

ROUGHNESS AND COLOUR PROPERTIES OF THERMALLY COMPRESSED POPLAR WOOD MATERIALS

Zeki CANDAN

Istanbul University-Cerrahpasa, Faculty of Forestry, Forest Products Engineering Department
34473, Sariyer, Istanbul, Turkey
Tel: 0090 212 3382400 - 25356, Fax: 0090 212 3382424, E-mail: zekic@istanbul.edu.tr

Oner UNSAL

Istanbul University-Cerrahpasa, Faculty of Forestry, Forest Products Engineering Department
34473, Sariyer, Istanbul, Turkey
Tel: 0090 212 3382400 - 25363, Fax: 0090 212 3382424, E-mail: volkan.gorgun@istanbul.edu.tr

Hızır Volkan GORGUN

Istanbul University-Cerrahpasa, Faculty of Forestry, Forest Products Engineering Department
34473, Sariyer, Istanbul, Turkey
Tel: 0090 212 3382400 - 25360, Fax: 0090 212 3382424, E-mail: volkan.gorgun@istanbul.edu.tr

Oktay GONULTAS

Bursa Technical University, Faculty of Forestry, Forest Products Engineering Department
Mimar Sinan Campus, Yildirim, 16310, Bursa, Turkey
Tel: 0090 224 3003571, Fax: 0090 224 3003429, E-mail: oktay.gonultas@btu.edu.tr

Abstract:

*The aim of this study was finding out the effect of the thermal compression process on the roughness and color properties of Poplar (*Populus* spp.) solid wood as a fast-growing species. The clear samples were thermally compressed along 45min. with four combinations of different pressure (1 and 2 MPa) and temperature (150°C and 170°C) values. Each group and untreated samples were compared to each other.*

*Roughness properties were determined at both parallel and perpendicular to grain with a profile-meter. Color properties were measured according to the CIE L*a*b system by using a spectrophotometer.*

The results showed that surface roughness results changed significantly with thermal compression. Especially pressure had an important effect that all values in all directions. On the other hand, the temperature didn't affect the roughness of samples at the same pressure levels. When the color values were evaluated; the treatment changed the wood appearance at high levels and the samples became darker after treatments.

The results of this research showed that thermal compression method which is used generally for surface densification to increase fast-growing species, significantly changed of some roughness and color properties of Poplar wood with especially at the 170°C and 2 MPa parameters.

Key words: thermal compression; fast-growing species; poplar; color; surface roughness.

INTRODUCTION

Although wood is a renewable material, increasing demand due to increasing population and awareness to positive features of this material caused pressure to forests. Several tree species can be characterized as mid or slow-grown to meet the demand. Therefore industrial plantation forests were usually established with fast-grown species such as Pine, Eucalyptus etc. In these plantations, yield rather than timber quality is the primary consideration for species choice and management methods. However, the fast rate of growth results in wide growth rings, producing low-density timber (Hill 2006). Low-density is an undesirable character especially where mechanical properties are preferred.

A fast-grown species Poplar is a "hardwood" which has various usage area as a "softwood" with low density, hardness etc. values. It was reported that many Italian Renaissance painters such as Leonard da Vinci painted on wooden panels which were often made of *Populus alba* (WD 2019). On the other hand, being not durable to fungi and poorly permeable, low mechanical properties, very soft surface with low density are not desirable. These disadvantages limit the usage area of this fast-grown species. Generally, wood has many positive material properties and also similar as other products, it has some disadvantages. However, the disadvantages of this material can be described as "ameliorative" properties which can be realized with modification methods.

The wood modification methods become varied from basically chemical reaction and/or impregnation, thermal treatment with studies day by day. Good results of the studies lead up commercialization such as impregnation, acetylation, oil and/or thermal modification etc. (Donath et al. 2004; Wang and Cooper 2005;

Esteves and Pereira 2008; Çetin et al. 2011). In these studies, methods are generally focused on improving whole material or surface properties. In surface modification methods, chemical reactions with foreign matters are usually used as Compreg (Stamm and Seborg 1960). However, some thermal compression methods as Staypak (Seborg et al. 1945) which is generally used for densification, can change surface properties and can be categorized whole material modification method without foreign matter.

Thermal compression is about plasticizing of components of wood material particularly lignin. As a result of the process, a surface which is contacting part of material changes its characteristics. After relatively high press and temperature, the higher surface density is obtained due to squeezing of the components. Other surface properties can vary according to wood species, material and process conditions. In studies with Poplar, hardness increased (Candan et al. 2013), non-uniform deformation distribution in the growth rings (Dogu et al. 2015), similar wearing resistance (Gong et al. 2010), crystallinity index increased and became darker (Ucuncu et al. 2017) for surface evaluation with thermal compression were obtained.

The aim of this study was evaluating roughness and color change of the thermally compressed Poplar samples surfaces with two pressure and two temperature levels combinations.

MATERIAL, METHOD, EQUIPMENT

Wood material and thermal compression method

Clear (without defect) Poplar (*Populus* spp.) samples with 25 x 100 x 500 mm dimensions were used. Thermal compression process was performed with a small-sized temperature and pressure controlled the hot press. Totally five groups including control (untreated samples) were generated. Ten samples were used for each treatment group, while nine samples were used for the control group. The treatment parameters were shown in Table 1.

Table 1

Thermal Compression Parameters of Samples

Group	Treatment Parameters		
	Temperature (°C)	Pressure (MPa)	Duration (min)
Control	-	-	-
A	150	1	45
B	150	2	45
C	170	1	45
D	170	2	45

Surface Roughness

The surface roughness values were measured with a stylus type profile-meter device (Mitutoyo SJ-301). Arithmetical average roughness (Ra), maximum height (Ry), ten-spot average roughness (Rz) and root-mean-square deviation (Rq) were measured according to JIS B 0601 (2001) standard. The tests were made both parallel (//) and perpendicular (⊥) to the grain direction of each sample.

Color Change

The color values were measured with a spectrophotometer equipped with an integrating sphere according to the CIE L*a*b* system (Minolta CM-2600d) (Fig. 1.).



Fig. 1.
Surface Roughness
Test Device (Mitutoyo 2002)



Fig. 2.
Portable Spectrophotometer
CM-2600d - (Konica Minolta 2018)

Total color change (ΔE^*) was calculated using the difference L*, a* and b* values of compared groups each sample (Equation 1) (In the equation, each “ Δ ” indicates the difference of each parameter). The magnitude of ΔE^* results was classified according to the grading rules reported by Cividini et al. (2007). It can be seen in Table 2.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

Table 2

Grading Parameters of total color change (ΔE^*) (Cividini et al. 2007)

ΔE^* value	Observation	Change Level
$0.2 > \Delta E^*$	Not visible difference	0
$0.2 < \Delta E^* < 2$	Small difference	1
$2 < \Delta E^* < 3$	Color difference visible with high quality screen	2
$3 < \Delta E^* < 6$	Color difference visible with medium quality screen	3
$6 < \Delta E^* < 12$	High color difference	4
$\Delta E^* > 12$	Different colors	5

Additionally, brightness (R457 nm) according to the ISO 2470 standard, while whiteness and yellowness according to ASTM E313 standard, whiteness and yellowness according to ASTM E313 standard were determined. Also, thermally compressed samples were compared with untreated samples for finding out getting lighter (positive values of ΔL^*) or darker (negative values of ΔL^*) after treatment.

RESULTS AND DISCUSSION

Surface Roughness

The effect of thermal compress conditions to the surface roughness both parallel and perpendicular to grain were investigated. The results were shown in Table 3.

Table 3

Effect of different conditions on surface roughness values*

Temperature (°C)	Pressure (bar)	Ra (μm)		Ry (μm)		Rz (μm)		Rq (μm)	
		//	⊥	//	⊥	//	⊥	//	⊥
Control		6,45 ^b (1,17)	7,29 ^a (1,25)	54,19 ^b (10,05)	72,74 ^b (10,34)	40,55 ^c (7,37)	56,01 ^b (9,31)	8,80 ^b (1,84)	10,13 ^a (1,57)
150	1	3,22 ^a (1,12)	4,45 ^b (1,41)	30,97 ^a (8,82)	49,78 ^a (12,22)	21,99 ^b (6,40)	39,37 ^a (10,49)	4,38 ^a (1,39)	6,30 ^b (1,99)
150	2	5,88 ^b (1,62)	6,87 ^b (2,31)	51,80 ^b (16,79)	66,40 ^b (16,93)	37,84 ^c (10,14)	53,85 ^b (15,11)	8,19 ^b (2,30)	9,59 ^b (3,18)
170	1	3,96 ^a (1,46)	6,29 ^b (2,11)	41,47 ^{ab} (17,98)	61,36 ^{ab} (14,09)	26,62 ^{ab} (10,36)	49,47 ^{ab} (11,65)	5,65 ^a (2,27)	8,87 ^b (2,70)
170	2	5,49 ^b (1,58)	6,42 ^b (1,72)	51,41 ^b (16,18)	68,89 ^b (13,27)	34,12 ^{bc} (8,57)	53,16 ^b (12,59)	7,64 ^b (2,08)	9,10 ^b (2,40)

* The same letter on the numbers shows that there are no difference homogeneity groups in each column ($p < 0.05$).

As seen in Table 3, some groups were statistically significantly ($p < 0,05$) different. Especially pressure had a significant effect that all values on all directions (except Ra - ⊥) were different. It can be clearly summarized that when the pressure level increased at these temperatures, the Poplar could have a rougher surface. Moreover, the temperature didn't affect the roughness of samples at the same pressure levels. The result shows that the effect of pressure change can't be explained with temperature, melting or crush of compounds. Nevertheless, this result could occur by the reason of heterogeneous spring back after treatment. Because the measurements didn't realize immediately after treatment.

When the treatment effect with comparing untreated group was investigated, a significant difference can't be commented clearly. Only Rq - ⊥ values of control samples were statistically different from all treated groups.

Colour Changes

The color values of each group were presented in Table 4.

Table 4

*Effect of different conditions on color values***

Temperature (°C)	Pressure (MPa)	L*	a*	b*	Whiteness	Brightness	Yellowness
Control		83,32 (2,11) ^c	3,43 (0,67) ^a	17,52 (0,25) ^a	60,95 (3,94) ^c	45,14 (3,17) ^c	37,48 (0,96) ^a
150	1	75,56 (3,75) ^b	5,67 (0,93) ^b	20,35 (1,77) ^b	49,38 (5,93) ^b	33,60 (4,56) ^b	47,23 (3,85) ^b
	2	73,91 (3,87) ^{ab}	5,81 (0,69) ^b	21,66 (0,91) ^{bc}	46,78 (5,92) ^{ab}	30,71 (4,25) ^{ab}	50,50 (2,26) ^b
170	1	72,72 (6,01) ^{ab}	6,84 (2,12) ^{bc}	21,81 (2,69) ^{bc}	45,25 (8,96) ^{ab}	30,10 (7,50) ^{ab}	52,65 (9,43) ^{bc}
	2	68,56 (5,21) ^a	7,86 (1,42) ^c	23,13 (2,20) ^c	39,11 (7,40) ^a	24,25 (6,60) ^a	58,31 (8,06) ^c

**Mean (standard deviation) and the same letter on the numbers show that there are no difference homogeneity groups in each column (p<0.05).

As seen in Table 4, treatment significantly changed all color parameters of Poplar wood samples. When the temperature effect was analyzed, all parameters were changing. However, the changes stood out with pressure, especially at 170°C & 2 MPa.

In thermal based modification methods, it can be said that darkening characterized change about appearance. Therefore the lightness changes (ΔL^*) of treated groups according to the control group was evaluated (Fig 1.).

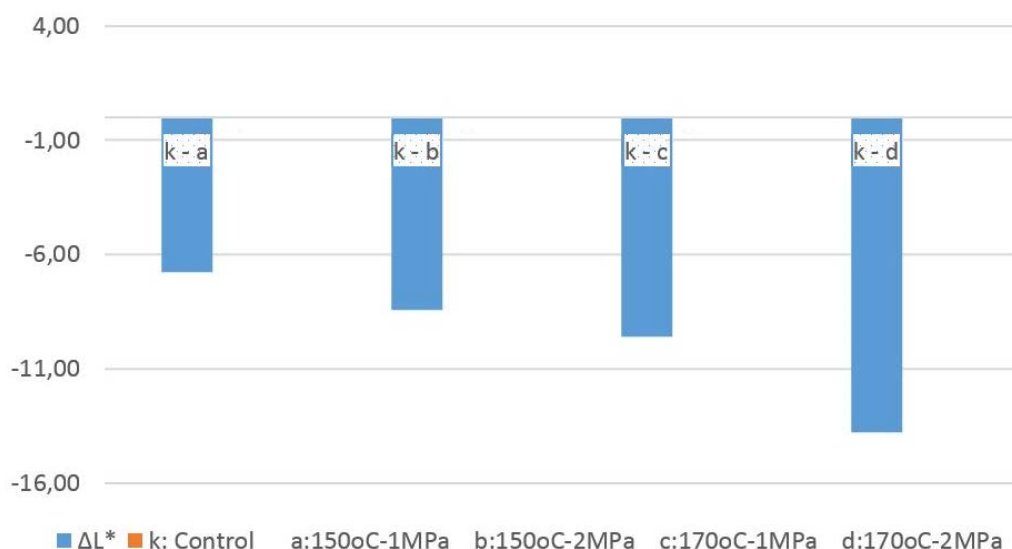
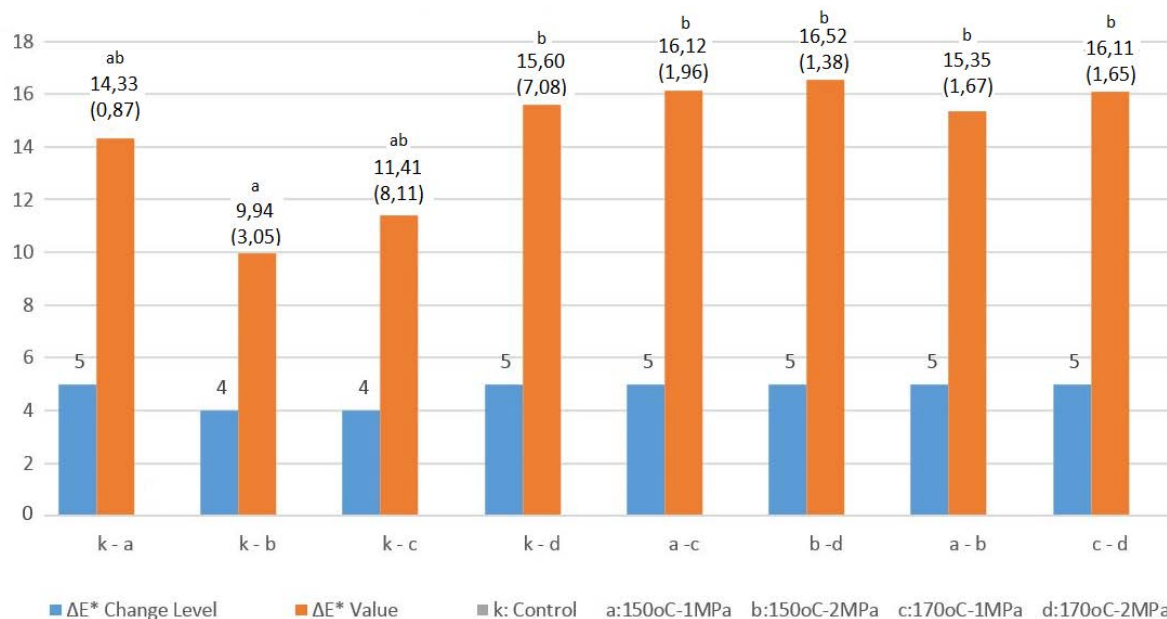


Fig. 1.
Brightness change (ΔL^*) values.

As seen in Fig. 1., the samples got dark after treatment. The darkening increased when the treatment conditions increased. Result of getting darker is similar to thermal modification method. However, the temperature is the most important factor for darkening in that method. Addition of pressure affects more darkening. Lightness results were similarly found with the study of Ucuncu et al. (2017).

Each group including control were compared and the color change values (ΔE^*) and change levels according to Cividini et al. (2007) were presented in Fig 2.



**Mean (standard deviation) and the same letter on the numbers show that there are no difference homogeneity groups in each column ($p < 0.05$).

Fig. 2.
Total color change (ΔE^*) according to each treatment condition.**

As seen in Fig. 5., similar results to Fig. 4. were obtained. Only between untreated and treated at 170°C & 2 MPa samples had a significant difference. However, all treatment conditions had significant differences between each other. Total color change results were similarly found with the study of Ucuncu et al. (2017).

On the other hand, the classification of Cividini et al. (2007) evaluated samples that there were "High color difference" (4/5) and "Different colors" (5/5). When the study of Ucuncu et al. (2017) was investigated, results showed that 3/5 treatment groups were found higher than 12 for total color change value. If photographs in the study were evaluated visually, it can be evaluated that only two groups changed their color. Another grade values according to some characteristics such as wood species, evaluation surface (radial, tangential) etc. can be added for tangible comparisons. Because it is a subjective classification, the comments of results can change per researcher with these parameters.

CONCLUSIONS

The results showed that surface roughness results changed significantly with thermal compression at these process conditions. Especially pressure had an important effect that all values in all directions. On the other hand, the temperature didn't affect the roughness of samples at the same pressure levels. When the color values were evaluated; the treatment changed the wood appearance at high levels and the samples became darker after treatments.

The results of this research showed that thermally compressed method which is used generally for surface densification to increase fast-growing species, significantly changed of some roughness and color properties of Poplar wood with especially at the 170°C and 2 MPa parameters.

REFERENCES

- Candan Z, Korkut S, Unsal O (2013) Thermally compressed Poplar wood (TCW): Physical and mechanical properties. *Drvna industrija*, 64(2):107-111.
- Cividini R, Travan L, Allegretti O (2007) White beech: A tricky problem in drying process. *Proceedings of 7th ISCHP (International Scientific Conference on Hardwood Processing)*, Quebec City, Canada. 135-140.
- Çetin NS, Özmen N, Birinci E (2011) Acetylation of wood with various catalysts. *Journal of Wood Chemistry and technology*, 31(2):142-153.
- Dogu DA, Bakir D, Tirak Hizal K, Tuncer DF, Candan Z, Unsal O (2015) Anatomical structures of thermally compressed poplar (*Populus spp.*) wood. *PRO LIGNO*, 11(4).

Donath S, Militz H, Mai C (2004) Wood modification with alkoxysilanes, Wood Science and Technology, 38 (7): 555-566, <https://doi.org/10.1007/s00226-004-0257-1>

Esteves B, Pereira H (2008) Wood modification by heat treatment: A review. BioResources, 4(1):370-404.

Gong M, Lamason C, Li L (2010) Interactive effect of surface densification and post-heat-treatment on aspen wood. Journal of Materials Processing Technology, 210(2):293-296.

Hill CAS (2006) Wood Modification: Chemical, Thermal and Other Processes, John Wiley & Sons, Ltd. ISBN: 0-470-02172-1.

Konica Minolta (2018) Portable Spectrophotometer CM-2600d, <https://www5.konicaminolta.eu/en/measuring-instruments/products/colour-measurement/spectrophotometers-portable/cm-2600d-cm-2500d/introduction.html>

Mitutoyo (2002) surface roughness tester, Mitutoyo Surftest SJ-301, Product no. 99MBB035A 1. Series No. 178, Mitutoyo Corporation, 20-1, Sakado 1-chome, Takatsu-ku, Kawasaki, Kanagawa 213-0012, Japan

Stamm AJ, Seborg RM (1960) Forest Products Laboratory resin-treated, laminated, compressed wood (compreg).

Ucuncu T, Durmaz E, Kaymakci A (2017) Characteristics of Hot-compressed Poplar Wood Boards. BioResources, 12(4):9038-9049.

Wang JY, Cooper PA (2005) Effect of oil type, temperature and time on moisture properties of hot oil-treated wood. Holz als Roh-und Werkstoff, 63(6):417-422.

WD (2019) White Poplar, The Wood Databases, <https://www.wood-database.com/white-poplar/>