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Effect of Thermal Compression Treatment on the Surface Hardness, Vertical Density Propile and Thickness Swelling of Eucalyptus Wood Boards by Hot-pressing*[1]

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ABSTRACT

Thermal treatment techniques are used for modifying wood and wood-based materials to improve dimensional stability and hygroscopicity. This study investigated the effects of press pressure and temperature on density, vertical density profile, thickness swelling and surface hardness of eucalyptus wood boards. The experimental wood boards were prepared from Turkish River Gum (*Eucalyptus camaldulensis* Dehn.). The surface hardness value increased with increasing press pressure in the treated groups. The application of a higher pressure at the same temperature level increased the amount of swelling of wood. It means that it is not needed for application of higher pressure to enhance the dimensional stability of wood. It is expected that it is possible to produce increased hardness, dimensional stability and durability by application of hot pressing treatment. This research showed that different press pressure and temperature values should be used to improve the performance properties of eucalyptus wood so that the end-use of the wood materials could be expanded.

Keywords : Thermal compressing, heat modification, dimensional stability, solid wood boards, spring-back phenomenon, density, *Eucalyptus camaldulensis*

1. INTRODUCTION

Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) has been grown on plantations in the Tarsus region of Mersin, Turkey. This species has some advantageous such as fast growth and low price. However, it has several undesired properties such as low dimensional sta-

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bility and several drying problems limiting its use.

Heat treatment of wood and wood composites is known to improve and control dimensional stability, durability and discoloration (Burmester, 1973; Giebeler, 1983; Yeo *et al.*, 2010). Various heat treatment procedures such as the Plato Process, Retification Process, Boise Perdure, Oil-Heat Treatment Process, and Thermowood Process are widely used in the forest products industry (Militz, 2002). Compression and temperature is generally used on wood products to improve their physical and mechanical properties. Thermally compressed wood is known as staypak (Seborg *et al.*, 1945; Stamm, 1964), while compressed wood with phenol formaldehyde (PF) resin pretreatment is called compreg (Stamm, 1964; Stamm and Haris, 1953). Further studies were done by Tarkow and Seborg (1968) studying surface densification of wood. After the 1980s, compressed wood products with lower densities from cheaper wood species were produced, especially utilizing some of the fast growing trees in Asia (Norimoto, 1993, 1994; Wang, 2000).

Compression in wood is generally considered to be analogous to hot pressing wood composites, except that it takes longer to obtain a solid wood compression set without the bonding effects of resins. Wang and Cooper (2004) studied the effects of grain orientation and surface plasticizing methods on the vertical density profiles (VDPs) of compressed balsam fir and spruce. In another study, Wang and Cooper (2005) studied the effects of the closing rate of the hot press, the initial moisture content of the wood, and the sample size on the VDPs of thermally compressed fir wood. The density distribution throughout the thickness of wood composites such as fiberboard and oriented strandboard traditionally exhibits higher surface density and lower core density. The density gradient is affected by the combined influences of pressure, MC, temperature, resin curing, and other factors during pressing and affects the physical and mechanical properties of wood composites (Wang and Winistorfer, 2000; Candan, 2007; Strickler, 1959; Kamke and Casey, 1988). Since there are differences in material properties and hot pressing parameters for wood composite production, densified solid wood boards could exhibit a different density profile. The Thermal compression process might affect drying characteristics, dimensional stability and density, and hardness and surface quality.

Esteves *et al*. (2007) utilized a steam heating process on eucalyptus wood and found that the equilibrium MC decreased by 61% and dimensional stability increased. However, mechanical properties of the material decreased. It was reported that modulus of rupture (MOR) decreased by 50% and modulus of elasticity (MOE) decreased by 15%. Unsal and Ayrilmis (2005) used a heat treatment process on eucalyptus and determined the properties of density and compression strength. It was stated that density and compression strength decreased with increasing treatment temperature and time. Unsal *et al*. (2003) studied the effect of the heat treatment process on the physical and mechanical properties of eucalyptus wood. They concluded that density, swelling and Janka hardness values decreased with an increasing duration of heat treatment and temperature.

Unsal and Candan (2008) studied the effectsof press pressure and temperature on vertical density profile, Janka hardness, and MC of pine wood boards. They found that final MC decreased while density and Janka hardness increased. Unsal *et al*. (2009) used a thermal compression technique on pine wood panels. They used a press temperature of 120°C and 150°C with a press pressure of 5 and 7 MPa. Thickness swelling values for the boards im-

Table 1. Pressing parameters for experimental groups

Groups	Pressure (bar)	Temperature (°C)	Time (h)
Control	-	-	-
A	40	130	1
B	40	150	
C	60	130	
D	60	150	

proved except for the boards pressed at 7 MPa at 150°C.

In this study, the effects of the thermal modification process using a hot-press on final MC, density, VDP, dimensional stability, and Janka hardness of eucalyptus wood boards were investigated.

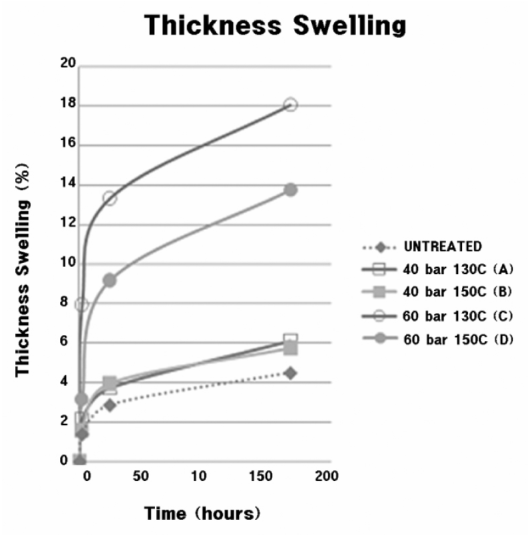

Fig. 1. Thickness swelling (TS) of hot-pressed and untreated specimens after soaking in water.

2. MATERIALS and METHODS

2.1. Material

In this study, Turkish River Gum (*Eucalyptus camaldulensis* Dehn.) wood was used. The logs were obtained from the Tarsus region of Mersin, Turkey. Experimental boards with dimensions of 250 mm by 500 mm by 16 mm were cut from the logs. Average initial MC of the samples was 16%.

2.2. Thermal Compression Process

The boards were compressed at a press temperature of either 130°C or 150°C and at a press pressure of either 4 or 6 Mpa for 1 hour in a 500 mm by 500 mm laboratory type hot press. A total of five board groups with four treatment groups (A, B, C, and D group) and a control group were investigated. Hot pressing parameters are shown in Table 1.

2.3. Testing Methods

Larger specimens with dimensions of 16 mm (thickness) by 250 mm (width) by 500 mm (length) were cut into 16 mm (thickness) by 50 mm (width) by 50 mm (length) for all tests. Radial grain wood specimens were chosen for this study. Since there were two solid wood panels in one treatment group, a total of ten boards were initially used in the five groups and five pressed boards were the end products. Density, vertical density profile, thickness swelling, and Janka hardness were evaluated in this study according to international standards. VDPs weremeasured with an X-ray density profiler (GreCon Measurement Systems, Germany) at Kastamonu Integrated Inc., a quality laboratory located in Kocaeli. The Janka hardness test was done according to ASTM D1037 (1999) standard using a universal test machine. The initial MC of the samples was measured before pressing to determine drying behavior of the panels. After the treatment, the final MC

Table 2. Thickness swelling of boards

Groups	Thickness swelling (%)		
	2 h	24 h	One week
Control	1.39	2.87	4.50
A	2.12	3.71	6.10
B	1.59	3.95	5.74
C	7.95	13.33	18.07
D	3.14	9.17	13.76

was also measured to evaluate the difference.

3. RESULTS and DISCUSSION

3.1. Thickness Swelling (TS)

After hot pressing, the thickness of the A, B, C and D boards decreased by 27.4%, 28.7%, 30.1% and 31.4% of original dimension, respectively. Decrement in thickness increased with increasing press time and temperature. 2 h, 24 h and one week thickness swelling (TS) values of the boards are illustrated in Fig. 1 and shown in Table 2. Among the treated groups, the boards pressed at 4 MPa at 150°C (group B) had the lowest thickness swelling value for both 2h and one week. The highest thickness swelling values were obtained from boards pressed at 6 MPa at 130°C (group C) with 2 h, 24 h, and one week water soaking time.

All thermally pressed panels showed higher thickness swelling values than the control group. This result might be explained by spring-back due to the boards' densification from the thermal compression process. Thickness swelling values of the treated boards increased with increasing press pressure while the values decreased with increasing press temperature. An Increase in TS values with increasing press pressure could be explained with an increasing springback effect. Improvement in TS with increasing press temperature could be explained

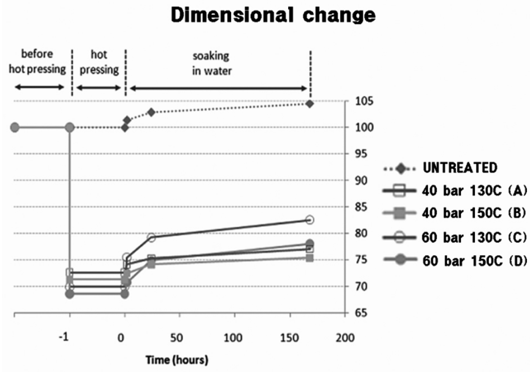

Fig. 2. Thickness of specimen in each state, before hot pressing, after hot pressing and after soaking in water.

by the changes in chemical composition of the wood. In a previous study, Unsal *et al*. (2009) obtained similar results for pine wood. They reported that thickness swelling and water absorption of thermally hot pressed boards significantly increased with increasing press pressure.

The spring-back phenomenon is greatly controlled by the pressure level, not temperature level. Higher pressure in hot press treatment causes a greater amount of spring-back. On the other hand, higher temperature causes a bigger permanent deformation. Using the above swelling graph and shrinkage data from hot pressing (27.4% (A), 28.7% (B), 30.1% (C), and 31.4% (D)), a graph can be made to predict the thickness change of the boards quantitatively as shown in Fig. 2. Fig. 2 shows the thickness of the wood in each state : before hot pressing, after hot pressing, and after soaking in water. A specimen's thickness prior to hot-press treatment was assigned as 100% of the starting dimension thickness. And each dimension of thickness after treatment can be presented by % scale. Using this % scale, thickness change of the boards with any other dimension can be predicted.

Fig. 2 shows that a higher pressure applica-

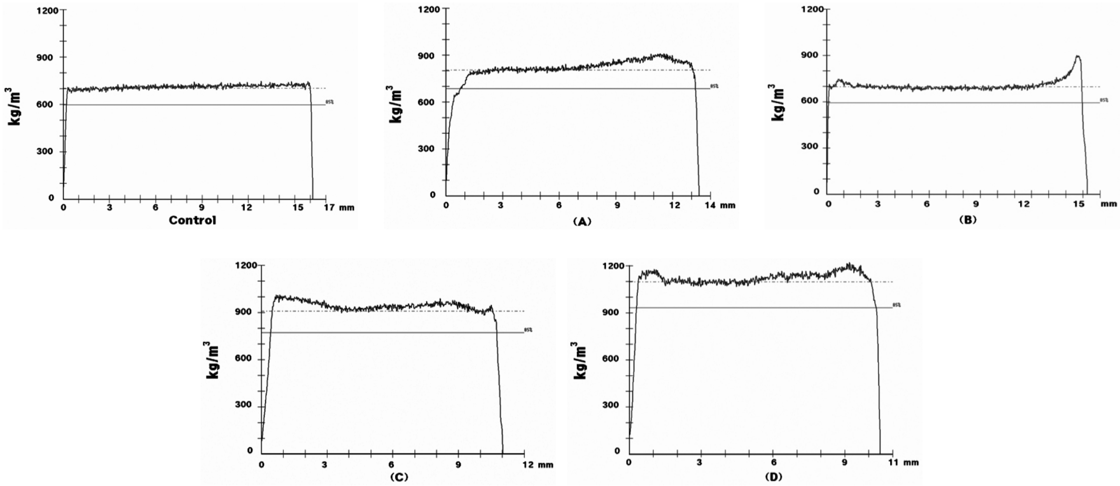

Fig. 3. Vertical density profile (VDPs) of boards.

tion at the same temperature level and a higher temperature at the same mechanical load (pressure) level in the hot press treatment cause a more decrease in thickness. Viscous and elastic deformation in the thickness decrement can't be separated based on observation of the pressing process. However, the effect of temperature on viscous deformation could be evaluated by comparing the thickness decrement in hot press treatment to the thickness swelling of boards soaked in water. Since a higher temperature application at the same pressure level decreases the amount of spring-back, most of the viscous deformation seems to occur due to the temperature effect.

Moreover, a higher pressure application at the same temperature level increases the amount of spring-back. This means that the pressure induces just recoverable deformation, elastic, and/or viscous-elastic deformation, and there are fewer thermo-chemical modifications in the wood at a higher compressed state. The greater mechanical load by a higher pressure reduces the space in lumen of the woods' cells and the distance between cellulose chains in cell wall structures. The greater mechanical load reduces the space of the lumen and the distance between cellulose chains. It seems that the reduced space in lumen and distance between cellulose chains might interrupt thermo-chemical modifications which cause permanent deformation in wood's cell wall during the hot press treatment.

3.2. Drying Characteristics

Average initial MC of the samples was 16%. At the end of the process, similar MC values were obtained. Therefore, it was concluded that the drying effect of hot pressing was not remarkable those conditions. Unsal and Candan (2008) did the thermal compression technique on pine wood panels, and they obtained significant drying effects from the process. One possible reason for the disparity between our study and Unsal and Candan study is that they used a higher press pressure and a higher initial MC. In addition, the wood species used in that study was pine which is softer than eucalyptus wood.

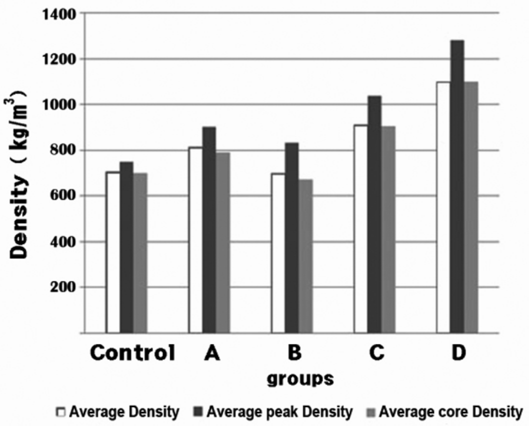

Fig. 4. Density, Peak density (PD) and core density(CD) of thermally modified wood boards.

3.3. Density and Vertical Density Profile (VDP)

The VDPs are shown in Fig. 3 and mean density values of the boards are shown in Fig. 4. Group D had the highest mean density value with 1,099 kg/m^3. Group B showed the lowest mean density value with 698 kg/m^3. Mean density values of the boards both pressed at 130°C and 150°C increased as the press pressure increased. Peak density (PD) and core density(CD) values as VDP characteristics of the boards are shown in Fig. 4. The lowest PD value (748.0 kg/m^3) was observed in the control group while the highest value (1,278.2 kg/m^3) was obtained in group D. The lowest CD value (668.9 kg/m^3) was observed in group B while the highest value (1,097.5 kg/m^3) was measured in group D. PD values of the boards significantly increased with increasing press pressure for both 130°C and 150°C. PD values of hot pressed boards were higher than the control group. Similarly, Unsal and Candan (2008) found that PD values in the pine wood panels increased with increasing press pressure.

Table 3. Janka hardness of boards

Groups	Janka hardness value (N)	Force per unit area (N/mm^2)
Control	4295	42.95
A	4011	40.11
B	3027	30.27
C	4914	49.14
D	3815	38.15

3.4. Janka Hardness

Janka hardness was evaluated for the control and all treatment groups as shown in Table 3. The lowest Janka hardness value, 3,027 N, which can be expressed to 30.27 MPa in unit of pressure with consideration of 100 mm^2 projected area of steel ball, was observed in group B while the highest value (4,914 N) was obtained in group C. When the hot press pressure increased from 4 to 6 MPa at 130°C, the hardness value increased from 4,011 to 4,914 N. Similarly, when the press pressure increased from 4 to 6 MPa, the hardness value of the boards pressed at 150°C increased from 3,027 to 3,815 N. The Increase in Janka hardness values can be attributed to an increase in density. The Janka values except for group C were lower than the control group because the brittleness of the boards increased during the hot pressing procedure.

Unsal and Candan (2008) had similar results for the pine boards. It was stated that Janka hardness values increased as press pressure increased. The hardness values were negatively affected by an increase in press temperature. This result was also similar to Unsal *et al.* (2003). They reported that Janka hardness values of eucalyptus wood significantly decreased with increasing heat treatment temperatures.

4. CONCLUSION

The thermal compression procedure did not improve thickness swelling of the boards. Moisture movement in the wood was not achieved under the treatment conditions because of a low initial MC. Mean density values of the boards increased as press pressure increased. It was concluded that the VDP in the solid wood panels was closely related with the press pressure and pressing temperature. An increase in pressure and temperature resulted in improved PD and MD values which are defining factors of VDP.

This research showed that the hardness values of Eucalyptus wood boards increased with increasing press pressure for both temperatures. Because of densification on the surface layers of the solid wood boards, hardness values were positively affected. The highest hardness value was obtained in the board pressed at a pressure of 6 MPa at 130°C.

Consequently, surface hardness of wood materials from fast growing and low quality wood species could be improved by the thermal compression procedure using a hot press. Thus, the use of these wood species might be extended. Future studies will focus on the effects of the pressing parameters on bending properties, surface roughness, and decay and termite resistance of the solid wood boards.

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