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THE EFFECT OF DENSIFICATION ON DENSITY AND BENDING STRENGTH OF THERMALLY TREATED BLACK POPLAR (*Populus nigra*) WOOD

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Key words

Wood material, Thermal treatment, Densification, Bending strength.

Abstract

The aim of this study was to determine the effect of thermo-mechanical densification on density and bending strength of thermal treated black poplar wood specimens. The wood specimens were thermally treated at four different temperatures (140 °C, 160 °C, 180 °C and 200 °C) for 7 and 9 hours. The specimens were then densified at 150 °C with compression ratios of 20% and 40%. Air-dry density and static bending strength tests were performed on these wood specimens. According to the results of the tests, it was observed that thermal treatments negatively affected the density and bending strength values of the specimens. Compared to control (untreated) specimens, the density and bending strength values of the specimens decreased by up to 8.2% and 37%, respectively, due to the increase in temperature and time of the thermal treatment. On the other hand, the densification process positively affected the determined properties of the wood specimens. Higher values were obtained at high compression ratio (40%). After densification, the density and bending strength values of the wood specimens increased up to 42% and 41% respectively. According to the results, it may be suggested to apply a densification process in order to increase the density and strength in thermal treated specimens.

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1. INTRODUCTION

Thermal treatment is a physical process based on treatment of (fresh or conditioned) wood at relatively high temperatures in a kiln or vessel without the use of chemicals. The industrial processes are carried out at temperatures between 180 and 240 °C under different conditions, either steam, vacuum, nitrogen or oil to create an oxygen-low atmosphere, in order to prevent the material from burning during the treatment. Although thermal modification is a physical process, it causes chemical changes of the main wood components, cellulose, hemicelluloses and lignin, which affect the hygroscopicity, dimensional stability, diffusibility and permeability of wood (Boonsra 2016). Thermal treatments are considered as a nonbiocidal alternative to wood preservatives against wood rotting fungi for applications in hazard classes 2 and 3 (Herrera-Díaz et al. 2019). As a result of the high temperatures applied to the wood during the thermal treatment, some permanent changes or degradation occurs in the structure of the chemical compounds of wood (Tjeerdsma and Militz 2005; Yang et al. 2007; Kocaefe et al. 2008; Tümen et al. 2010). The biological resistance and dimensional stability increases in the thermally treated wood gained new properties (Kamdem et al. 2002; Lekounougou and Kocaefe 2014; Yalçın and Şahin 2015; Kaygın et al. 2009; Cai et al. 2013; Kocaefe et al. 2015). In addition, the wood color can be changed homogeneously to darker tones (Gündüz et al. 2010; Toker et al. 2016; Pelit 2017). In constrast, as a result of thermal degradation of wood components, the brittleness of thermally treated wood increases and most of the mechanical strength properties are reduced (Bekhta and Niemz 2003; Boonstra et al. 2007; Korkut et al. 2008; Perçin and Altınok 2017). Thus, thermally modified wood is not suitable for structural applications or where high mechanical solicitations are required (Kamdem et al. 2002).

With the densification processes, the density of wood species with relatively low densities can be increased. Thus, it is possible to obtain a higher specific strength than that of most structural metals and alloys. These properties make densified wood a cost-effective, lightweight and high-performance alternative (Song et al. 2018). The main purpose of the densification is to increase the hardness, abrasion resistance and mechanical strength properties of the wood. After mechanical densification, the density of wood can theoretically be increased to a value close to that of the cell wall, about 1500 kg/m^3, and thereby achieve considerable improvements in strength properties (Báder et al. 2018). Many of the previous studies have reported significant increases in the strength properties of mechanically densified wood (Navi and Girardet 2000; Welzbacher et al. 2008; Pelit et al. 2018; Şenol 2018; Song et al. 2018). The main issue associated with mechanically densified wood is the fixation of the compressed thickness. Mechanically densified wood tends to return to its original dimensions prior to compression when exposed to water or heat (Navi and Heger 2004; Laine et al. 2013).

The aim of this study is to determine the effect of mechanically post-densification on the density and bending strength properties of thermally pre-treated black poplar (*Populus nigra*) wood. It is thought that the reduced strength properties as a result of the thermal treatment can be increased by the densification process.

2. METHODS AND MATERIALS

WOOD MATERIAL

In this study, black poplar (*Populus nigra*) wood were used. The black poplar was supplied as round wood from a lumber yard in the Istanbul city in Turkey. Round wood was cut from the sapwood with an band sawing machine in accordance with the study methodology. Attention was paid to ensure that no rot, knot, crack, density difference were present in the specimens. Sapwood planks were subjected to natural drying to approximately 12% moisture content, and then cut with a tolerance of 15-20% from the draft dimensions of the specimens to be used for densification.

THERMAL TREATMENT OF WOOD SIPECIMENS

Thermal treatment was carried out in a laboratory type oven and at atmospheric pressure. The specimens placed in the oven were first stored at 103 ± 2 °C until they became fully-dry (approximately 30-36 h). The specimens were then thermally treated separately at target temperatures (140 °C, 160 °C, 180 °C and 200 °C) for 7 and 9 h. The total duration of thermal treatment for each group was 40-47 hours. After thermal treatment, specimens remained in a conditioning cabin (RH 65 ± 3% and 20 ± 2 °C) until they reached a stable weight, and then cut to the dimensions of 320 × 20 mm (longitudinal direction × tangential direction) and thicknesses 20 (for non-compressed specimens), 25 and 33.3 mm (radial direction).

DENSIFICATION PROCESS

Thermally treated wood specimens were densified using special metal molds in a hydraulic test press. The densification was carried out at 150 °C with a compression ratio of 20% and 40%. Channels 10 mm in depth and 20 mm wide were opened in the metal molds used for densification. The specimens placed in the channels were pre-heated in hot press for 20 minutes. Afterwards, the compression of the wood specimens was performed in the radial direction with a loading speed of 60 mm / min. In order to achieve the targeted wood thickness (20 mm), the load was applied until the metal molds contacted each other (Figure 1).

Figure 1. Densification of specimens by using metal molds

The compressed specimens were kept under pressure for 10 min and then were removed from the press together with the molds and cooled to room temperature under an average pressure of 0.5 MPa in order to minimize the spring-back effect. After the densification process, specimens remained in a conditioning cabin (RH 65 ± 3% and 20 ± 2 °C) until they reached a stable weight according to TS 2471 (1976). The test specimens were prepared in a number sufficient to accommodate ten repetitions (n = 10) for each variable.

DETERMINATION OF DENSITY AND BENDING STRENGTH

Air-dry density of the wood specimens was determined according to TS 2472 (1976). The mass of each specimen (M) was measured on an analytical balance, with a sensitivity of ±0.01 g. Dimensions (length, width, thickness) were measured with a vernier caliper having ± 0.01 mm sensitivity, and volumes (V) were determined. The air-dry density (δ) was calculated using Eq. 1.

$$\delta\ (\text{g/cm}^3) = M / V \quad (1)$$

Bending strength (or modulus of rupture) (MOR) of the specimens were determined according to TS 2474 (1976). The MOR values were calculated using Eq. 2.

$$MOR\ (\text{N/mm}^2) = 3P_{max}L / 2bd^2 \quad (2)$$

Where P_{max} is the maximum load when the specimen is broken (N), L is the supporting span (mm), b is the width of the specimens (mm), and d is the thickness of the specimens (mm).

STATISTICAL ANALYSES

Analysis of variance (ANOVA) tests were performed to determine the effect of thermal treatment and densification on density and bending strength of poplar wood at the 0.05 significance level. Significant differences between the variables were compared using Duncan's test.

3. RESULTS AND DISCUSSION

ANOVA results of density and bending strength measurements from specimens thermally pre-treated and compressed are given in Table 1. The results show that the effect of thermal treatment and compression ratio factors on the density and bending strength of poplar wood was statistically significant ($P \leq 0.05$). Mono comparison results of the Duncan's test conducted for the factors of thermal treatment and compression ratio are shown in Table 2.

Table 1. ANOVA results for density and bending strength of thermally pre-treated and compressed poplar specimens

Tests	Factors	Degrees of freedom	Sum of squares	Mean square	F-value	$P \leq 0.05$
Density	Thermal treatment (A)	8	0.038	0.005	6.3076	0.0000*
	Compression ratio (B)	2	1.291	0.646	859.8993	0.0000*
	Interaction (AB)	16	0.005	0.000	0.4025	ns
	Error	243	0.182	0.001		
	Total	269	1.516			
Bending strength	Thermal treatment (A)	8	27854.176	3481.772	91.2130	0.0000*
	Compression ratio (B)	2	25094.833	12547.416	328.7083	0.0000*
	Interaction (AB)	16	1914.521	119.658	3.1347	0.0001*
	Error	243	9275.769	38.172		
	Total	269	64139.299			

*Significant at 95% confidence level, ns: Not significant

Table 2. Duncan's test results for mean values of density and bending strength

Factor	Density (g/cm^3)		Bending strength (N/mm^2)	
	Mean	SG	Mean	SG
Thermal treatment				
Untreated	0.488	a	78.39	a
140 °C – 7 h	0.480	ab	77.55	ab
140 °C – 9 h	0.475	ab	77.31	ab
160 °C – 7 h	0.478	ab	75.80	ab
160 °C – 9 h	0.475	ab	74.63	b
180 °C – 7 h	0.471	b	67.82	c
180 °C – 9 h	0.466	bc	63.17	d
200 °C – 7 h	0.454	cd	54.53	e
200 °C – 9 h	0.448	d	49.61	f
Compression ratio				
Non compressed	0.395	c	57.60	c
20%	0.455	b	67.54	b
40%	0.562	a	81.12	a

SG: statistical group (different letters denote a significant difference)

With respect to thermal treatment conditions, the highest density and bending strength average was found in untreated specimens and the lowest was determined in thermally treated specimens for 9 h at 200 ºC (Table 2). In both control and compressed specimens, the density value was generally reduced with an increase in thermal treatment temperature and duration (Figure 2). The air-dry density value of thermally treated specimens at 200 °C for 9 h decreased by 8% compared to untreated specimens. It can be said that the decrease in the equilibrium moisture content (EMC) of the specimens and the mass losses in the specimens were effective on the decreases in density after thermal treatment. In previous studies, it was reported that due to changes in the chemical structure of thermally treated wood, it is less hygroscopic and consequently reduces EMC (Aydemir et al. 2011; Esteves ve Pereira 2009). In addition, the destruction of the main components of wood (especially hemicellulose) and the evaporation of the extractives cause mass losses in the thermally treated wood (Hakkou et al. 2005; Esteves et al. 2008).

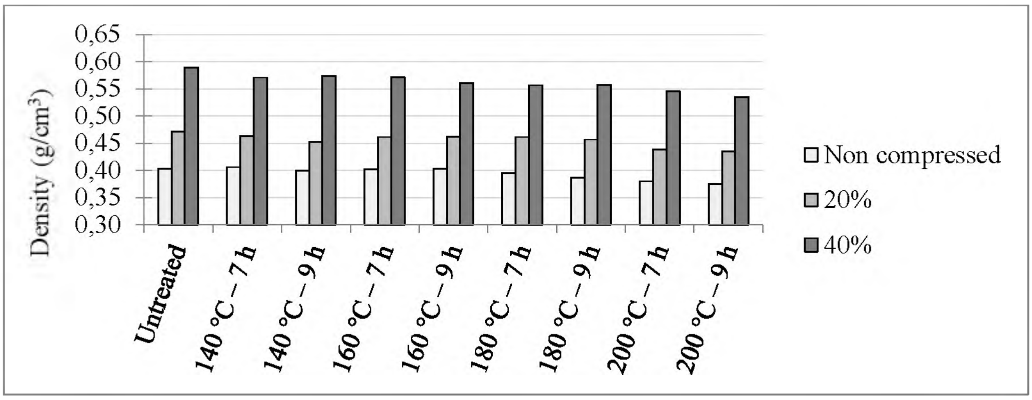

Figure 2. Comparisons of the density values in the poplar specimens

The bending strength increased slightly in the non-compressed specimens thermally treated at 140 °C and 160 °C. However, in all other specimens with thermal pre-treatment (compressed and non-compressed), the bending strength gradually decreased due to the increase in thermal treatment temperature and duration (Figure 3). According to untreated specimens, the bending strength of thermally treated poplar specimens at 200 °C for 9 h were decreased by 37%. It is thought that the possible degradation in the structure of the chemical components of the wood specimens after the thermal treatment (especially at high temperature) is effective on the results (Tjeerdsma and Militz 2005; Yang *et al.* 2007; Kocaefe et al., 2008; Tumen *et al.* 2010; Aydemir *et al.* 2011).

Regarding compression ratio, the highest density and bending strength average was found to be in the specimens 40% compressed, while the lowest was determined in the non-compressed specimens (Table 2). The density values determined in both untreated and thermally treated specimens were in parallel with the compression ratios and higher density values were obtained at high compression ratio (40%). After densification, the density value of untreated poplar specimens increased by 46%, and the density value of specimens with thermal treatment at 200 °C for 9 h increased by 43% (Figure 2). The increases in density can be explained by a decrease in the void volume of wood as a result of compression and an increase in the cell wall amount per unit volume (Ülker *et al.* 2012; Pelit *et al.* 2018).

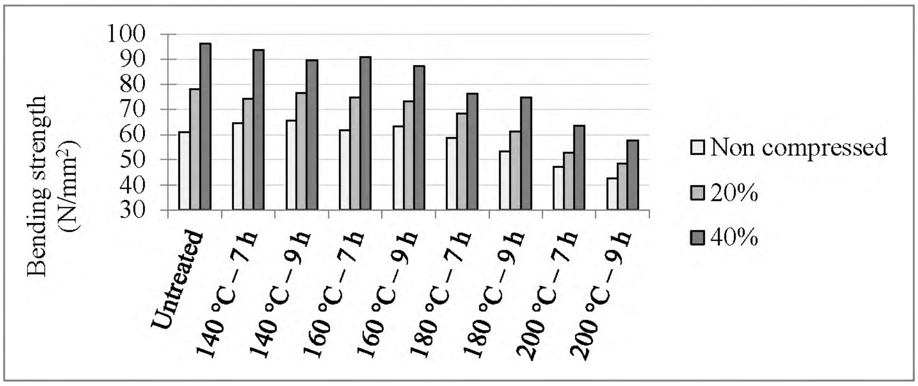

Figure 3. Comparisons of the bending strength in the poplar specimens

As shown in Figure 3, bending strength of the all poplar specimens (untreated and thermally treated) increased depending on the compression ratio after densification. The higher bending strength was obtained at high compression ratio (40%). This situation can be explained by the amount of density increase in the specimens depending on the compression ratio. It is well known that most of the mechanical strength properties of wood are closely related to the density of wood. Similar results have been reported in previous studies on wood densification (Tabarsa and Chui 1997; Kutnar *et al.* 2008; Pelit *et al.* 2018). Compared with non-compressed specimens, the bending strength increased by 41% in the compressed specimens with the ratio of 40%.

4. CONCLUSIONS

In this study, the effects of mechanical densification on the density and bending strength of thermally pre-treated poplar wood were investigated. Density and bending strength decreased in thermally pre-treated specimens (compressed and non-compressed) depending on increase in process temperature and duration. According to untreated specimens, the density and bending strength values of wood specimens thermally pre-treated at 200 ºC for 9 decreased by 8% and 37%, respectively.

After the densification, the density and bending strength of the wood specimens increased due to the increase in the compression ratio. Compared with non-compressed specimens, the density and bending strength increased up to 46% and 41% in the specimens compressed at 40% ratio. The reductions in bending strength of poplar specimens due to thermal treatment were tolerated after mechanical densification.

References

Aydemir D., Gündüz G., Altuntaş E., Ertas M., Şahin H. T., Alma M. H. (2011): Investigating changes in the chemical constituents and dimensional stability of heat-treated hornbeam and Uludağ fir wood. BioResources 6(2): 1308-1321.

Báder M., Bak M., Németh R., Rousek R., Horníček S., Dömény J., Klímek P., Rademacher P., Kudela J., Sandberg D., Neyses B., et al. (2018): Wood densification processing for newly engineered materials. In 5th International Conference on Processing Technologies for the Forest and Bio-based Products Industries (PTF BPI 2018), pp. 255-263.

Bekhta P., Niemz, P. (2003): Effect of high temperature on the change in color, dimensional stability and mechanical properties of spruce wood. Holzforschung 57(5): 539-546.

Boonstra M. J. (2016): Dimensional stabilization of wood and wood composites. Lignocellulosic fibers and wood handbook. Wiley, Hoboken, pp. 629-655.

Boonstra M. J., Van Acker J., Tjeerdsma B. F., Kegel E. V. (2007): Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. Annals of Forest Science 64(7): 679-690.

Cai J., Yang X., Cai L., Shi S. Q. (2013): Impact of the combination of densification and thermal modification on dimensional stability and hardness of poplar lumber. Drying Technology 31(10): 1107-1113.

Esteves B., Pereira, H. M. (2009): Wood modification by heat treatment: A review. BioResources 4(1): 370-404.

Esteves B., Graca J., Pereira, H. (2008): Extractive composition and summative chemical analysis of thermally treated eucalypt wood. Holzforschung 62(3): 344-351.

Hakkou M., Pétrissans M., Zoulalian A., Gérardin P. (2005): Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polymer Degradation and Stability 89(1): 1-5.

Herrera-Díaz R., Sepúlveda-Villarroel V., Torres-Mella J., Salvo-Sepúlveda L., Llano-Ponte R., Salinas-Lira C., ... & Ananías, R. A. (2019): Influence of the wood quality and treatment temperature on the physical and mechanical properties of thermally modified radiata pine. European Journal of Wood and Wood Products 77:661-671.

Kamdem D. P., Pizzi A., Jermannaud A. (2002): Durability of heat-treated wood. Holz als Roh -und Werkstoff 60(1): 1-6.

Kaygın B., Gündüz G., Aydemir D. (2009): Some physical properties of heat-treated paulownia (Paulownia elongata) wood. Drying Technology 27(1): 89-93.

Kocaefe D., Huang X., Kocaefe Y. (2015): Dimensional stabilization of wood. Current Forestry Reports 1(3): 151-161.

Kocaefe D., Poncsak S., Boluk Y. (2008): Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. BioResources 3(2): 517-537.

Korkut S., Kök M. S., Korkut D. S., Gürleyen T. (2008): The effects of heat treatment on technological properties in red-bud maple (Acer trautvetteri Medw.) wood. Bioresource Technology 99(6): 1538-1543.

Kutnar A., Kamke F. A., Sernek M. (2008): The mechanical properties of densified VTC wood relevant for structural composites. Holz als Roh-und Werkstoff 66(6): 439-446.

Laine K., Rautkari L., Hughes M., Kutnar A. (2013): Reducing the set-recovery of surface densified solid Scots pine wood by hydrothermal post-treatment. European Journal of Wood and Wood Products 71(1): 17-23.

Lekounougou S., Kocaefe D. (2014): Durability of thermally modified Pinus banksiana (Jack pine) wood against brown and white rot fungi. International Wood Products Journal 5(2): 92-97.

Navi P., Girardet F. (2000): Effects of thermo-hydro-mechanical treatment on the structure and properties of wood. Holzforschung 54(3): 287-293.

Navi P., Heger F. (2004): Combined densification and thermo-hydro-mechanical processing of wood. MRS Bulletin 29(5): 332-336.

Pelit H. (2017): The effect of different wood varnishes on surface color properties of heat-treated wood materials. Journal of the Faculty of Forestry Istanbul University 67(2): 262-274.

Pelit H., Budakçı M., Sönmez A. (2018): Density and some mechanical properties of densified and heat post-treated Uludağ fir, linden and black poplar woods. European Journal of Wood and Wood Products 76(1): 79-87.
Perçin O., Altınok M. (2017): Some physical and mechanical properties of laminated veneer lumber reinforced with carbon fiber using heat-treated beech veneer. European Journal of Wood and Wood Products 75(2): 193-201.
Song J., Chen C., Zhu S., Zhu M., Dai J., Ray U., Li Y., Kuang Y., Li Y., Quispe N., et al. (2018): Processing bulk natural wood into a high-performance structural material. Nature 554: 224-228.
Şenol S. (2018): Determination of physical, mechanical and technological properties of some wood materials treated with thermo-vibro-mechanical (TVM) process. Ph.D. Thesis, Duzce University, Düzce, Turkey.
Tabarsa T., Chui Y. H. (1997): Effects of hot pressing on properties of white spruce. Forest Products Journal 47(5): 71-76.
Tjeerdsma B., Militz H. (2005): Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood. Holz als Roh- und Werkstoff 63(2): 102-111.
Toker H., Baysal E., Kötekli M., Türkoğlu T. T., Kart S., Şen T. F., Peker H. (2016): Surface characteristics of oriental beech and scots pine woods heat-treated above 200 °C. Wood Research 61(1): 43-54.
TS 2471, (1976): Determination of moisture content for physical and mechanical tests in wood. Turkish Standards Institute, Ankara, Turkey.
TS 2472, (1976): Determination of density for physical and mechanical tests in wood. Turkish Standards Institution, Ankara, Turkey.
TS 2474, (1976): Wood-Determination of ultimate strength in static bending. Turkish Standards Institution, Ankara, Turkey.
Tümen İ., Aydemir D., Gündüz G., Üner B., Çetin H. (2010). Changes in the chemical structure of thermally treated wood: BioResources 5(3): 1936-1944.
Ülker O., İmirzi Ö., Burdurlu E. (2012): The effect of densification temperature on some physical and mechanical properties of Scots pine (Pinus sylvestris L.). BioResources 7(4): 5581-5592.
Welzbacher C. R., Wehsener J., Rapp A. O., Haller P. (2008): Thermo-mechanical densification combined with thermal modification of Norway spruce (Picea abies Karst) in industrial scale - Dimensional stability and durability aspects. Holz als Roh - und Werkstoff 66(1): 39-49.
Yalçın M., Şahin H. İ. (2015): Changes in the chemical structure and decay resistance of heat-treated narrow-leaved ash wood. Maderas. Ciencia y tecnología 17(2): 435-446.
Yang H., Yan R., Chen H., Lee H. D., Zheng C. (2007): Characteristics of hemicelluloses, cellulose and lignin pyrolysis. Fuel 86(12): 1781-1788.

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