Selected Properties of Heat-Treated Eastern Red Cedar (*Juniperus virginiana* L.) Wood

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The objective of this study was to evaluate the effect of heat treatment on properties including oven-dry density, weight loss, surface roughness, shear strength, and hardness of eastern red cedar (*Juniperus virginiana* L.). The anatomical structures of samples were also examined by scanning electron microscope (SEM). Two different heat treatment schedules, with temperatures of 130°C and 160°C and 3 and 7 h exposure times, were considered for the experiment. A stylus method was employed to evaluate the surface properties of heat-treated samples. Three roughness parameters, average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}), were determined from the surface of specimens and used to evaluate the effect of heat treatment on the surface properties. The shear strength of samples bonded with polyvinyl acetate (PVAc) adhesive was also measured. All properties of the samples exposed to different heat treatment schedules were significantly different (p = 0.05) from each other. The results of this study demonstrated that the oven-dry density, surface roughness, shear strength, and hardness of the samples decreased, while their weight loss increased slightly, with increasing heat treatment temperature and time.

Keywords: Eastern red cedar; Heat treatment; Oven-dry density; Shear strength; Hardness

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INTRODUCTION

Increased environmental demand has resulted in the development of wood products treated at high temperature as an alternative method to traditional wood preservation techniques. The heat treatment process does not require the addition of any chemicals to the wood to modify its properties. Heat-treated wood has attracted a lot of interest in North America as a raw material with improved properties for manufacturing flooring, siding, kitchen cabinets, and windows (Kocaefe *et al.* 2007).

In general, heat-treated wood is natural wood exposed to temperature levels ranging from 160 to 230 °C, depending on the species and the desired target properties (Kocaefe *et al.* 2013). Heat treatment of wood has been developed in Europe within the last 20 years. The main objective of heat treatment is to improve the physical and mechanical properties of wood and wood products so that they can be used more effectively during their service life (Korkut *et al.* 2013).

It is well known that heat treatment improves the physical properties of wood, such as equilibrium moisture content, shrinking, and swelling. However, the mechanical properties of wood are adversely influenced as a result of heat treatment. Many previous investigations have reported that wood heat treatment reduced its overall strength properties (Yildiz *et al.* 2006; Korkut and Kocaefe 2009). Gunduz *et al.* (2008) reported that heat treatment of Camiyani black pine (*Pinus nigra* Arn.) at temperature levels ranging from 120 °C to 180 °C for time periods of 2, 6, and 10 h reduced the surface roughness and the Janka-hardness of the specimens. Hardness and surface roughness values of such specimens also decreased with increasing heat treatment temperature and exposure time. Priadi and Hiziroglu (2013) examined similar property changes with heat-treated oak, pine, and some tropical species, including mahogany and mindi. In their study, it was found that the dimensional stability of such species improved as a result of heat treatment (Priadi and Hiziroglu 2013).

Heat treatment of Scots pine (*Pinus sylvestris* L.) at a temperature of 180 °C for 10 h resulted in reduced compression strength, bending strength, modulus of elasticity, Janka-hardness, impact bending strength, and tensile strength perpendicular to the grain on the order of 25.40% to 46.22% versus the control samples (Kocaefe *et al.* 2010). On the other hand, red-bud maple (*Acer trautvetteri* Medw.) samples subjected to similar heat treatment conditions resulted in decreased surface roughness values up to 15.06% (Korkut *et al*. 2008).

Eastern red cedar (*Juniperus virginiana* L.) is one of widely distributed species in Oklahoma. The current area covered by eastern red cedar in Oklahoma is estimated beyond 11 million acres, and it is projected to be 13 million acres by 2013, which is approximately 28% of the Oklahoma landscape. The eastern red cedar population is growing at the rate of 750 acres per day, resulting in a significant adverse impact on ecology: the trees are negatively affecting people’s health, reducing productivity from grasslands, and destroying wildlife habitat. Recently the eastern red cedar Registry Board formed by Representative Richard Morrisette’s office has been trying to evaluate alternative solutions to this important environmental problem in Oklahoma. Use of low-quality eastern red cedar as a raw material in lumber manufacturing is not currently substantial due to its low value and its irregular growth pattern (Hiziroglu 2002). However there is increasing interest by small and mid- size manufacturers in Oklahoma to use such species to produce value-added products, such as cabinets and furniture units. Although different properties of eastern red cedar have been investigated in previous studies, there is very limited information on the behavior of this species as a function of heat treatment. The importance of this work lies in its potential to expand the use of low quality eastern red cedar with enhanced properties that may result in the development of an environmentally sound way to utilize this resource in Oklahoma. Therefore, the main objective of this study was to determine basic properties of heat-treated red cedar specimens so that this species can possibly be used to manufacture cabinets and furniture units with improved properties employing such initial data.

EXPERIMENTAL

Twenty-millimeter-thick boards of eastern red cedar were supplied by a local sawmill in Oklahoma. Each board having 100 % heartwood was planed and cut into 30-mm-wide strips before being reduced to 50-mm-long samples. Defect-free samples with tangential grain orientation were conditioned in a room with a temperature of 20 °C and a relative humidity of 65% until they reached an equilibrium moisture content of 12%. The dimensions and mass of each sample were determined at accuracy levels of 0.01 cm and 0.01 g, respectively. Heat treatment of the specimens was carried out at two temperature levels of 130 °C and 160 °C for 3 and 7 h in an atmospheric laboratory oven controlled to within ±1 °C. Weight loss of the specimens after heat treatment was estimated according to the formula,

$$WL(\%) = (m_0 - m_1) / m_0 \times 100 \quad (1)$$

where m_0 is the initial oven-dried mass of the wood sample before treatment and m_1 is the oven-dried mass of the same sample after treatment. Thirty measurements with a tracing span of 15.2 mm were taken from both sides of the specimens across the grain orientation by employing a stylus-type profilometer (Hommel T-500; Hommel-America Corp., Rochester Hills, MI, USA) before and after heat treatment and compression of the specimens. The stylus unit used in this study consists of the main unit and the pick-up model TkE. The pick-up has a skid type diamond stylus with a 5-μm tip radius and a 90° tip angle. The stylus traverses the surface at constant speed of 1 mm/s over a 15.2-mm tracing length, converting the vertical displacement of the stylus into an electrical signal. The calibration of the instrument was checked every 100 measurements using a standard reference plate with an average roughness (R_a) values of 3.02 µm and 0.48 µm. A cut-off length of 2.54 mm, a parameter that differentiates roughness and waviness profiles from each other, was used for the test (Mummery 1993).

Polyvinyl acetate (PVAc) adhesive was used to bond sample pairs to determine their shear strength. Adhesives were applied to both surfaces of each shear pair at a spread rate of 200 g/m^2. The pair was then cold pressed using an approximate pressure of 4 kg/cm^2 for 2 min at room temperature before shear tests were carried out.

Hardness of the control and treated specimens was tested by embedding a steel hemisphere having an 11.2-mm diameter onto the surface tangential to the grain direction using a Comten 95 Series Universal Testing machine (COM-TEN Industries, Pinellas Park, FL USA). Four measurements were taken from each samples and recorded in kN to evaluate their Janka hardness.

The effect of heat treatment on the anatomical structure was also investigated using a scanning electron microscope (SEM) model Quanta 600F (FEI; Hillsboro, Oregon USA). Samples with sizes of 5 mm by 5 mm by 5 mm were coated with a thin layer of gold in the vacuum chamber of a sputter coater for 2 min. Micrographs were taken from the cross sections of control and heat-treated specimens exposed to various treatment schedules.

For the oven-dry density, surface roughness, shear strength and hardness, all multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant differences between the mean values of control and treated specimens were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Table 1 displays the physical and mechanical properties of the specimens exposed to heat treatment. The average density value of control samples was determined to be 0.482 g/cm^3. This value sequentially decreased with increasing temperature and exposure time, as illustrated in Fig. 1. For example, samples exposed to a temperature of 160 °C for 3 h had 4.15% reduction in their density value compared to that of the control samples. This reduction further increased to 37.7% for samples exposed to a temperature of 160 °C for 7 h. In a previous work, it was found that samples of beech and spruce exposed to a temperature of 200 °C for 10 h had 18.37% and 10.53% reduction in their density levels, respectively (Yildiz 2002).

In another study, the density of Scots pine and Norway spruce also had 10% and 8.5% density reduction, respectively, as a result of heat treatment (Boonstra *et al.* 2007). Degradation of hemicellulose into volatile substances and evaporation of extractives are the primary parameters responsible for the density reduction of wood when heat treated (Esteves and Pereira 2009).

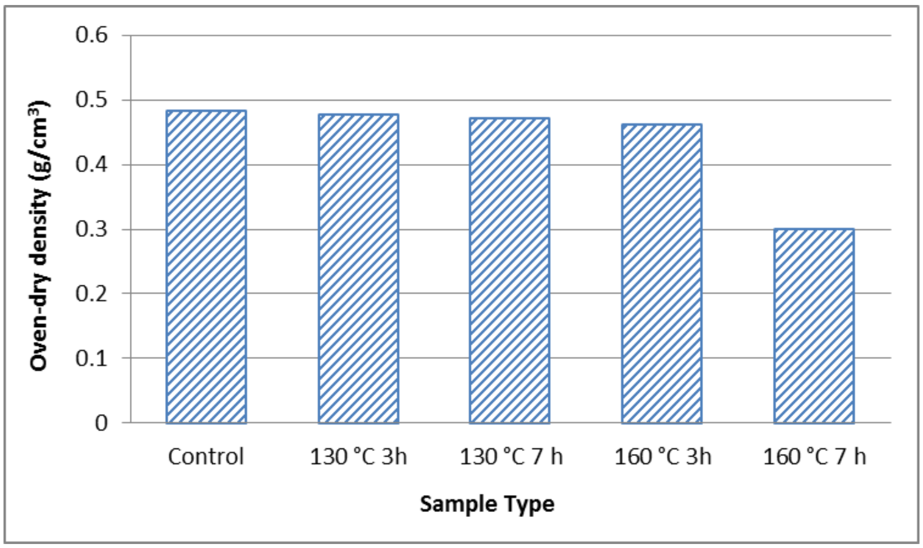

Fig. 1. Oven-dry density values of the specimens

Eastern red cedar has 3.8% oil in its heartwood (Kasemsiri *et al.* 2012). The oil is volatile and evaporates easily during heat treatment, which results in higher density reduction than the different wood species mentioned above.

In this work, in addition to density reduction, the specimens also exhibited weight loss that increased with increasing magnitude of temperature and exposure time (Table 1). The weight loss of spruce exposed to a temperature of 225 °C for 6 h was 12.5% (Alén *et al.* 2002). Overall, the findings in the study are relatively similar to those reported in past studies. The weight loss of heat-treated wood is directly associated with the temperature level and the exposure time (Esteves and Pereira 2009). Eastern red cedar samples exposed to a temperature of 160 °C for 7 h had a 10.3% weight loss.

Average roughness values of 7.31 µm were determined for the control samples. Heat treatment did not significantly enhance the overall surface quality of the specimens. Even when the samples were exposed to a temperature of 160 °C for 7 h, the R_a value only decreased to 7.17 µm from the 7.31 µm value of the control samples. Similar results were also determined with a previous study that evaluated the effects of heat treatment on the surface quality of pine, oak, and two tropical species, mindi and mahogany (Priadi and Hiziroglu 2013). Overall, the R_a values of the samples decreased by 1.87% to 5.61% versus the control, which was not significant (Fig. 2).

Table 1. Test Results of Heat-Treated Eastern Red Cedar (*Juniperus virginiana* L.) Specimens*

Heat Treatment	Time	Oven-dry Density	Weight Loss	Roughness Parameters			Shear strength	Janka-hardness
	(h)	D_o (g/cm^3)	WL (%)	R_a (µm)	R_z (µm)	R_{max} (µm)	MPa	kN
Control	-	0.482 a (0.02) *0* *30*	-	7.31 a (0.71) *0* *30*	48.91 a (5.18) *0* *30*	59.41 a (11.08) *0* *30*	6.04 a (1.06) *0* *18*	3.89 a (0.60) *0* *30*
130 °C	3	0.476 b (0.03) *1.22* *30*	8.62	7.26 a (0.55) *0.68* *30*	48.32 a (3.85) *1.19* *30*	58.91 a (11.06) *0.84* *30*	4.78 b (1.25) *20.88* *18*	3.81 b (0.46) *2.06* *30*
	7	0.471 b (0.03) *2.25* *30*	9.52	7.24 a (0.76) *0.96* *30*	48.04 a (4.61) *1.78* *30*	58.25 a (8.45) *1.95* *30*	4.65 c (1.24) *23.01* *18*	3.75 c (0.54) *3.72* *30*
160 °C	3	0.461 c (0.03) *4.23* *30*	9.99	7.22 a (0.63) *1.19* *30*	47.86 a (4.96) *2.13* *30*	58.14 a (6.13) *2.14* *30*	4.51 d (1.17) *25.23* *18*	3.70 d (0.53) 4.93 30
	7	0.300 d (0.01) *37.60* *30*	10.36	7.17 a (0.72) *1.87* *30*	47.69 a (4.41) *2.49* *30*	56.08 a (6.76) *5.61* *30*	4.15 e (1.08) *31.29* *18*	3.40 e (0.68) *12.70* *30*

* Values in parentheses are standard deviations. Italic values are property reduction values in percent and number of samples used in each test. Groups with the same letters in each column indicate that there is no statistical difference ($p < 0.05$) between the samples according to Duncan's multiple range test. [R_a is average roughess, R_z is mean peak-to-valley height, and R_{max} is maximum roughness (Mummery 1993)]

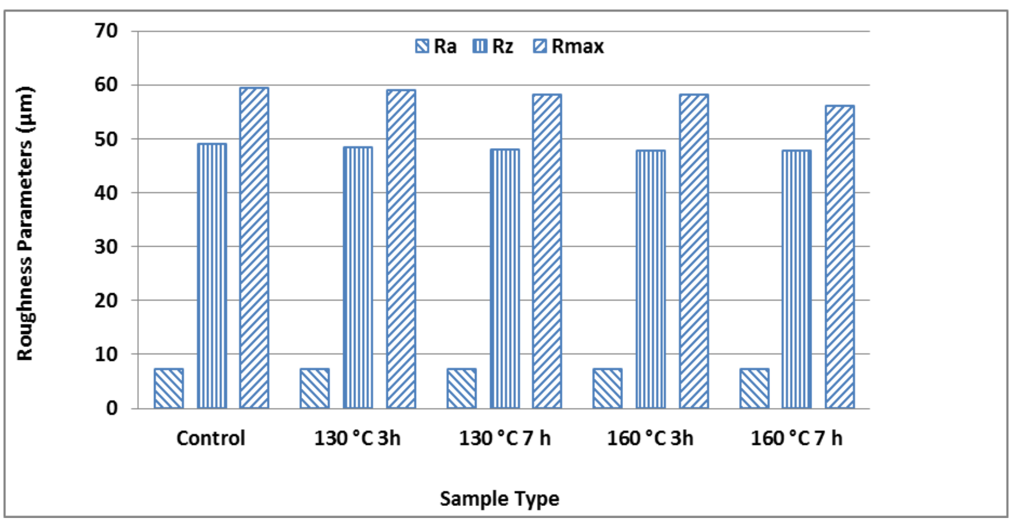

Fig. 2. Roughness values of the specimens

As can be seen from Table 1 and Fig. 3, the control specimens had the highest shear strength, 6.04 MPa, which was 31.29% higher than that of samples exposed to 160 °C for 7 h. The adverse effect of heat treatment on the mechanical properties of wood has been reported by others in various past investigations (Kasemsiri *et al.* 2012; Bakar *et al.* 2013). In one of these studies, eastern red cedar samples exposed to a temperature of 190 °C for 2 h had a 51.78% reduction in their shear strength (Kasemsiri *et al.* 2012); the reductions in shear strength were lower in this work, which could be related to the lower heat treatment temperature used. The shear strength of the specimens would possibly have been influenced more negatively if the temperature were increased. The magnitude of the temperature showed less of an impact than did exposure time on the overall mechanical properties of wood, as found in previous studies (Mitchell 1988; Korkut and Hiziroglu 2009; Priadi and Hiziroglu 2013; Bakar *et al.* 2013).

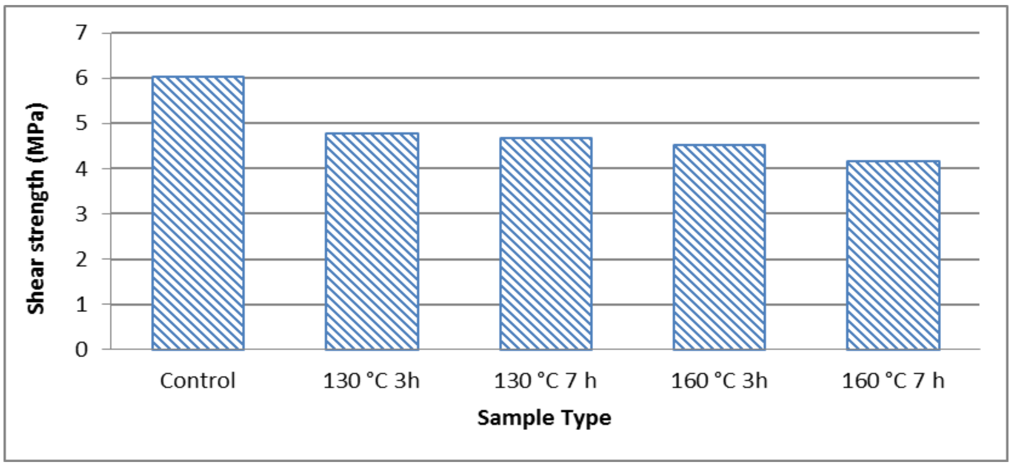

Fig. 3. Shear strength values of the specimens

Control samples had a 3.89 kN Janka hardness value. It is clear that both heat treatment temperatures and times reduced the hardness of the samples (Fig. 4).

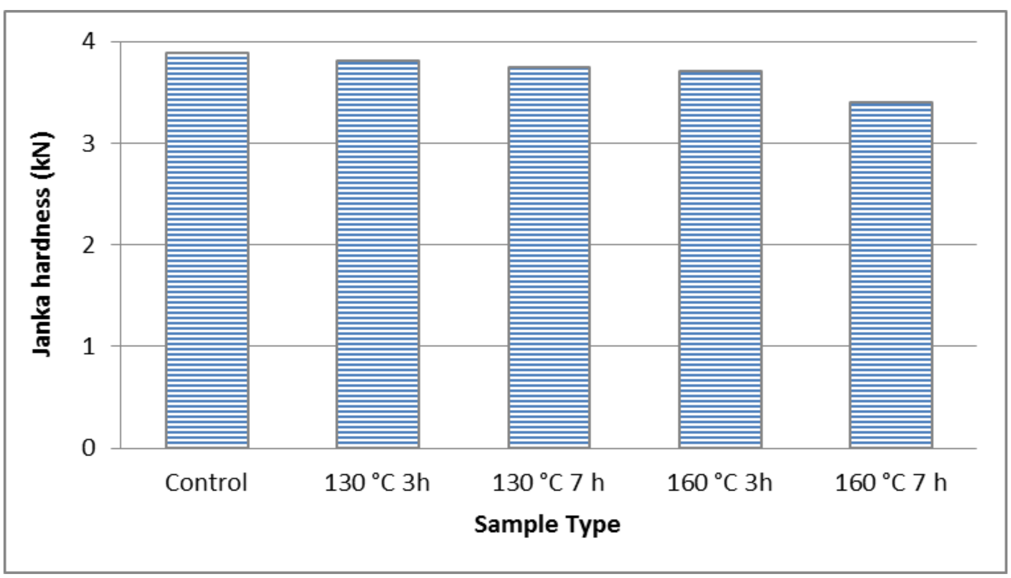

Fig. 4. Janka hardness values of the specimens

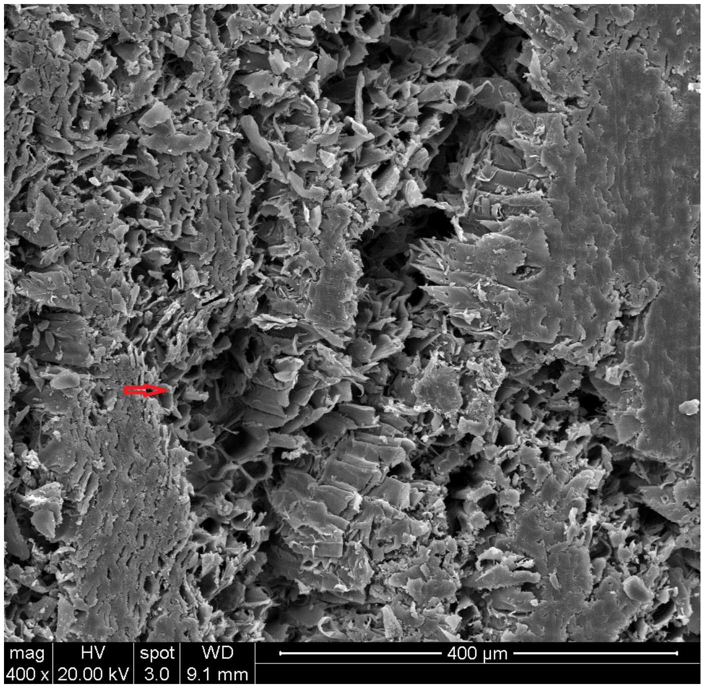

Fig. 5. Red cedar sample exposed to a temperature of 160 °C for 7 h

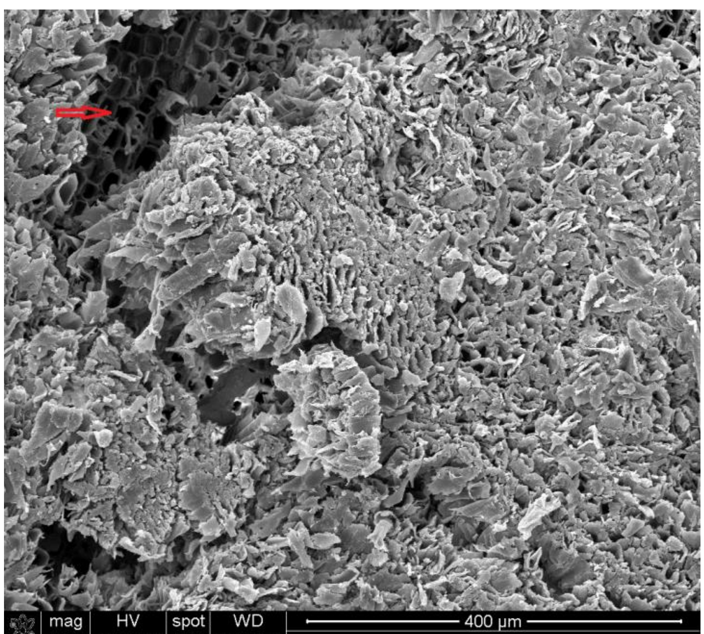

Fig. 6. Eastern red cedar control sample

Even a 3-h exposure at 160 °C reduced the samples' hardness by 4.88%; further reductions to 3.40 kN (a 12.5% reduction) were observed for a 7-h exposure at 160 °C. In a previous study, oak specimens exposed to a temperature of 200 °C for 2 h had a 42.7% reduction in their hardness values (Priadi and Hiziroglu 2013). The adverse influence of heat treatment on the hardness properties of different wood species has been discussed in various previous studies (Kocaefe *et al.* 2008; Cao *et al.* 2012; Bal and Bektaş 2013;

Priadi and Hiziroglu 2013). The negative impact of heat treatment on the strength properties of wood is directly related to the degradation of hemicelluloses (Kocaefe *et al.* 2008). It has been reported that hardness values decreased with increasing heat treatment temperature and exposure time (Gunduz *et al.* 2008), which was similar to the results of this work.

Figures 5 and 6 show micrographs taken from the cross sections of heat-treated and control specimens, respectively. It is clear that the exposure of the samples to high temperature resulted in certain damage, such as broken cell walls, as highlighted in Figure 5 with the red arrow. In a previous study, some damage of the cell wall was observed in the case of heat-treated specimens from rubberwood and red oak based on SEM analyses (Bakar *et al.* 2013). However, the cell walls of the tracheids in our work were complete and undamaged in the control samples as can be seen in Fig. 6. Such findings from the surface of heat-treated samples may be related to these samples having lower hardness values.

CONCLUSIONS

1. The oven-dry density, weight loss, surface roughness, shear strength, and hardness of eastern red cedar decreased for all treatment conditions compared to those of control samples. The lowest reductions in values of the specimens were determined for heat treatment at 130 °C for 3 h.

2. The results of this study indicated that heat treatment at 160 °C for 7 h had adverse effects on the mechanical properties of eastern red cedar. Therefore, it can be concluded that this species may not be suitable for structural applications due to reduced mechanical properties after being heat-treated at 160 °C. However, heat-treated eastern red cedar wood could be used for outdoor uses, such as house cladding, decks, garden furniture, and window frames, as well as indoor use including kitchen furniture, flooring, and decorative panels. Heat treatments having different temperature levels and time spans should be considered to investigate the effects of heat treatment on the properties of such species in further phases of this work to enable a better understanding of the behavior of such species.

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