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ORIGINAL ARTICLE

Surface quality and hardness of eastern redcedar as function of steaming

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Abstract The objective of this study was to evaluate influence of steam treatment on surface quality and hardness of eastern redcedar (*Juniperus virginiana* L.). Defect-free samples with dimensions of 40 mm by 50 mm in by 20 mm were used for the tests. Specimens were exposed to steam having a temperature of 130 °C for 1-h and 3-h periods of time. Surface roughness of the samples at initial and exposed conditions was determined using stylus type equipment across the grain orientation on tangential surface of each sample. Janka hardness of the control and treated samples was also determined on Comten testing system. Based on the findings in this work, no significance was found between surface roughness values of the specimens steamed for 1 and 3 h. However, both types of steamed specimens had higher average roughness values ranging from 52 and 60 % than those of control samples. It appears that 3-h steaming adversely influenced hardness of the samples reducing its 9 % as compared to those of control samples. Densification effect of steaming on the samples was also evaluated using scanning electron microscope (SEM) and it was determined that steaming had some crushing effect on the cell wall.

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Introduction

Modification of wood and wood-based materials using different techniques is getting more popular to improve overall quality of the final product. For example, heat treatment is one of the most commonly used modification processes to enhance properties of different wood species. Generally heat treatment does not require addition of any chemicals into the wood to change its characteristics. Heat treatment of wood has attracted substantial interest in North America having raw material with improved properties for different applications including flooring, siding, kitchen cabinets and windows. Main idea behind heat treatment is to enhance dimensional stability and change the color of the final product so that they can be used more effectively during their service life. However, mechanical properties of wood are adversely influenced as a result of heat treatment process. As it is well known the main objective of modification of properties of wood is to enhance their physical and mechanical characteristics [1–6]. In addition to heat treatment, steaming among the various methods is considered as one of the most environmentally friendly one since no chemicals or any additives involve with the process similar to heat treatment.

Steaming of wood has been used for many years to change its color, to bend the wood for different applications [7, 8]. For example, steam bending of wood is very popular to consume less material so that resource can be used efficiently. Overall steaming process depends on species, size and configuration of the place. It is suggested that overall steaming time could be set as 1 h for every

25-mm thickness of the member [9–12]. Steaming is widely applied to European beech to change its color for furniture and flooring manufacture. Some of the physical and mechanical properties of steam-treated European beech were determined by Yilgor et al. [11]. It was determined that 100-h steaming reduced compression strength and modulus of elasticity of the samples 13.3 and 16.5 %, respectively [11]. It is important to determine both hardness and surface quality of steamed wood since they are widely used for flooring [9, 13]. The hardness of steamed samples from different hardwood has been investigated in various studies [9, 13–16]. It was concluded that overall hardness of the specimens from both softwood and hardwood species reduced due to steaming. Hardness values of wood samples steamed at different conditions were also investigated employing Brinell and Janka hardness method in a previous study [9].

Eastern redcedar (*Juniperus virginiana* L.) is one of the widely distributed indigenous conifers in Oklahoma. Over four million hectares of Oklahoma lands are infested with redcedar, primarily in the eastern part of the state. However, in recent decades the trees have begun to take over the tall grass prairies and plain lands of north central and western Oklahoma. Use of low-quality eastern redcedar as a raw material in lumber manufacturing is not substantial due to its low value and irregular growth pattern. Therefore, eastern redcedar is a nuisance to farmers and ranchers who often lose crop and pasture land to the species. Many wildlife species that need open range also are affected negatively by this species [17–20]. Eastern redcedar also tends to be very aggressive in areas where naturally occurring range fires have been suppressed. Although most of western Oklahoma's eastern redcedar is of poor quality, range-grown trees are not efficient for lumber manufacturing, while some of eastern Oklahoma's forested lands produce redcedar suitable for lumber production [19–21]. Experimental panels such as particleboard from whole-tree chipped eastern redcedar were manufactured in a previous study [22, 23]. It appeared that physical and mechanical properties of the panels were comparable to the panels made from other wood species and foliage content in the panels did not reduce their properties substantially [23]. Based on the results of this study, low-quality redcedar trees had a potential as whole-tree chipped furnish for manufacturing particleboard [22].

Properties of eastern redcedar exposed to heat treatment schedules have been investigated in several studies [17, 18]. It was found that shear strength of heat-treated samples was adversely influenced by such process while their dimensional stability enhanced.

The surface quality of wood and wood-based materials plays an important role to have final products with accepted cost and customer satisfaction. Sanding and amount of finishing material used are two parameters directly related to surface quality of the raw material. Although different properties of eastern redcedar have been investigated there is only poor information on surface quality and hardness of this species as function of steam treatment. The steam is effective on the wooden surface. Therefore, the objective of this work is to evaluate eastern redcedar samples within the scope of such approach so that data from this study could possibly be employed as a quality control (glossiness, hardness, adhesion, finishing tests) tool to use eastern redcedar more efficiently in further manufacturing steps.

Materials and methods

Defect-free eastern redcedar samples with width of 40 mm, length of 50 mm and thickness of 20 mm were used for the experiments. A total of 60 specimens were conditioned in a room with temperature of 20 °C and a relative humidity of 65 % until they reach 12 % equilibrium moisture content. Next, tangential surfaces of the samples were sanded with 150 grit sand paper applying six light strokes. Including control samples, six types of samples were prepared to evaluate their surface roughness and hardness characteristics as function of steaming.

As experimental schedule displayed in Table 1, samples were exposed to steam for 1 and 3 h following natural drying in room conditions for 2 weeks as well as drying in a laboratory type kiln at a temperature of 110 °C for 1 h. Dimensions and weight of each sample

Table 1 Experimental schedule

Sample type	Experimental process	Number of sample
A	Control samples	10
B	Kiln dry	10
C	Dried after 1-h steaming	10
D	Kiln dried after 1-h steaming	10
E	Dried after 3-h steaming	10
F	Kiln dried after 3-h steaming	10

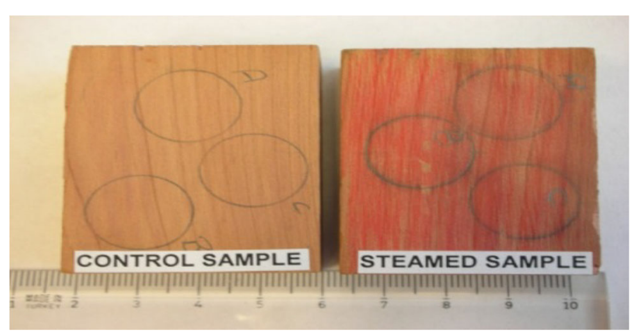


Fig. 1 Control and 3-h steamed eastern redcedar samples

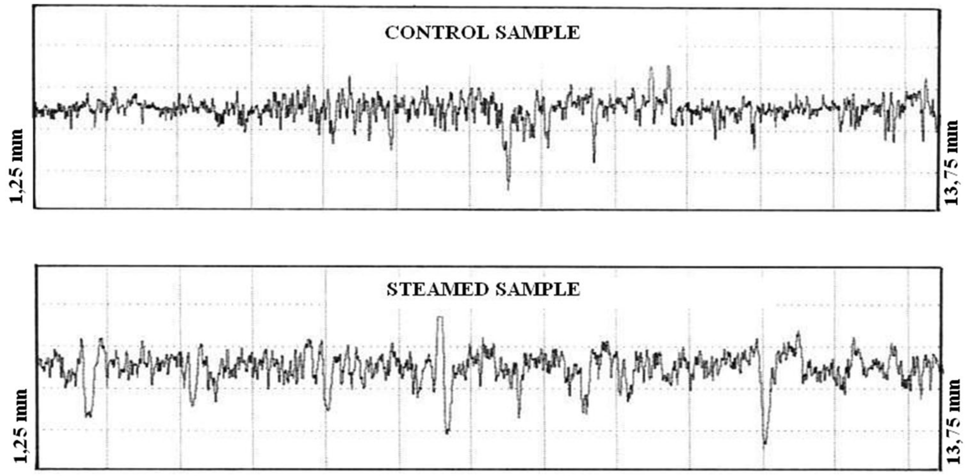


Fig. 2 Typical surface roughness profiles of the samples

were also determined at accuracy levels of 0.10 mm and 0.10 g to calculate their density. Steaming process of the samples was carried out in stainless steel container heated up to create steam with a temperature of 130 °C. Figure 1 illustrates control and steam samples. Surface quality of the samples at each exposure process along with control samples was evaluated employing a fine stylus type profilometer T-500 Hommel Unit. A total of three random measurements were taken using a tracing span of 15 mm. The stylus profilometer, Hommel T-500 Unit equipped with a Tk-300 skid type pick-up resulted in two roughness parameters, namely average roughness (R_a) and mean peak-to-valley height (R_z). Definition of above roughness parameters are described in previous studies [24, 25]. Figure 2 also depicts typical roughness profiles of control and steamed samples.

Hardness of the samples was determined using Comten Testing System equipped with a load cell having capacity of 1000 kg. Hardness of the control and treated specimens was tested by embedding a hemisphere steel having 11.2-mm diameter onto their tangential surface to the grain directions using Comten Testin Unit. Three measurements were taken from each samples and recorded in kg to evaluate their Janka hardness.

Effect of steaming on the samples was also evaluated using scanning electron microscope (SEM) Joel Model Quanta 600F. The samples with size of 5 mm by 5 mm by 5 mm were previously coated with a thin layer of gold in a vacuum chamber of sputter coater for 2 min. Micrographs were taken from the cross section of the control and steam-treated samples exposed to various experimental process schedule.

Results and discussion

Table 2 displays surface roughness and hardness values of the samples exposed to steam for two time spans. Average roughness (R_a) value of 4.65 µm was determined for the control samples. As the specimens were exposed to steam, their surface quality became slightly rougher. For example, 1-h steaming resulted in an average R_a value of 7.06 µm which is 52 % higher than that of the control samples. Overall roughness of the sample did not show any substantial change with increasing steam exposure time to 3 h as shown in Fig. 3. Such change could be related to an isotropic structure of wood along the tangential grain orientation. It appears that swelling of the samples created fine separation between the fibers resulting in rougher surface quality of the specimens. Although anatomical structure of eastern redcedar is not considered as a porous, still penetration of moisture to the surface layer of the specimens reduced their smooth surface which can be quantified by the stylus type equipment.

Table 2 Surface roughness and Janka hardness values of the samples

Sample type	Density (g/cm^3)	Roughness parameters (µm)		Janka hardness (kg)
		R_a	R_z	
A	0.482	4.65 (0.73)[a]	44.39 (5.76)	379 (39.60)
B	0.491	5.03 (0.75)	34.49 (6.74)	373 (39.40)
C	0.479	7.06 (0.76)	48.66 (6.68)	399 (34.32)
D	0.471	7.33 (0.80)	49.48 (7.01)	409 (28.59)
E	0.470	7.34 (0.68)	49.24 (7.89)	345 (30.01)
F	0.463	7.43 (0.76)	51.34 (6.79)	355 (29.56)

[a] Numbers in parentheses are standard deviation values

In a previous work, effect of steam treatment of oak on surface foot printing deformation resistance due to friction was investigated [9]. The results of above study revealed that steaming showed approximately 5 % residual deformation on the samples [9, 11]. It is well known fact that steaming plasticization would also release stress within the wood, especially on the surface layers creating rougher

Fig. 3 Average values of surface roughness parameters of the samples

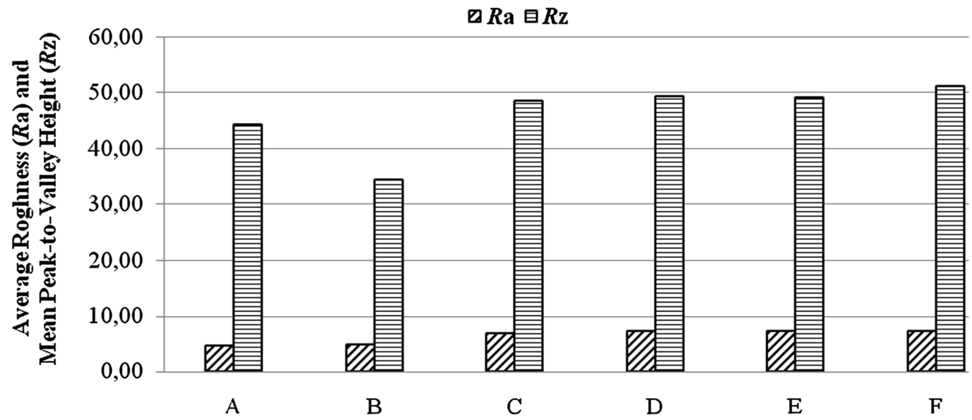
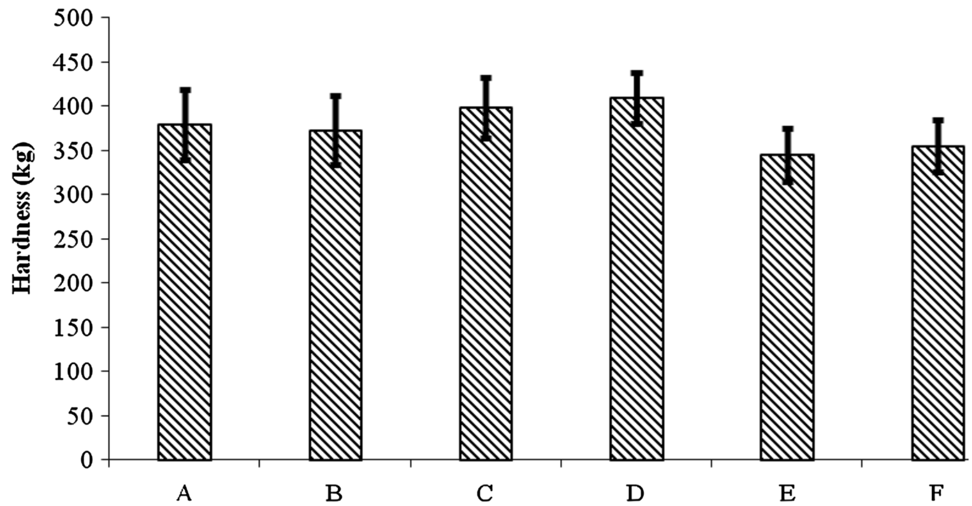


Fig. 4 Average hardness values of the samples



surface quality [26, 27]. Another study carried out in the area of drying temperature of oak veneer also revealed that samples dried at a temperature of 130 °C had higher R_a values than those of control samples [28]. Beech and an exotic species including sapela samples also had higher R_a values when they were steamed at a temperature of 108 °C. As mentioned above, raised fibers as a result of high relative humidity would be the main reason of having rougher surface quality of the samples when they are exposed to steam treatment [26].

As illustrated in Fig. 3 both R_a and R_z values of the specimens did not show any significant change with increasing steaming time. Roughness values of the dried samples in the kiln or keeping them for 2 weeks in room condition following the steaming also did not show any substantial difference from each other.

Hardness of the samples as function of steaming is illustrated in Fig. 4. Both 1-h and 3-h steaming adversely influenced hardness of the specimens. The lowest hardness value of 345 kg was determined to those samples exposed to 3-h steaming followed by drying in the kiln. This value was 9 % lower than that of control samples. Effect of steaming on oak samples was also investigated and it was found that hardness of the samples proportionally reduced as a result of steaming at temperature levels of 95 °C, 100 °C and 108 °C for time span ranging from 3 to 20 h [9]. In addition to steaming, it was also determined that thermally treated beech, ash, spruce, white oak, Scots pine species had lower hardness characteristics [26, 29]. Reduction in hardness due to steaming could be related to swelling which caused release of fibers possible damaged by stress development. Furthermore, steaming and drying could modify the properties of the cell wall making it more fragile. The decrease of hardness and roughness of steamed or heat-treated samples from different wood and wooden materials has been investigated in various studies [30–33].

Samples were cut from steamed samples for SEM analysis. Surely samples were not cut right after steaming process. They were conditioned before sample preparation for SEM. Here, it is objective to show damage and structural deformation of the cross section due to steaming.

Reduction in hardness values is also supported by micrographs taken using SEM as shown in Fig. 5. Cross section of the control sample (X) is quite clear and no

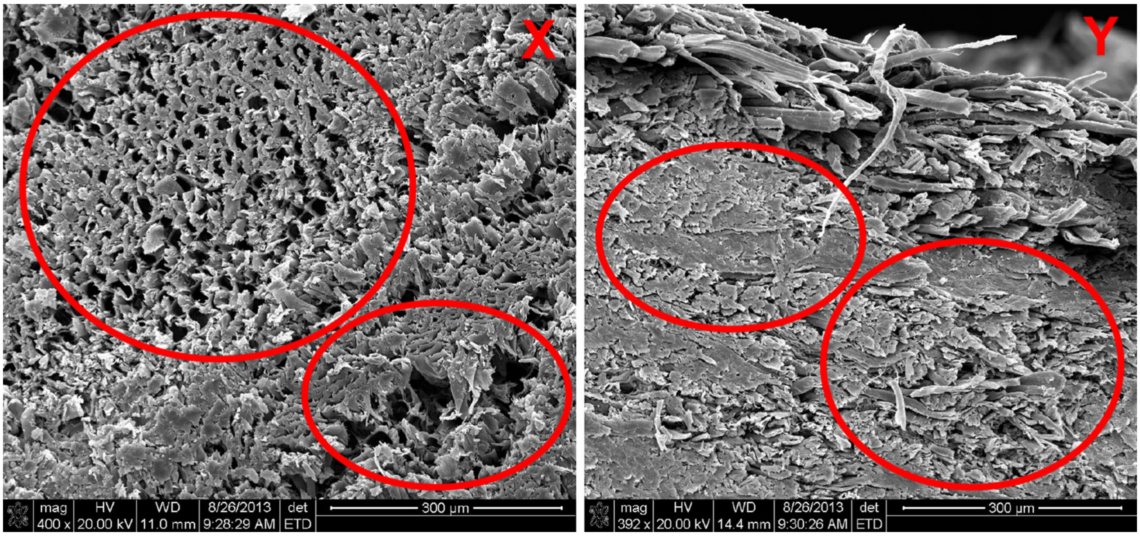


Fig. 5 Scanning electron micrographs taken from the cross section of control and steam-treated samples (*X* control sample, *Y* steamed sample)

distortion is observed in contrast to sample exposed to 3-h steaming having some densification in the center area along with torn fibers (Y).

It is known that steaming adversely influences overall structure of wood. Plasticization of the cell wall results in its deflection in the form of collapse as can be observed in Fig. 5. Although SEM micrographs illustrating typical cross section of the steamed sample may give impression of rather densification as compared to that of control sample (Fig. 5-X) it is fact that deformed cell wall would result in reduced structural characteristics. This can be related to lower hardness values of the steamed wood samples.

Conclusions

Directly affect the coating and bonding processes as surface quality and roughness, solid wood products is an important aspect that must be examined. Therefore, grated and sanded surface quality has always been one of the major concerns in wood industries. Surface quality in terms of roughness and hardness of eastern redcedar samples were tested as they were exposed to steam treatment. From the results, no substantial difference in surface roughness values of the control and steam treated samples was determined. Overall hardness of the specimens reduced as function of steam exposure time. Scanning electron micrographs taken from the cross section of the samples show the change after the treatment. In further studies, in addition to roughness and hardness evaluation of such samples, bending characteristics, bonding strength as well as compression along and across the grain orientation would be desirable to evaluate to have a better understanding of behavior of steam-treated eastern redcedar.

Conflict of interest The authors declare no conflict of interest.

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