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Mechanical Properties of Southern Pine Treated with Copper Betaine

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ABSTRACT

This study compared the bending properties of southern pine treated with a new generation wood preservative, copper betaine (KDS). Static bending tests indicated that treatment had no deleterious effect on bending property values when compared to control samples. Increasing KDS retention improved most property values. The reason for this improvement is not clear at this time and will require additional study.

Keywords: copper betaine, southern pine, strength, stiffness, bending, mechanical properties

INTRODUCTION

In order for standards to be promulgated for new preservative systems and treatments such treatments should not have deleterious effects on wood properties. Many studies (Barnes & Winandy 1986) have been conducted on the effect of various treatments on the mechanical properties of wood. For example, research by Winandy and others (Winandy *et al*. 1992; Winandy & Barnes 1991; Barnes *et al*. 1990; Barnes & Winandy 1989) recommended drying temperature limitations for CCA-treated wood, and these limitations were adopted by standards-setting organizations. Different post-treatment conditioning cycles have varying effects on the resultant strength of wood depending on species, treatment, and type of conditioning. Decreases in modulus of rupture from 8-33% have been reported depending on the steaming time, temperature, and preservative retention (Barnes 1985).

Other work has shown that ACQ and several other treatments do not cause significant reductions in mechanical properties (Barnes, *et al*. 1993; Barnes & Winandy 1986). There were no practical deleterious effects of waterborne copper naphthenate treatment on the bending properties of southern pine (Barnes *et al*. 2005) and post-treatment steaming of copper naphthenate-treated pine had no practical negative effect on mechanical properties (Barnes *et al*. 2007). Unpublished studies by the authors show no more than a treatment effect common with waterborne systems for other new copper-based systems. Treatment with an all organic system showed no differences between controls and treated samples (Barnes & Lindsey, 2008 submitted).

This paper reports on the testing of southern pine treated with copper betaine (Impralit-KDS). As defined by Ruzo et al. (2004), Impralit-KDS is a new preservative containing polymeric betaine (PB), copper carbonate and boric acid in water and monoethanolamine. The polymeric betaine is a reaction product solution formed from boric acid, propylene glycol, ethylene oxide, and didecylamine (DDA) in water. The resulting is a complex borate ester (didecyl-bis(2- hydroxyethyl) ammonium borate) which exists in the reaction product solution in equilibrium with the quaternary ammonium ion formed from the reaction of DDA and ethylene oxide and free boric acid.

METHODS & MATERIALS

Materials—Clear southern pine bending samples measuring 1-in x 1-in x 16-in (r, t, l) were cut from nominal 2 x 6 inch dimension stock and measured to the nearest 0.01 inch. Similar samples measuring 0.79

x 0.79 x 14-in were cut for toughness tests. Samples averaged 6-9 rings per inch and were placed in treatment groups of similar weight distribution. Samples were treated with copper betaine (KDS, Rütgers Organics GmbH) to target retentions of 4.0 and 6.4 kg/m^3 ai and CCA-C to a target retention of 6.4 kg/m^3 ai (active ingredient, oxide basis). Treating solutions were made from 15.25 % total ai KDS concentrate (CuO:PB:BAE=1.25:1:0.8) and 50% CCA-C concentrate by water dilution. The full-cell treating cycle consisted of a vacuum at 27+ in Hg for 30 minutes followed by filling under vacuum and a pressure period of 150 psig for 60 minutes. After treatment, samples were removed from the cylinder, wiped to remove excess solution, and weighed to determine retention by weight gain. Control samples were treated with water only. Samples were stickered and allowed to air dry in an indoor, vented lab at nominal room conditions (75º F, 65% relative humidity), until equilibrium was obtained. Samples for toughness testing were treated in separate charges at a later time. The actual retentions for these samples were slightly higher than those for the bending tests.

Testing—After equilibrating to room conditions, samples were tested in static bending with center-point loading according to D143 (ASTM International 2006). Thirty samples per treatment group were tested on a 14-in span. A 0.10 in/min rate of loading[1] was employed in order to make sure all samples failed in ten minutes or less. Modulus of elasticity (MOE), modulus of rupture (MOR), work-to-maximum load (WML), work-to-proportional limit (elastic resilience, WPL), and fiber stress at proportional limit (FSPL) were computed for each sample. Average moisture content and specific gravity of the test samples by group are shown in Table 1.

Toughness samples were tested on a 9.47-in span using a toughness testing machine. Half (15) of the samples in each group were loaded on the radial face and half on the tangential face

Data analysis—The data were analyzed using covariate analysis and a least square (LS) mean separation technique (SAS Institute 2001). Specific gravity and moisture content were analyzed as covariates. Specific gravity was found to be a significant covariate in the analyses of all properties, hence it was used to determine adjusted least squares values. In the LS technique, pre-planned comparisons are made. For this work, the comparison of controls vs. other treatments and the comparison of copper betaine at the two retentions were made.

RESULTS

Bending-A summary of the mean mechanical property values obtained are shown in Table 1. A comparison of the mean values can be seen in Figures 1 to 5. The least squares comparison of modulus of rupture adjusted means is shown in Figure 1. Comparisons showed that all treatments were statistically equivalent indicating no deleterious effect of treatment on strength. The same result was obtained for the least squares analysis of modulus of elasticity indicating no effect of treatment on stiffness (Figure 2).

A slightly different trend was found for fiber stress at the proportional limit (Figure 3). In this case the two KDS treatments were equivalent and statistically greater than the CCA treatment or water-treated controls indicating no deleterious effect. The CCA treatment and controls were equivalent.

An identical trend was seen with the work-to-proportion limit (elastic resilience) results following the trend KDS (6.4 kg/m^3) = KDS (4.0 kg/m^3) > CCA = water-treated control (Figure 4). Statistical analysis of the work-to-maximum load values showed no difference among the four treatments (Figure 5).

Overall, for treatment with the KDS system, all property values with the exception of work-to-maximum load increased with increasing retention. Whether this is an artifact or a real trend will require additional work. At the very least, this shows that no negative effect on mechanical property values may be expected with treatment of southern pine with copper betaine.

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[1] This rate of loading is twice that recommended in the Standard and was used in order to obtain failure in all specimens in 10 minutes or less. Any effects of changing the rate of loading were considered non-consequential since all specimens were tested under the same conditions.

Toughness-Least squares mean values for toughness are shown in Table 2. For samples loaded on the radial face, no differences among treatments were found. For samples loaded on the tangential face, KDS (4.0 kg/m^3) = water-treated control > KDS (6.4 kg/m^3) = CCA. As expected, radial face values were higher than those for the tangential face. These data indicate no practical loss in toughness for southern pine treated with copper betaine.

SUMMARY

The bending data obtained in this study indicates that no deleterious effect on bending properties of southern pine was seen with the KDS treatments used in this study, even for the highest retention. This result is similar to results obtained with other waterborne preservative systems except that treatment with KDS generally enhanced property values somewhat compared to controls. The reason for this effect is unknown at this time but illustrates the fact that KDS treatment has no deleterious effect on bending properties. A very slight effect was found for toughness for the highest retention KDS samples loaded on the tangential face with values being equivalent to CCA-treated samples. No differences were noted for loading on the radial face among any of the treatments; hence, no practical deleterious effect of treatment on toughness can be attributed to treatment with copper betaine.

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Barnes, H. M., G.B. Lindsey, J. Hill. 2008. Mechanical properties of southern pine treated with copper betaine. Proceedings, American Wood-Preservers' Association. 104:89-95.

Table 1. Comparison of unadjusted and adjusted least squares means for bending properties

Treatment (target)	MOE (psi)	MOR (psi)	WML (in-lbf/in^3)	WPL	FSPL (psi)	MC (%)	Specific gravity
UNADJUSTED MEANS							
CCA (6.4 kg/m^3)	1,205,730	11,085	12.46	1.55	5,483	12.5	0.492
KDS (4.0 kg/m^3)	1,201,854	10,810	12.63	1.49	5,531	12.9	0.490
KDS (6.4 kg/m^3)	1,298,327	11,408	11.85	1.58	5,771	13.4	0.507
Untreated	1,221,422	11,385	13.7	1.61	5,669	11.4	0.483
ADJUSTED LEAST SQUARES MEANS						Actual retention (kg/m^3)	
CCA (6.4 kg/m^3)	1,206,817	11,098	12.47	1.52	5,427	6.69	
KDS (4.0 kg/m^3)	1,224,101	10,931	12.94	1.67	5,957	4.20	
KDS (6.4 kg/m^3)	1,269,367	11,149	11.63	1.88	6,325	6.65	
Untreated	1,227,047	11,510	13.61	1.16	4,747	0.00	

Table 2. Adjusted least squares means for toughness

Treatment	Retention (kg/m^3)	Specific gravity	MC (%)	Toughness (in-lbf)
RADIAL				
KDS	4.6	0.440	15.1	272.5
KDS	7.3	0.454	13.8	243.7
CCA	6.6	0.476	14.3	271.1
H_2O	0.0	0.455	14.8	276.7
TANGENTIAL				
KDS	4.3	0.457	13.9	222.7
KDS	7.3	0.455	13.7	187.6
CCA	6.6	0.471	14.7	167.8
H_2O	0.0	0.451	14.9	209.7

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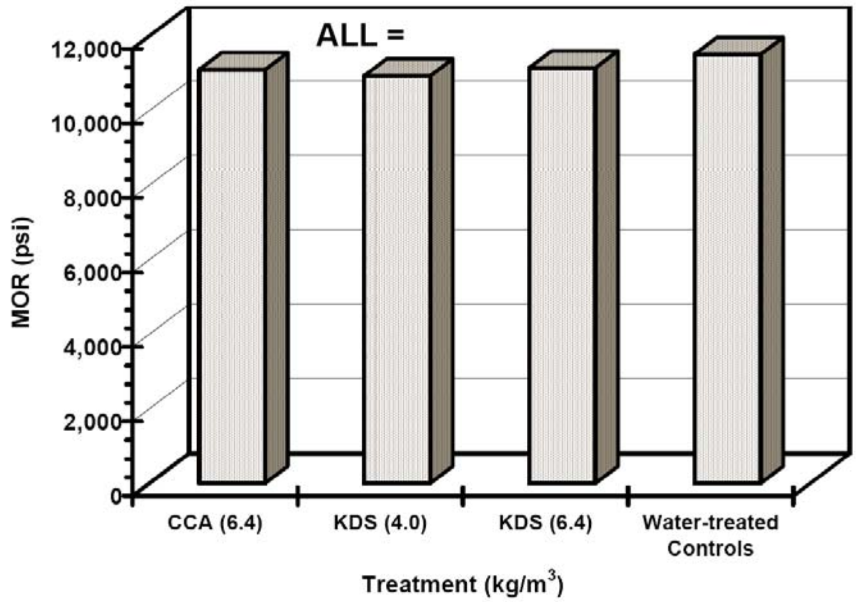

Figure 1. A comparison of modulus of rupture mean values.

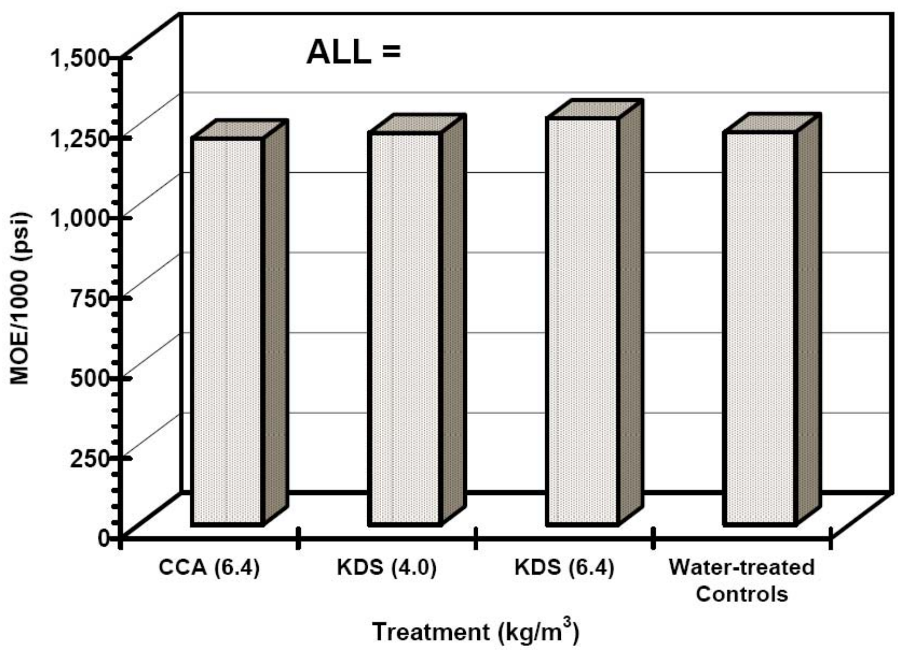

Figure 2. Modulus of elasticity values for the various treatments.

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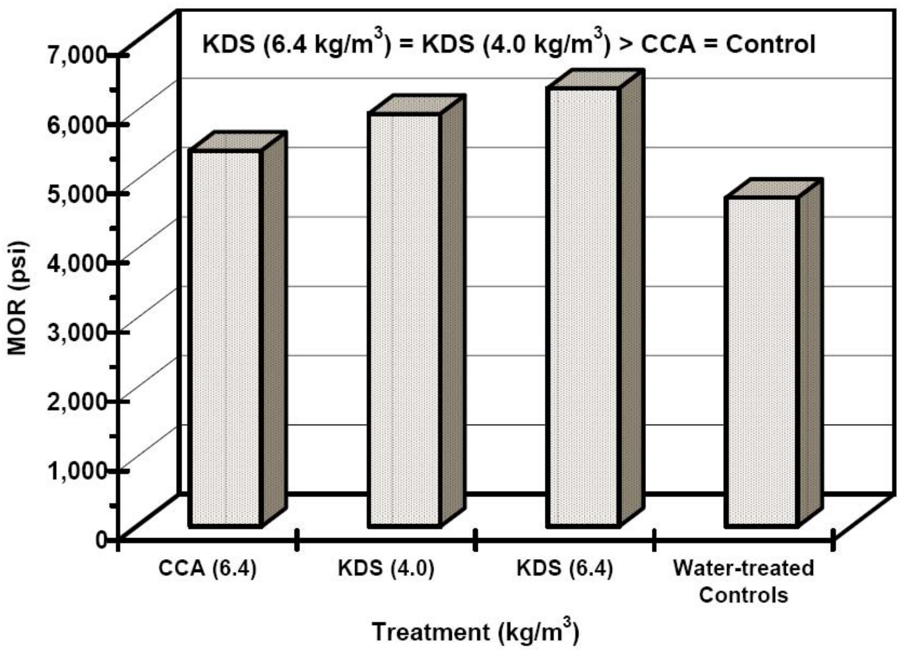

Figure 3. Least squares mean comparisons for fiber stress at proportional limit.

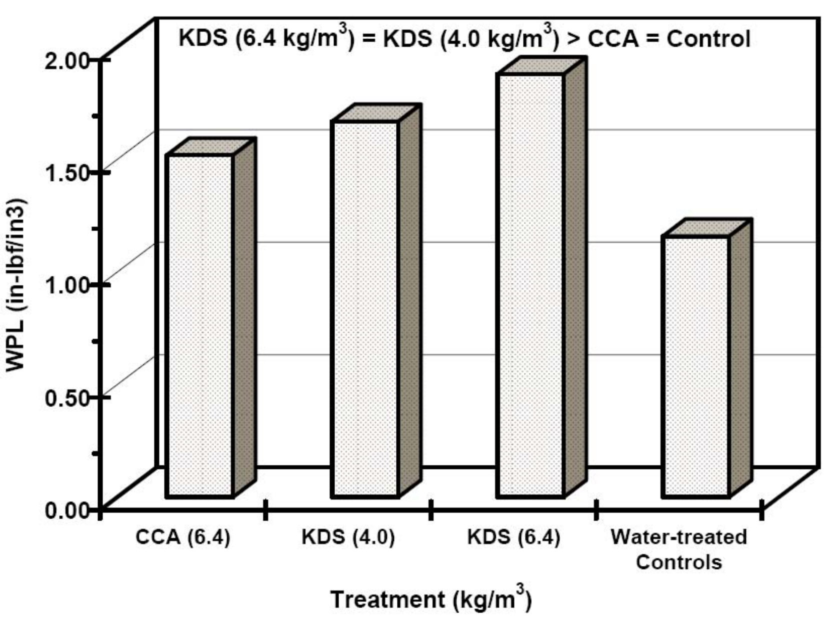

Figure 4. Least squares mean values for work-to-proportional limit.

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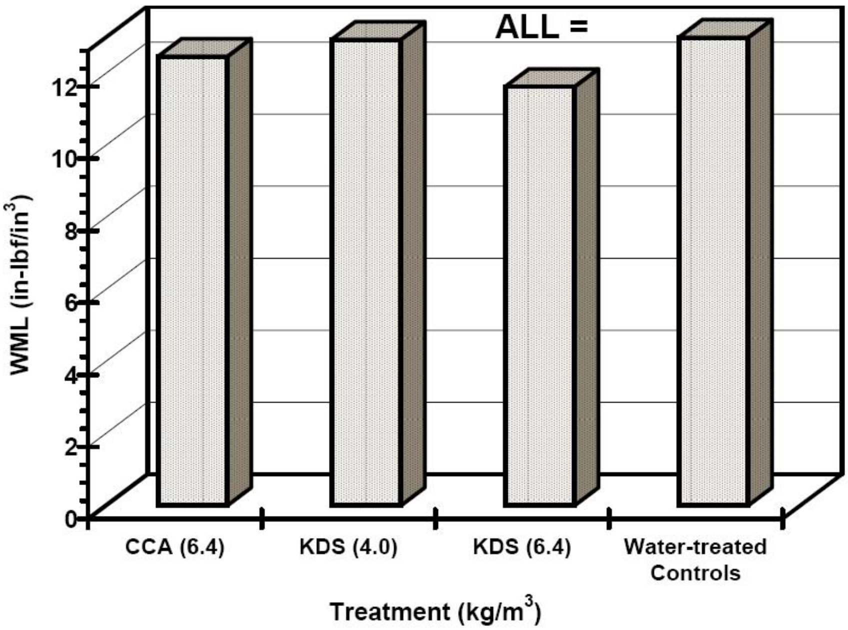

Figure 5. A comparison of least squares means for work-to-maximum load.

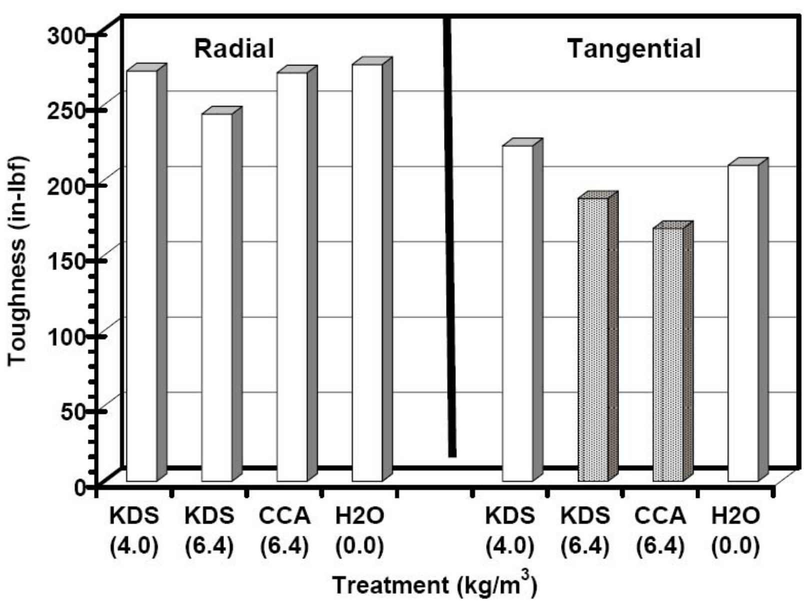

Figure 6. A comparison of least square toughness means for samples loaded on the radial and tangential faces.