

THERMO MECHANICAL PROCESSING OF CAPPADOCIAN MAPLE (*Acer c.*)

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Abstract:

*The objective of this work was to determine effect of heat treatment and compression on some of the mechanical properties of Cappadocian maple (*Acer c.*) samples. Bending, compression and shear strength along with Brinell hardness of defect free specimens compressed using temperature levels of 120°C, 140°C, and 160°C were evaluated. Based on findings in this work densification of the samples resulted in 59%, 16%, 12%, 28% 145% and 174% increase for modulus of rupture, modulus of elasticity, shear strength, compression strength, hardness in radial and tangential grain orientations, respectively. It seems that data determined in this study would provide basic information on better utilization of Cappadocian maple. The densification process significantly increased the strength properties of specimens. The ideal temperature level was determined as 120°C for the highest bending, shear and compression strength values while the samples exposed to 160°C had the highest radial and tangential hardness values for densified samples.*

Key words: thermal densification; Cappadocian maple; technological properties; wood compression.

INTRODUCTION

Cappadocian maple (*Acer cappadocicum*) is indigenous species in Asia, mostly from ancient Cappadocia currently Turkey to southwestern China. It is a deciduous tree growing up to height of 30 m with a wide rounded top. The bark is greenish-grey, smooth in young trees, that develops slight grooves once they are mature (Rushforth 1999). Maple has wood with light color having a density of $0.644 \pm 0.05 \text{ g/cm}^3$. It is used for primary veneer and furniture manufacture. In USA and Europe, kitchen cabinets, furniture, parquet and interior doors are widely manufactured from maple wood. Grain orientation of maple wood provides aesthetic view for furniture, interior doors and parquet.

Wood densification process is explained as compression of the member by pressing with a combination of heat treatment filling the cell lumens with liquid, namely polymer, resins and other materials (Kollman *et al.* 1975; Ulker *et al.* 2012; Kamke and Sizemore 2005). It is known fact that overall mechanical properties of wood increase with increasing density. Wood densification plays more important role on properties of low density species (Morsing 2000; Ulker and Hiziroglu 2017).

Typical thermal compression wood densification takes place in five stages. These stages are softening wood cells, plastic softening of the cell wall under compression in a radial grain orientation, climatizing in a densified unit, fixation of dimensional stability and set recovery of the densified cells. Major parameters influencing properties of densified woods are species, temperature level, softening time span, pressure and densification technique (Blomberg *et al.* 2005; Bucur *et al.* 2000; Imirzi *et al.* 2014; Ulker and Burdurlu 2016; Hillis and Rozsa 1978; Kennedy 1968; Sadatnezhad *et al.* 2017).

The species, the temperature and period of softening or plasticizing, the densification method, and the compression pressure and period are also important variables affecting the strength of densified wood. Application of these variables differently can increase the strength properties of the densified wood at a rate reaching 100%. In one of the past studies mechanical properties including surface quality, adhesive bondline shear strength, hardness and color changes of the samples investigated using different temperature levels ranging from 100°C to 180°C were compressed (Ulker and Hiziroglu 2017). Based on the findings in this work surface roughness of compressed specimens decreased with increasing temperature. (Ulker and Hiziroglu 2017). Overall adhesive bondline shear strength of the samples decreased as compared to that of control specimens as a result of compression. It appears that densified samples exposed to a degree of 180°C had significantly darker surface than those of the others based on color measurement (Ulker and Hiziroglu 2017). Hydrothermal treatment of wood samples in a closed chamber was investigated in a past study (Pelit *et al.* 2016; Li *et al.* 2014). In this approach the specimens were compressed by employing heated setup in one step before they were cooled off. Such idea is relatively related to the Staypak method (Seborg *et al.* 1945; Ulker and Burdurlu 2016). Surface densification of maple specimens was also carried

out using heat and compression in a continuous belt type press by heating up surface of the sample to a temperature of 220°C (Esteves *et al.* 2017; Stamm *et al.* 1955; Santos 2000; Le Van *et al.* 1990).

Most of the properties Cappadocian maple have been investigated in previous works (Garkoti 2011; Amiri and Naghdi 2016; Abbasi *et al.* 2017). However, there is little or no information how such species behaves as a result of densification in terms of its mechanical properties.

OBJECTIVE

In this study the effect of heat treatment and compression on mechanical properties of the densified Cappadocian maple (*Acer c.*) were determined. Data from this work could be beneficial for more efficient utilization of such species for value added products with enhanced properties.

MATERIALS AND METHODS

Materials

Defect free Cappadocian maple (*Acer c.*) strips with dimension of 60 (thickness) by 80 (width) by 560 (length) mm were supplied by a local sawmill in Ankara. They were kept in a condition chamber with a temperature of 20°C and a relative humidity of 65% until they reach conditioning to equilibrium moisture content of 12%. A total of 24 samples were cut from long strips with tangential grain orientation as illustrated in Fig. 1.

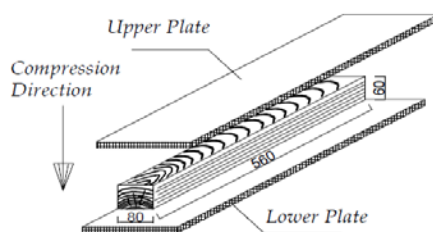


Fig. 1.

Sample size and grain orientation before densification (mm).

All surfaces of each sample were sanded sequentially with 100 and 200 grit sand paper with several light strokes so that certain irregularities were eliminated. A total of 125 samples, 25 for each temperature levels of 120°C, 140°C, 160°C and control samples were compressed along their tangential surface on a Hursan press with a capacity of 100 tons. Samples were compressed using pressure of 6.08MPa at each temperature level for 20min. Both control and compressed samples were kept in the conditioning room for several days prior to any tests were carried out.

Moisture content of the control samples were determined by measuring their initial and oven dried weight at accuracy of 0.01g after they were kept in an oven at a temperature of 103±2°C. Following equation was employed for moisture content calculation of the samples.

$$\text{Moisture Content (\%)} = [(\text{Mass when cut} - \text{oven dry mass}) / \text{Oven dry mass}] \times 100.$$

Density of each sample was also determined by weighting and measuring its dimensions at accuracy levels of 0.01g and 0.1cm, respectively.

Thermo mechanical processing of samples

The press temperature was adjusted to the target temperature levels at an accuracy of ±1°C. The samples were placed on the lower platen in a way that the pressure would be applied in a radial direction. In order to ensure heat, transfer to both sides, the upper flat surface was contacted on surfaces without applying pressure. The samples were kept until they reach the target temperature values of 120°C, 140°C, and 160°C. A 100 tons laboratory press having 60cm by 60cm platen with a maximum heating capacity of temperature of 250°C was employed for densification of the specimens as illustrated in Fig. 2 (Ulker and Burdurlu 2016).

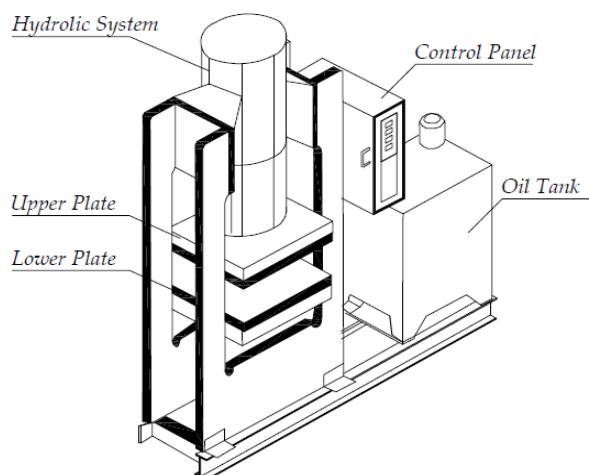


Fig. 2.
Schematics of press used for compression of the samples.

Samples were cut from the strips with the dimensions of 20mm by 20mm by 20mm for density, 30mm by 20mm by 20mm for compression strength, 50mm by 50mm by 22mm for shear strength, 360mm by 20mm by 20mm for bending strength and 30mm by 20mm by 20mm for Brinell hardness tests. They were kept in a climate chamber at a temperature of $20\pm 2^{\circ}\text{C}$ and a relative humidity of $65\%\pm 5\%$ until they reach constant weight.

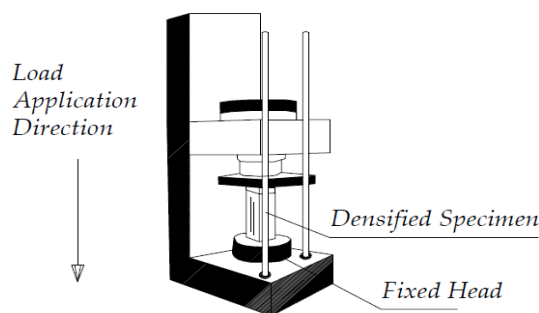


Fig. 3.
Compression strength at universal testing machine.

The specimens were subjected to an axial compressive load applied at their end until failure occurred. The load at the moment of failure was observed and recorded. The compression strength of each specimen was calculated by using the following formula;

$$S = P_{\max} / A \text{ (N / mm}^2\text{)}$$

Where, S is the compressive strength, P_{\max} is the maximum load applied to the specimen, and A is the cross-section area of the specimen. Compression strength, bending strength (MOR), bondline shear strength and Brinell hardness of the compressed specimens were evaluated based on standards TS 2595 (1976), TS 2474 (2005), TS 3459 (2012) and TS 2479 (2005), respectively.

Bending strength and modulus of elasticity (MOE) values of the specimens were determined according to the procedures described in TS 2474 (1976) standard as shown in Fig. 4. The test specimen was simply supported and applied by concentrated load. The following equations were used to calculate bending strength and modulus of elasticity of the samples.

$$\text{MOE} = PL^3 / 4 bd^3 \Delta \text{ (N / mm}^2\text{)}$$

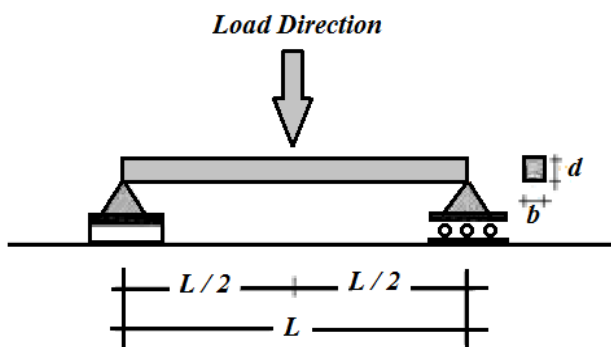


Fig. 4.
Bending strength test at universal testing machine.

$$\text{MOR} = 3 PL / 2 bd^2 \text{ (N/ mm}^2\text{)}$$

Polyvinyl acetate (PVAc) adhesive was used to bond samples in the form of pair to determine their adhesive bondline shear strength. Adhesive was applied to both surfaces of each bondline shear pair at a spread rate of 120g/m². The pair was then cold pressed using an approximately pressure of 40.8kg/cm² for 20min at room temperature before bondline shear tests were carried out. Adhesive bondline shear strength test was also carried out on a Universal testing machine unit equipped with a load cell having capacity of 1,000kg as illustrated in Fig. 5 (Ulker and Hiziroglu 2017).

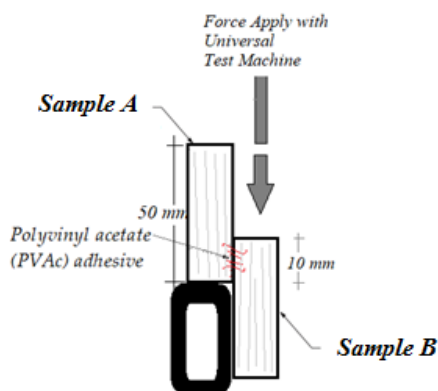


Fig. 5.
Adhesive bondline shear strength test set up.

The Brinell hardness values of the specimens were determined according to the procedures described in the TS 2479 (2005) standard. The surface of the specimen was imbedded with 10mm diameter hardened steel ball subjected to load of 5000N for 15 seconds. The diameter of the indentation left in specimen was measured with a microscope. The Brinell hardness number was calculated by dividing the load applied by the surface area of the indentation and as illustrated in Fig. 6.

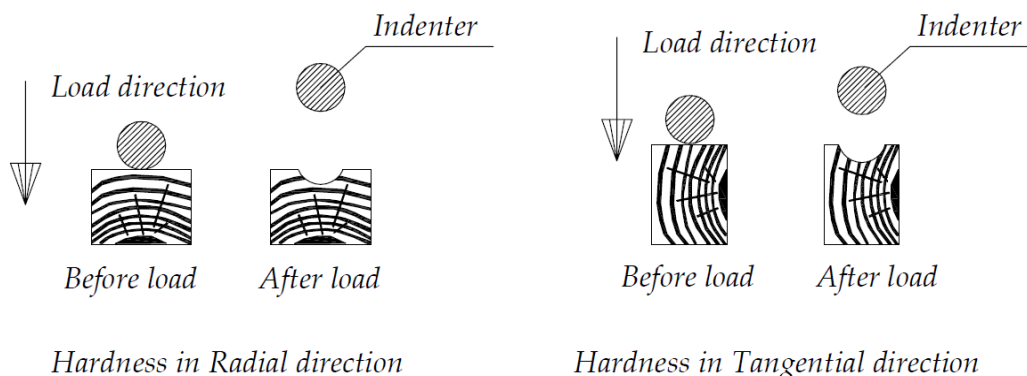


Fig. 6.
Brinell hardness measurement in radial and tangential directions.

One-way analysis of variance (one-way ANOVA) was performed to analyze the significant differences of all parameters used in this study. All results were computed by IBM Statistical Package for the Social Sciences version 21 software.

RESULTS AND DISCUSSION

Table 1 displays mechanical properties of the samples. Average density values of 0.64g/cm³ was determined for control samples. Once the samples were compressed and exposed to heat their density values increased to 0.94g/cm³. It appears that three different temperature levels did not influence overall density of the samples. Similar results were determined in a previous study which densified specimens were exposed to comparable temperature levels. It is clear that compression of the samples significantly increased their density levels. Both MOE and MOR values of the samples enhanced as a result of compression. Control samples had MOE and MOR values of 13197N/mm² and 124N/mm², respectively.

Table 1

Mechanical Properties of Densified Samples

	Statistical Value	Density (g/cm ³)	MOR (N/mm ²)	MOE (N/mm ²)	Bondline Shear Strength (N/mm ²)	Compression Strength (N/mm ²)	Hardness Radial Direction (N/mm ²)	Hardness Tangential Direction (N/mm ²)
Control	Average	0.64	124.00	13197.21	11.82	76.40	63.22	71.50
	Std. Deviation	0.02	2.29	133.47	0.45	0.62	0.85	0.30
Densified at 120°C	Average	0.89	196.07	15353.14	13.26	98.05	104.14	113.82
	Std. Deviation	0.03	2.80	262.58	0.55	0.95	1.93	1.28
Densified at 140°C	Average	0.92	194.69	14541.18	12.39	84.87	133.85	169.79
	Std. Deviation	0.02	2.55	235.44	0.47	0.41	1.31	1.45
Densified at 160°C	Average	0.94	177.93	13984.69	12.47	81.18	155.27	195.93
	Std. Deviation	0.01	1.40	553.75	0.37	0.61	3.49	2.22

Both MOE and MOR values of the samples reduced slightly with increase of the temperature from 140°C to 160°C and adversely influenced both properties of the specimens. Bondline shear strength and compression values of the samples followed the similar trend. For example, bondline shear strength value of 13.26N/mm² was determined for the densified samples exposed to 120°C heat exposure which is 12% higher than that of control samples. The analysis of variance related to the effectiveness of the temperature level applied in densification was effective on mechanical properties as displayed in Table 2.

Table 2

Analysis of Variance Related to the Effect of the Temperature Level on Density

Applied Tests	Statistical Values	Sum of Squares	Level of
Density	Between groups	0.35	0.000
MOR	Between groups	20567.36	0.000
MOE	Between groups	14874028.43	0.000
Bondline shear strength	Between groups	6.31	0.001
Compression strength	Between groups	1553.44	0.000
Hardness.in.radial	Between groups	28639.28	0.000
Hardness.in.tangential	Between groups	56232.14	0.000

All the mechanical properties of the samples considered in this work had improved when there were densified at a temperature of 120°C. Beyond this temperature level all four types mechanical characteristics declined but still higher than those of control samples. It seems that once temperature level is increased beyond that point no significance improvement was determined. The densification process was found to be effective on the density, bending strength, modulus of elasticity, shear strength, compression strength, hardness in radial direction and hardness in tangential direction of Cappadocian maple (p<0.05). Table 3 displays the homogeneity tests results related to the temperature levels that created a difference according

to the values of density, bending strength, shear strength, compression strength and hardness in radial and tangential directions of the samples.

Table 3

Comparative Test Results at Different Temperature

Tests	Densification Temperature °C	H.G.(A) N/mm ²	H.G.(B) N/mm ²	H.G.(C) N/mm ²	H.G.(D) N/mm ²
Density	Control Group	0.6383			
	120 °C		0.8950		
	140 °C		0.9200		
	160 °C		0.9400		
MOR	Control Group	123.99			
	160 °C		177.93		
	140 °C			194.69	
	120 °C			196.06	
MOE	Control Group	13197			
	160 °C		13984		
	140 °C			14541	
	120 °C				15353
Bondline Shear Strength	Control Group	11.82			
	140 °C	12.39			
	160 °C	12.46			
	120 °C		13.26		
Compression Strength	Control Group	76.39			
	160 °C		81.17		
	140 °C			84.86	
	120 °C				98.05
Hardness in Radial Direction	Control Group	63.22			
	120 °C		104.14		
	140 °C			133.85	
	160 °C				155.27
Hardness in Tangential direction	Control Group	71.50			
	120 °C		113.81		
	140 °C			169.78	
	160 °C				195.92

H.G.(A): Homogeneity Group of A, H.G.(B): Homogeneity Group of B
H.G.(C): Homogeneity Group of C, H.G.(D): Homogeneity Group of D

All mechanical properties of the samples tested in this work improved when they were densified at a temperature of 120°C. However, such properties reduced beyond above temperature exposure but they were still higher than those of control specimens. It appears that 120°C was threshold point and no significant enhancement of mechanical properties of the samples was achieved. Table 4 displays homogeneity test results ($p < 0,05$) of the densified samples and control samples exposed to three temperature levels.

Control samples had MOR value of 123.00N/mm², correspond value of 177.93N/mm² was determined for the samples densified and exposed to a temperature of 120°C as temperature increased these values also increased to 194.69N/mm² and 196.06N/mm². Compression and shear strength characteristics of the samples also had similar trend as can be seen in Table 4. Overall compression strength values of control samples increased from 76.39N/mm² to 98.05N/mm² when they were exposed to a temperature of 160°C. The highest hardness value of 195.92N/mm² was determined for the samples exposed 160°C which was 174% higher than that of control samples.

It is a known fact that chemical degradation takes place within cellular structure at certain temperature levels during the densification process (Hilis 1978; Navi and Girardet 2000). The most important degradation occurs at the temperature intervals between the 120°C to 160°C in the hemicelluloses, whereas, the beginning of degradation emerges in lignin. At these temperature intervals, the hemicelluloses with hydrolysis reactions are depolymerized into oligomers and monomers (Kollman and Cote 1984; Kutnar and

Kamke 2012). Connected to temperature and period of time, the side chain components, such as arabinose and galactose separate, and it is followed by the degradation of main components, such as mannose, glucose, and xylose (Trenard 1977; Korkut and Kocaepe 2009; Tabarsa and Chui 2001). Pentoses and hexoses are dehydrated to furfural (C₅H₄O₂) and hydroxymethylfurfural (C₆H₆O₃). Furthermore, acetic acid from the acetyl side chains of hemicellulose is separated, and the acetyl (COCH₃) content of wood is decreased. With these degradation, the degree of polymerization of hemicelluloses decreases and the secondary bonds, such as hydrogen and the Van der Waals bonds within the hemicellulose polymer, the secondary bonds between the hemicellulose and cellulose, and the covalent bonds between the hemicellulose and lignin are broken (Korkut and Kocaepe 2009; LeVan 1990). The decrease in the strength due to increase in the temperature level in densified can be explained by such concept. The improvement of the strength properties with the densification process gives the possibility of bearing a heavier load with the same sectional area of wood or bearing the same load with a thinner section in buildings. Furthermore, the enhancement of hardness of the densified samples would provide for utilization of even softwoods to be used as flooring.

CONCLUSIONS

Mechanical properties of the samples compressed using 6.08MPa pressure at three different temperature levels improved based on the findings in this work. Overall density of compressed specimens enhanced from 0.64g/cm³ to 0.94g/cm³ having a value of 46% increase. It appears that increasing temperature to a certain level during densification of the samples had positive influence on their mechanical properties. Samples compressed using a temperature of 120°C resulted in the highest bending, shear and compression strength characteristics while those were compressed at a temperature of 160°C had the highest hardness values in both radial and tangential grain orientations.

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