Compression and Bending Strength of Steamed, Treated Hardwoods

H. Michael Barnes,* Michael G. Sanders, and G. Brian Lindsey

A study was designed to examine the practical effects on bending and compression perpendicular to the grain of heating and treatment with preservative agents. Red oak and sweetgum were steamed to an internal temperature of 71 °C. Samples were subsequently treated with creosote or ammoniacal copper zinc arsenate (ACZA) while still hot. Samples were tested in bending and compression perpendicular to the grain using ASTM standards. The data indicate no severe reduction in bending properties of red oak or of the compression properties of sweetgum or red oak heated and then treated with ACZA or creosote.

Keywords: Steaming; ACZA; Creosote; Bending; Compression perpendicular to grain; Red oak; Sweetgum

*Contact information: Department of Forest Products, Mississippi State University, Box 9820, Mississippi State, MS 39762-9820; *Corresponding author: mbarnes@cfr.msstate.edu*

INTRODUCTION

With respect to hardwoods, Simpson (1983) stated: *A problem more subtle than obvious drying defects like honeycomb and collapse sometimes occurs in high-temperature drying. The time of exposure to high temperature at high moisture content sometimes results in a thermal degradation that reduces some mechanical properties such as modulus of rupture and modulus of elasticity.* This statement generally conforms to our understanding of the effects of steaming/elevated temperatures on hardwoods unless special provisions are made. Review articles are available (Barnes 1987; Barnes and Winandy 1986; Richards 1958; Wengert 1972). Koch's (1985) tome on hardwoods is an excellent reference. A thorough review of treatment of hardwoods has been published by Thompson and Koch (1981).

The study of steaming effects goes back to the work of Hatt (1906) who showed the strength-reducing effects of steaming on wood. Most of the work with hardwoods and high temperature has been done as part of accelerated drying studies. In their review of high temperature drying of hardwoods, McMillen and Wengert (1978) indicated that strength loss, discoloration, and other degrading factors limited research with high temperature effects on hardwoods. Some work on sterilization of hardwoods has been conducted (Simpson and Wang 2006; Simpson *et al.* 2005). Denig *et al.* (2000) indicated that permanent strength loss can be expected when wet hardwoods are exposed to temperatures greater than 160 °F. MacLean (1952, 1953) showed strength losses for hardwoods exposed to high temperature steam at 250 to 350 °F. Simpson (1976) showed that pre-steaming could reduce drying time without loss in quality.

Hardwoods are the primary species for crossties and have been traditionally treated with creosote. Newer hardwood treatments, especially ammoniacal copper zinc arsenate (ACZA), require the application of steam and heat prior to treating.

This study was designed to determine if steam heating and subsequent preservative treatment had any effect on the compressive strength perpendicular to grain of two hardwoods, red oak (*Quercus rubra*), and sweetgum (*Liquidambar styraciflua* L.). Additionally, the impact of steaming and treatment on red oak samples in bending was determined.

EXPERIMENTAL

Materials

The wood species investigated were red oak (*Quercus rubra* spp) and sweetgum (*Liquidambar styraciflua* L.). Samples were mixed heart/sapwood and were chosen to represent the range of pore distributions (ring porous to diffuse porous) in commercial crosstie production. Preservatives utilized included ammoniacal copper zinc arsenate (ACZA) and P2 creosote, both conforming to AWPA standards (2011a,b).

Steaming

A preliminary experiment was conducted to determine the appropriate steaming time for a sample to reach 71 °C in the center of the sample. Samples of the appropriate cross sectional area (1- x 1-in for bending; 1.5- x 1.5-in for compression) were center-bored to accept a thermocouple. After insertion, the hole was filled with a silicon sealant. Samples were placed in a steam autoclave with a monitoring piece on the top and bottom rows on opposite sides of the stack.

The autoclave was turned on and heated until the internal temp of the monitoring samples reached approximately 43 °C. The autoclave was then turned off and the door remained closed until the controls reached approximately 71 °C. Time of heating varied depending on species and specimen size. The door was then opened and the samples removed.

Preservative Treatment

Steamed samples were treated while still hot. The solution concentration for ACZA was adjusted to yield a net retention of 0.4 pcf ai. For the creosote treatment, creosote was diluted with toluene to yield an approximate target of 6 pcf after treatment. The treating cycle was 30 min at maximum vacuum (>27 in Hg) and 60 min of pressure at 150 psig. After treatment, samples were wiped to remove excess preservative and weighed to determine the retention. Samples were then allowed to condition at ambient room conditions for 30 days prior to testing. Table 1 shows the study design.

Testing

For each combination of species (sweetgum, red oak)/treatment (ACZA, creosote, untreated)/steaming (steaming, no steaming), 30 samples were tested in compression perpendicular to the grain according to ASTM D143 (2010), with the exception that samples measuring 1.5- x 1.5-inches rather that the 2- x 2-in specified by the standard were tested. Red oak was also tested in static bending using the 1- x 1- x 16-in specimen specified in ASTM D143 (2010). Data were analyzed using SAS (2012) software and Tukey's test was used to separate means.

Table 1. Experimental Design

Test	Species	Treatment	Steam	No. samples
Compression ⊥ grain	Sweetgum	Untreated	No	30
		0.4 pcf ACZA		30
		6 pcf creosote		30
		Untreated	Yes	30
		0.4 pcf ACZA		30
		6 pcf creosote		30
	Red oak	Untreated	No	30
		0.4 pcf ACZA		30
		6 pcf creosote		30
		Untreated	Yes	30
		0.4 pcf ACZA		30
		6 pcf creosote		30
Static bending	Red oak	Untreated	No	30
		0.4 pcf ACZA		30
		6 pcf creosote		30
		Untreated	Yes	30
		0.4 pcf ACZA		30
		6 pcf creosote		30

RESULTS AND DISCUSSION

Static Bending

For static bending, Table 2 shows the comparison of mean values of the modulus of rupture (MOR), modulus of elasticity (MOE), work-to-proportional limit (W_{pl}), and maximum load (W_{ml}) for red oak. An analysis of variance was conducted in order to determine significant differences between a given treatment and the untreated samples. Moisture content and specific gravity were evaluated as covariates and were not significant.

When compared to untreated, steamed stock, no steaming/treatment combination caused a significant reduction in MOR, MOE, or work values. While there were differences among preservative treatments, no clear trend emerged. When compared to control values for unsteamed or steamed red oak, a maximum drop in MOE or MOR of around 10% or less was noted across all properties evaluated. For control values, steaming caused an 8% drop in MOE and a 6% drop in MOR. The ratio of treated to similar control value ranged from 91% to 107% for MOE and 89 to 108% for MOR. This is consistent with published data, which indicates a decline of 15% or less in properties after treatment (Barnes and Winandy 1986). From a strength and stiffness standpoint, steaming to an internal temperature of 160 °F and subsequent treatment of red oak causes no problems with bending and should be fine for treatments requiring steaming before treatment

Table 2. Mean Values from Static Bending of Red Oak Samples[1]

Treatment	Conditioning	MOE (kpsi)	Ratio[2]	MOR (psi)	Ratio[2]	W_{pl} (in-lbf/in^3)	Ratio[2]	W_{ml} (in-lbf/in^3)	Ratio[2]	Retn (pcf)	MC (%)	Sp gr
ACZA	Steamed	1,764 (183)	103%	16,954 (1,374)	99%	2.17 (0.6)	94%	21.37 (4.2)	104%	0.41 (0.09)	8.65 (0.67)	0.70 (0.04)
	Unsteamed	1,702	91%	16,309	89%	2.11	91%	20.44	87%	0.4	8.45	0.70
Creosote	Steamed	1,820	107%	18,456	108%	2.88	124%	21.22	104%	5.9	10.98	0.75
	Unsteamed	1,837	99%	18,147	99%	2.86	124%	19.56	84%	6.1	10.46	0.75
Untreated	Steamed	1,705		17,144		2.32		20.48		0.0	8.18	0.69
	Unsteamed	1,861		18,296		2.31		23.37		0.0	7.52	0.70
Control: Steamed/Unsteamed			92%		94%		100%		88%			

[1](standard deviation); [2]Ratio (treated/untreated)

Cumulative frequency diagrams showing value distributions are shown in Fig. 1 for MOE and Fig. 2 for MOR. Distributions are similar indicating little difference in the treatment combinations.

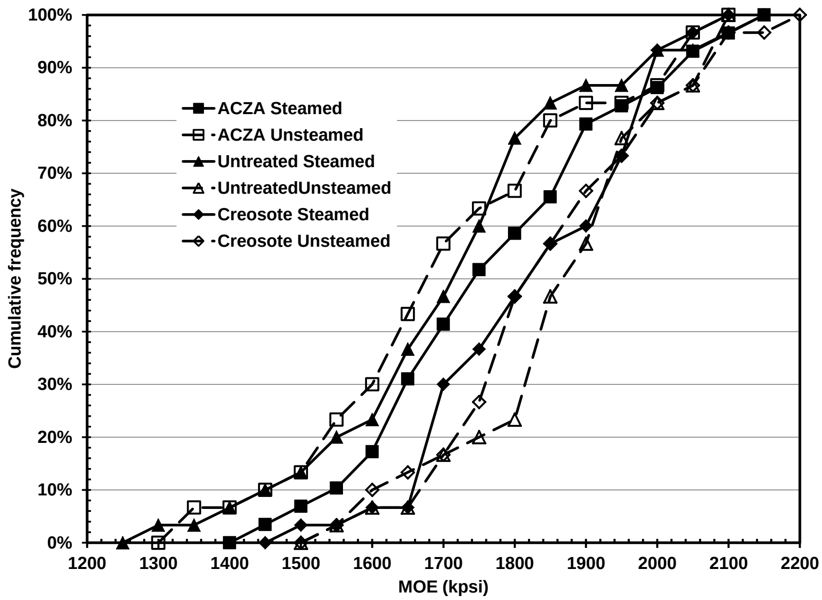

Fig. 1. Cumulative frequency of MOE values for red oak

As indicated, no deleterious effect of steaming was found for stiffness or strength, thus confirming the previous discussion. Distributions were very similar and for the most part showed equivalent or higher values than those for untreated, steamed samples.

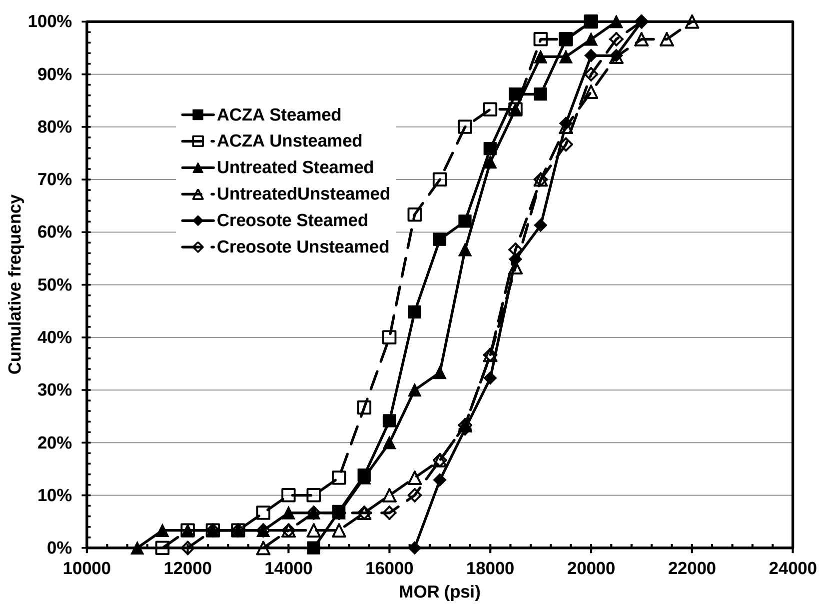

Fig. 2. Cumulative frequency diagram for MOR of red oak samples

Compression Perpendicular to Grain

Descriptive statistics are given in Table 3 for the sweetgum and red oak samples tested in compression perpendicular to grain. Mean comparisons are shown in Table 4. The coefficients of variation averaged 14% for sweetgum and 13% for red oak. These values are half of those reported in the Wood Handbook (FPL 2010) for compression perpendicular to grain.

Table 3. Descriptive Statistics for Compression Perpendicular to Grain

	Sweetgum					
	UNTREATED		ACZA		CREOSOTE	
	UNSTEAMED	STEAMED	UNSTEAMED	STEAMED	UNSTEAMED	STEAM
	(psi)					
Mean	1,392	1,416	1,311	1,275	1,519	1,59
Standard Deviation	230.6	203.1	166.4	129.2	227.2	236
Coefficient of variation	17%	14%	13%	10%	15%	15%
	Red Oak					
Mean	2,227	2,118	1,884	2,109	2,342	2,21
Standard Deviation	382.6	305.1	184.3	222.9	338.3	286
Coefficient of variation	17%	14%	10%	11%	14%	13%

Table 4. Comparison of Mean Values for Compression Perpendicular to Grain for Red Oak and Sweetgum Samples [1]

Species	Mean (psi)		Group	Ratio[2]	Mean (psi)		Group	Ratio[2]
	ACZA vs Controls				Creosote vs Controls			
Sweetgum	1,392	AB	UNT UNSTEAMED		1,392	AB	UNT UNSTEAM	
	1,416	A	UNT STEAMED		1,416	A	UNT STEAMED	
	1,311	AB	ACZA UNSTEAM	94%	1,598	B	CREO UNSTEAM	115%
	1,275	B	ACZA STEAMED	90%	1,519	B	CREO STEAMED	107%
Untreated								
Red Oak	2,227	A	UNT UNSTEAM		2,227	AB	UNT UNSTEAM	
	2,118	A	UNT STEAMED		2,118	B	UNT STEAMED	
	1,884	B	ACZA UNSTEAM	85%	2,342	A	CREO UNSTEAM	105%
	2,109	A	ACZA STEAMED	100%	2,217	AB	CREO STEAMED	105%

[1]Means not followed by a common letter are significantly different at $p = 0.05$; [2]Ratio (treated/untreated for the same conditioning)

For red oak, only the unsteamed ACZA group was lower in compression strength than the control values. This indicates that steaming had no effect on compression perpendicular to grain for creosote or ACZA-treated wood. For sweetgum, the no conditioning x treatment combination was significantly lower than the control values. Creosote treatment followed the same pattern with no significant effect of steaming. Across both species, the ratio of treated:control value ranged from 85 to 100% for ACZA and 105 to 115% for creosote.

CONCLUSIONS

1. Steaming and subsequent treatment had no significant impact on static bending values. Net reductions in MOR and MOE properties varied from -11% to +8%, depending on the property. Such values are consistent with published data, which show a 10% loss in bending strength due to treatment.

2. While some differences were found among combinations, steaming prior to treatment did not adversely affect the compression perpendicular to the grain values for ACZA or creosote-treated sweetgum and red oak.

3. Short duration steaming at 71 °C, as observed in this study, would not cause any significant loss of properties.

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