.7	0.90	63.3	17.6	0.92	39.72	17.38	0.77				
		71	60	11.6	12.3	2.8	11.7	11.9	0.92	42.1	10.9	0.61	15.51	5.11	0.30				
		71	160	10.7	12.1	2.9	11.8	11.5	0.88	33.5	12.5	0.48	10.55	6.14	0.20				

^a °C = (°F - 32)/1.8; 6.894 × 10³ Pa = 1 psi; 6.894 kJ/m³ = 1 in.-lb./in.³

^b MOE measured stress-wave transit time and density.

^c Ratio of observed post-exposure value to untreated, 91°C initially kiln-dried, pre-exposure control value.

^d SD = standard deviation.

TABLE 4. — Mechanical properties of combined initial kiln-drying temperature levels for untreated, water-treated, and CCA-treated lumber exposed to 65°C for up to 160 days.

Treatment	Redrying temp (°C) ^a	Duration of exp (days)	Moisture content (%)	MOE		NDE ^b			MOR			WML		
				Mean	SD ^d	Pre-exp	Post-exp	Ratio ^c	Mean	SD	Ratio ^c	Mean	SD	Ratio ^c
Untreated	none	0	12.0	12.9	3.6	12.1	12.2	1.01	69.9	17.4	1.00	58.6	27.7	1.00
	none	60	11.3	11.7	3.4	12.0	11.6	0.96	56.3	18.5	0.81	39.4	22.3	0.67
	none	160	11.4	12.3	3.6	12.4	12.3	1.02	59.3	19.3	0.85	36.6	22.0	0.62
Water	none	0	12.9	12.5	4.0	11.9	11.6	0.96	67.4	17.6	0.96	60.4	28.0	1.03
	none	60	11.5	12.6	2.5	11.7	11.0	0.91	62.1	16.4	0.89	47.3	27.9	0.81
	none	160	11.6	13.9	3.1	11.9	11.3	0.93	71.1	15.9	1.02	54.3	25.0	0.93
CCA	20	0	12.8	12.2	3.1	12.2	11.3	0.93	62.4	22.2	0.89	44.6	29.0	0.76
	20	60	11.7	12.5	3.6	12.4	11.1	0.92	51.4	17.5	0.74	28.2	16.6	0.48
	20	160	10.7	11.8	3.7	12.1	10.9	0.90	35.7	14.0	0.51	17.7	10.4	0.30
	71	0	12.5	12.9	3.9	12.3	11.7	0.97	66.3	17.2	0.95	53.7	25.3	0.92
	71	60	11.6	12.6	2.9	12.0	11.6	0.96	46.0	12.8	0.66	18.8	8.1	0.32
	71	160	10.8	12.0	2.9	12.1	11.2	0.93	32.0	10.3	0.46	9.2	4.7	0.16

^a °C = (°F - 32)/1.8; 6.894 × 10³ Pa = 1 psi; 6.894 kJ/m³ = 1 in.-lb./in.³.

^b MOE estimated from stress-wave transit time and density.

^c Ratio of observed post-exposure value to untreated, pre-exposed control value.

^d SD = standard deviation.

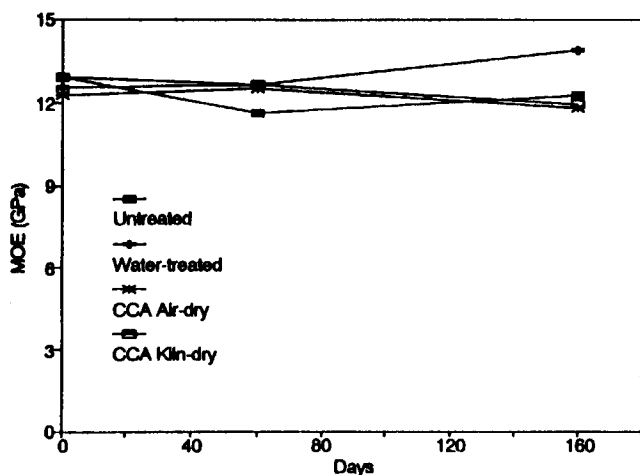


Figure 1. — MOE of untreated, water-treated, and CCA-treated southern pine exposed to 65°C (150° F).

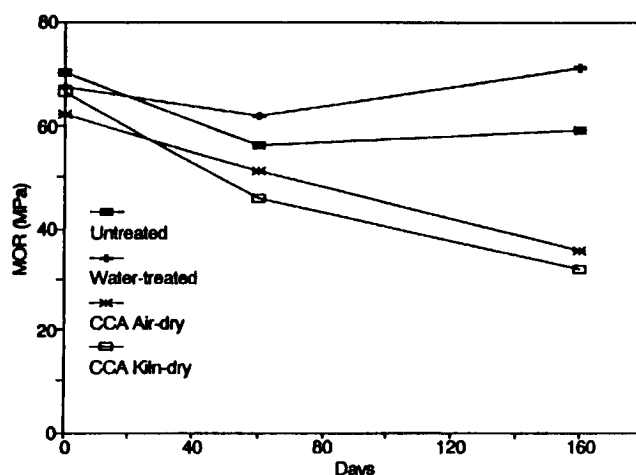


Figure 2. — MOR of untreated, water-treated, and CCA-treated southern pine exposed to 65°C(150°F).

An inspection of the combined data shows that, as expected, MOE was generally unaffected by increasing exposure to high temperatures, while both MOR and WML decreased as the duration of 65°C exposure increased (Table 4). However, distinct differences exist between the treatments.

For material that was water treated and not redried (i.e., wet), MOE, MOR, and WML generally appeared to be less affected after the 160-day high-temperature exposure than did untreated, dry material (Figs. 1 to 3). Analysis of covariance with specific gravity as a covariate found the effect of thermal exposure to be significantly less for water-treated material in MOE and WML ($p \leq 0.05$) and MOR ($p \leq 0.10$) than for untreated or CCA-treated and redried material (Figs. 1 to 3).

Two plausible hypotheses may partly explain this phenomenon. First, because of the cooling effect of water evaporation during resorption, wet water-

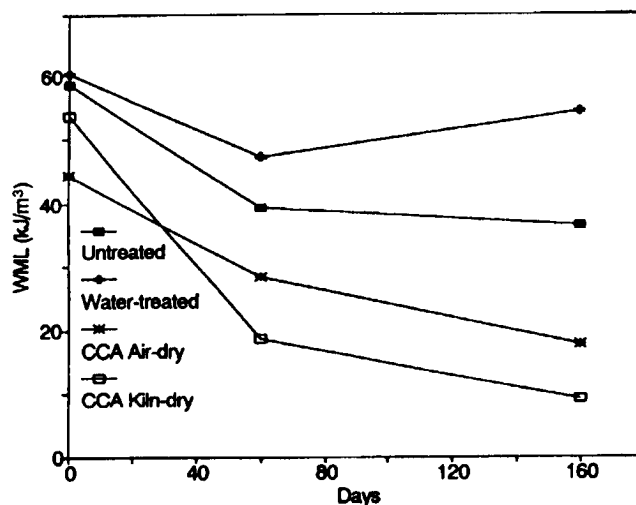


Figure 3. — WML of untreated, water-treated, and CCA-treated southern pine exposed to 65°C(150°F).

treated lumber experienced lower cumulative wood temperatures during the first few days of exposure. The temperature of the wet lumber was probably nearer the 60°C (140°F) wet-bulb temperature of the chamber (9) than was the 65°C dry-bulb temperature. Thus, the wet water-treated lumber experienced a lower cumulative thermal load than was experienced by dry untreated and CCA-treated material. Second, the water treatment may have removed or altered many water-soluble extractives. If present, these extractives might have acted as catalysts during the hydrolytic thermal degradation process. This could explain previous results in which water-treated, redried material showed greater strength than either matched untreated or CCA-treated material (16). It is further reasonable to assume that both scenarios may be acting in concert. Further work is currently underway to define this phenomenon.

The MOE of untreated and CCA-treated material was unchanged after extended high-temperature exposure (Fig. 1). Nondestructive evaluation of MOE using stress-wave transit time was not a strong indicator of thermal degrade because MOE was unaffected over time by high-temperature exposure (Table 4). Nondestructive evaluation based on stress-wave attenuation rather than transit time would probably have been a better indicator of degrade, because strength properties are generally more affected by chemical or thermal treatments than are MOE and because stress-wave attenuation is a more sensitive indicator of strength than is transit time, which is related to MOE (13).

The MOR and WML of untreated material appeared less affected by extended high-temperature exposure than did MOR and WML of CCA-treated and redried material (Figs. 2 and 3). No difference in MOR was noted between CCA-treated and air-redried material and CCA-treated material that was kiln-redried at 71°C. Analysis of covariance with specific gravity as a covariate found the rate of thermal degradation on MOR for untreated material to be significantly less than that for CCA-treated material ($p \leq 0.05$), regardless of redrying level. However, significant differences in WML were noted between CCA-treated and air-redried material and CCA-treated

material kiln-redried at 71°C. The rate of thermal degradation of WML for untreated material was significantly less than for CCA-treated and air-redried material ($p \leq 0.05$). Furthermore, the rate of thermal degradation on WML for CCA-treated and air-redried material was in turn significantly less than for CCA-treated material kiln-redried at 71°C. It is anticipated that lower CCA retention levels might experience less thermal degrade than the material evaluated in this study (9.6 kg/m³ retention).

The consistent reductions in MOR and WML of CCA-treated lumber at 9.6 kg/m³ (0.6 pcf) possibly indicate a need to develop an independent temperature modification factor (C_t) for allowable design stresses of CCA-treated material intended for use in high-temperature environments. Considering that the magnitude and the rate of thermal degradation in MOR and WML of CCA-treated lumber is double that for matched untreated lumber, a decrease in the C_t factor for both the 38°C to 52°C (100°F to 125°F) and 52°C to 65°C (125°F to 150°F) ranges in the National Design Specification (1) might be appropriate. However, because of the limited scale of this study, additional research data are needed to further define the relationship between strength loss and thermal load at temperatures less than 65°C before actual values for C_t could be recommended. No C_t adjustment factor appeared to be needed for MOE.

Chemical composition

The results of the high pressure liquid chromatographic analysis for carbohydrate content and the Klason lignin determinations are shown in Table 5. Little effect was noted in glucose or Klason lignin contents after the 160-day exposure to 65°C. However, after CCA-treated material was exposed at 65°C and 75 percent relative humidity for 160 days, its arabinose, galactose, mannose, and xylose content were reduced 59 to 69, 9 to 35, 8 to 16, and 6 to 10 percent, respectively (Table 5).

For CCA-treated material, the rate of thermal degradation for arabinose appeared to be greater than it did for untreated or water-treated material (Fig. 4). The arabinose content of CCA-treated material also ap-

TABLE 5. — Results of analysis for chemical composition by high pressure liquid chromatography. ^a

Treatment	Redrying temperature	Duration of exposure	Dry weight					
			Arabinose	Glactose	Glucose	Xylose	Mannose	Klason lignin
	(°C)	(days)	————— (%) —————					
Untreated	none	0	1.4	2.5	42.4	6.8	11.3	30.4
	none	60	1.4	2.1	41.3	6.5	10.4	30.4
	none	160	1.0	2.2	42.3	6.9	10.9	29.8
Water	none	0	1.3	2.4	43.9	6.6	11.6	29.0
	none	60	1.2	2.1	42.6	7.1	11.0	30.0
	none	160	1.2	1.8	43.5	6.7	11.7	29.9
CCA	20	0	1.2	2.3	41.5	6.6	10.9	29.4
	20	60	0.9	2.2	41.0	6.3	10.1	29.3
	20	160	0.5	1.9	41.0	6.2	9.9	30.5
	71	0	1.3	2.3	42.0	6.5	10.7	29.5
	71	60	0.9	2.1	41.8	6.2	10.5	29.2
	71	160	0.6	1.7	42.1	6.3	9.9	30.1

^a Two initial kiln-drying levels combined.

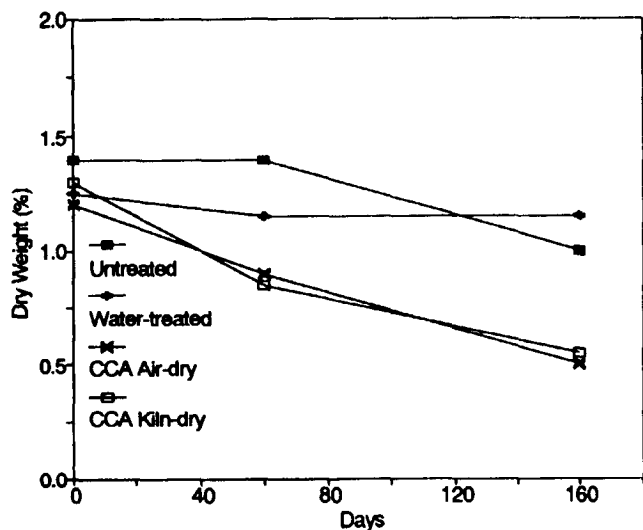


Figure 4. — Arabinose content as percentage of oven-dry weight for untreated, water-treated, and CCA-treated southern pine exposed to 65°C(150°F).

peared to exhibit a linear loss over time of exposure. More importantly, the rate of thermal degradation for arabinose appeared to be directly related to strength loss (Figs. 2 and 4). Untreated material appeared to exhibit no loss in arabinose content during the first 60 days of exposure, but arabinose content was reduced between the 60- and 160-day exposure. When compared to untreated material, the water-treated material appeared to exhibit a slight pre-exposure loss in arabinose content directly from the water treatment process. However, the water-treated material exhibited no further reduction in arabinose content during the 160-day high-temperature exposure.

The galactose content of untreated material appeared to be reduced during the first 60 days of high-temperature exposure, but remained stable thereafter (Fig.5). The galactose content of water or CCA-treated material tended to exhibit a linear rate of thermal degradation over time of exposure. The rate of thermal degradation for galactose also appeared to be directly related to strength loss (Figs. 2 and 5), but to a lesser extent than found for arabinose. The rate of thermal degradation for water-treated and exposed wet material appeared intermediate.

The results of this study appear to confirm recent findings relating strength loss to chemical composition with fire retardants (11) and with brown-rot decay (8,17). This new theory of degradation holds that sugars associated with sidechain hemicelluloses, such as arabinose and galactose, are attacked by acid hydrolysis prior to appreciable reductions in sugars associated with mainchain hemicellulose components, such as mannose, glucose, and xylose and cellulose components (i.e., glucose). Further work may find that the relationship between strength loss and chemical composition is quantitative.

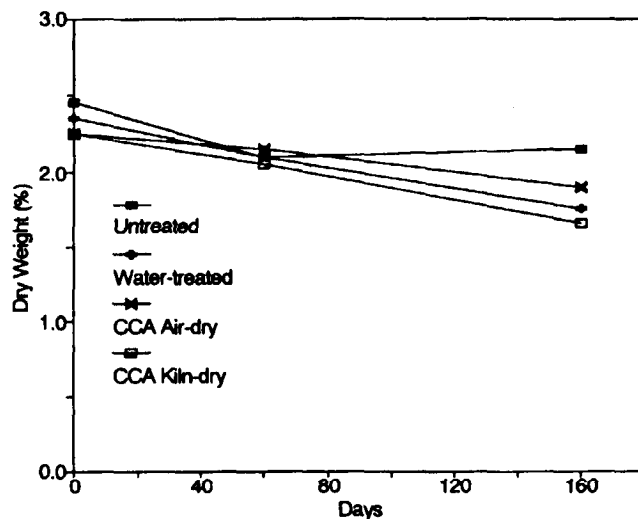


Figure 5. —Galactose content as percentage of oven-dry weight for untreated, water-treated, and CCA-treated southern pine exposed to 65°C(150°F).

Conclusions

In a limited-scale evaluation, 2 by 4, CCA-treated (9.6 kg/m³) southern pine experienced accelerated thermal degradation on extended exposure to near 65°C and 75 percent relative humidity when compared to untreated lumber. Both MOR and WML were significantly reduced; MOE was not affected. Chemical analysis indicated that arabinose and galactose contents of CCA-treated material were reduced more than 50 and 25 percent, respectively, after the 160-day high-temperature exposure. This chemical degradation of arabinose and galactose appeared to be directly related to strength loss.

Although use of CCA-treated southern pine lumber in environments exposed to temperatures near the 65°C limit of untreated wood is rare, it does occur in solar collectors, roof structures over machinery that emits hot, moist, air or steam, and foundation piles supporting hot tankage. The information from this study indicates that CCA-treated southern pine lumber may need a design modification factor for temperature to account for apparent accelerated thermal degradation of CCA-treated materials. Until such time, CCA-treated material may not be appropriate for use where it will be continually exposed to temperatures as high as 65°C. This negative effect of high-temperature exposure on strength would probably be accelerated, or at least equivalent, for other species of CCA-treated wood. Other untreated wood species, such as Douglas-fir, western hemlock, and spruce, have previously been shown to be even less resistant to thermal degrade than untreated southern pine (6,10,14). Additional research is needed to further define the relationship of strength loss in treated wood under extended in-service thermal load at elevated temperatures.

Literature cited

1. American Forest and Paper Association. 1991. National design specification for stress-graded lumber and its fastenings. Washington, D.C.
2. American Society for Testing and Materials. 1992. Standard method of static tests of timbers in structural sizes. ASTM D 198. The ASTM Book of Standard V4.09. Philadelphia, Pa.
3. _____. 1992. Standard test methods for specific gravity of wood and wood-based materials. ASTM D 2393. The ASTM Book of Standard Vol. 4.09. Philadelphia, Pa.
4. American Wood Preservers' Association. 1992. Lumber and plywood for permanent wood foundations — preservative treatment by pressure processes. AWPAC-22. The AWPAC Book of Standards. Woodstock, Md.
5. Barnes, H.M., J.E. Winandy, and P.H. Mitchell. 1990. The effect of initial and post-treatment drying temperature on the bending strength of CCA-treated southern pine. *J. of Institute of Wood Sci.* 11(6):222-230.
6. Comstock, G.L. 1976. Comparison of mechanical properties of Douglas-fir and southern pine lumber dried by CRT, high-temperature, and conventional schedules. In: C.C. Gerhards and J.M. McMiller, eds. Proc. of research conference on high-temperature drying effects on mechanical properties of softwood lumber. USDA Forest Serv., Forest Prod. Lab., Madison, Wis. pp. 63-69.
7. Effland, M.J. 1977. Modified procedure to determine acid-insoluble lignin in wood and pulp. *Tappi* 60(10):143-144.
8. Green, F. III, M.J. Larsen, J.E. Winandy, and T.L. Highley. 1991. Role of oxalic acid in incipient brown-rot decay. *Material und organismen* 26(3):191-213.
9. Hart, C.A. 1975. The drying of wood. Circular 471. North Carolina Agri. Ext. Serv., North Carolina State Univ., Raleigh, N.C.
10. Kozlik, C.J. 1968. Effect of kiln-temperature on strength of Douglas-fir and western hemlock dimension lumber. Rept. D-11. School of Forestry, Forest Res. Lab., Oregon State Univ., Corvallis, Oreg.
11. LeVan, S.L., R.J. Ross, and J.E. Winandy. 1990. Effects of fire retardant chemical on the bending properties of wood at elevated temperatures. Res. Rept. FPL-498. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
12. Pettersen, R.C. and V.H. Schwandt. 1991. Wood sugar analysis by anion chromatography. *J. of Wood Chemistry and Technology* 11(4):495-501.
13. Ross, R.J. and R.F. Pellerin. 1991. Nondestructive testing for assessing wood members in structures: a review. Gen. Tech. Rept. 70. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
14. Salamon, M. 1969. High-temperature drying and its effects on wood properties. *Forest Prod. J.* 19(3):27-34.
15. Sherwood, G.E. and W.E. Gatz. 1979. Performance of wood in a do-it-yourself solar collector. Res. Note FPL-0240. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
16. Winandy, J.E. and R.S. Boone. 1988. The effects of CCA preservative treatment and redrying on the bending properties of 2x6 southern pine lumber. *Wood and Fiber Sci.* 20(3):350-364.
17. _____ and J.J. Morrell. 1993. Relationship between incipient decay, strength, and chemical composition of Douglas-fir heartwood. *Wood and Fiber Sci.* 25(3):278-288.
18. _____, H.M. Barnes, and P.H. Mitchell. 1992. Effects of CCA-treatment and drying on the tensile strength of lumber. *J. of Materials Civil Engineering* 4(3):240-251.

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