Effect of Densification Temperature and Some Surfacing Techniques on the Surface Roughness of Densified Scots Pine (*Pinus sylvestris* L.)

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The effects of densification temperature, planing, circular sawing, and sanding on the surface roughness of densified Scots pine using the open-system thermodynamic method were studied. Densification was applied to Scots pine at 6 MPa pressure and at temperatures of 120 °C, 140 °C, and 160 °C. A total of 1040 specimens (160 × 50 × 10 mm) were prepared using the surfacing techniques of planing, circular sawing, and sanding. The surface roughness of the specimens were measured in conformance with the TS 2495, EN ISO 3274, and the TS 6212 EN ISO 4288 standards, and the results were subjected to statistical analysis. The surface roughness of the planed surfaces was 26% lower, of the surfaces cut circularly was 38% lower, and of the sanded surfaces was 32% lower in densified Scots pine compared to undensified Scots pine. According to the densification temperature, while the lowest roughness was obtained in the densified specimens at 140 °C, raising the temperature to 160 °C increased the roughness. An increase in the number of blades in planing, the tooth number in circular sawing, and the grit number in planing decreased the surface roughness. Furthermore, the roughness was less in tangential surfaces compared to radial surfaces.

Keywords: Wood densification; Surface roughness; Scots pine; Physical properties

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INTRODUCTION

Different cutting techniques are used to transform end products made of wooden materials, such as interior and exterior place decoration elements, building elements, and ships. The resulting surface quality after a cutting process (cutting, planing, lathing, or sanding) changes according to the factors given below (Kollmann and Cote 1984; Sandak and Negri 2005; Sandak *et al.* 2008; Taylor *et al.* 1999):

1. Characteristics of the materials (species, anatomical structure, grain figure, density/ porosity, humidity, early/late wood, heartwood/sapwood, defects and abnormalities, and biological deterioration);
2. Characteristics of the machine (design, vibration, and maintenance);
3. Characteristics of the cutter (geometry, wear, quality of sharpening, joining of cutting knives, and stiffness of the tool holder);
4. Variables related to machining of the materials (cutting direction, cutting speed, feed speed, and strength of the positioning of work piece);
5. Surfacing techniques (circular sawing, planing, shaping, lathing, and sanding);

6. Special processes (heat treatment, chemical impregnation, densification, and drying)

In the processing of wood with cutters, hardwoods produce smoother surfaces compared to softwoods due to the decrease in the volume of cavities. Similarly, the level of roughness decreases in summer wood compared to spring wood. The roughness is less in the cut surfaces parallel to the fibers compared to the cut surfaces perpendicular to the fibers (Iskra and Hernández 2009; Kamata and Kanauchi 1994), and is less in the tangential cut surfaces compared to the radial cut surfaces. Cross grain negatively affects roughness. As the moisture content changes, the roughness changes and an increase in moisture content also increases roughness (Wilkowski *et al.* 2010). The blade fixing element or vibration in the machine negatively affects roughness. An increase in the number of blades and high quality grinding decrease roughness. On the other hand, the dulling/abrasion of blades increases roughness (Hernández and de Moura 2002). Covering the blades with substances that prevent abrasion has been found to decrease roughness (Pinkowski *et al.* 2011). Increasing the cutting speed (Keturakis and Juodeikiene 2007; Magoss 2008) and feeding in a direction parallel to turning decreases roughness (Aguilera and Martin 2001; Sogutlu and Togay 2011), whereas, increasing the feeding speed and cutting depth increases roughness (Skaljic *et al.* 2009; Wilkowski *et al.* 2010; Kilic and Demirci 2003). Increasing the cutting speed accelerates the abrasion of the blades, and with the passage of time this increases roughness (Ratnasingam *et al.* 2008). Increasing or decreasing cutting depth does not significantly affect roughness (Hernández and Cool 2008; Iskra and Hernández 2009). In addition to the structural specifications of the wood material in the sanding process, the grain size and the type of abrasive mineral are important for roughness. As the grain size of the sandpaper increases, the roughness also increases. Silicon carbide abrasive mineral, rather than aluminum oxide abrasive mineral, decreases the roughness (Dereli 1997; Taylor *et al.* 1999). Regarding cutting with a circular saw, planing, and sanding processes, the surface roughness changes according to the tooth number and geometry of the circular saw, the number of blades in planning, and the grit number in sanding. A lower roughness level is obtained with an increase in the number of blades in the planing process compared to other techniques (Burdurlu *et al.* 2005; Kilic *et al.* 2006; Burdurlu *et al.* 2007).

In addition to the structural features of the wood material in the sanding process, the grain size and the type of abrasive mineral are important for roughness. As the grain size of the sandpaper increases, the roughness also increases. Using silicon carbide instead of aluminum oxide as an abrasive mineral decreases the roughness (Dereli 1997; Taylor *et al.* 1999). During cutting with a circular saw, planing, and sanding processes, the surface roughness changes according to the tooth number and geometry of the circular saw, the number of blades in planing, and the grit number in sanding. A lower level of roughness is obtained with an increase in the number of blades in the planing process (Burdurlu *et al.* 2005; Kilic *et al.* 2006; Burdurlu *et al.* 2007).

The densification process in wood consists of compression by pressing heated wood, filling the cell lumens with a liquid material (polymer, melted natural resins, sulfur, melted metal, *etc.*) in an impregnation process, or a combination of these two processes (Kollmann *et al.* 1975; Kultikova 1999; Kutnar and Sernek 2007). The densification under high pressure by heating wood decreases the cavity volume and increases density, and a change is observed in the structural characteristics. As a result of this modification, all the physical and mechanical characteristics and the processing characteristics of wood become different. The species of wood, the temperature and period of softening or plasticizing, the densification method (thermo-mechanical, thermo-hydro-mechanical, or viscoelastic thermal compression), and the compression pressure and period are the most important variables that influence the strength of wood after densification. Application of these variables in a different manner can increase the strength properties of the densified wood materials at a rate reaching 100% (Seborg *et al.* 1945; Stamm *et al.* 1955; Kennedy 1968; Kunesh 1968; Trenard 1977; Hillis and Rozsa 1978; Bucur *et al.* 2000; Morsing 2000; Santos 2000; Navi and Girardet 2000; Lenth and Kamke 2001; Reiterer and Stanzl-Tschegg 2001; Tabarsa and Chui 2001; Blomberg *et al.* 2005; Kamke and Sizemore 2005; Kutnar and Sernek 2007; Kocaefe *et al.* 2008a; Kocaefe *et al.* 2008b; Korkut and Kocaefe 2009; Kutnar and Kamke 2012).

The springback effect is one of the most important problems associated with the densification process of wood. When densified wood is exposed to moisture, reversible or irreversible swelling occurs. Reversible swelling is due to the hydroscopic nature of wood, whereas irreversible swelling is due to the springback of densified wood. Irreversible swelling or springback can be reduced by minimizing the build-up of internal stresses that build up in compressing. Permanent fixation of deformation can be achieved by steaming the wood after or prior to compression treatment or heating the compressed wood to high temperature levels (Morsing 2000; Santos 2000; Reynolds 2004; Kutnar and Sernek 2007).

Despite the fact that there have been many studies related to the surfacing characteristics of undensified wood, there are insufficient studies related to the surfacing of densified wood. This study aimed to determine the effects of densification and densification temperature as well as some variables, such as planing, circular sawing, and sanding with different blades, number of revolutions/minute, and cutting direction, on surface roughness in densified Scots pine at a pressure of 6 MPa using the open system thermodynamic method and at temperatures of 120 °C, 140 °C, and 160 °C.

EXPERIMENTAL

Materials

Scots pine

In order to determine the effect of the temperature level applied in the thermo-mechanical densification on surface roughness, Scots pine (*Pinus sylvestris* L.) was selected as a wood species due to its relatively low density, as well as its being one of the most widely distributed conifers in the world, with widespread use in the wood products industry.

Scots pine wood was procured from the Siteler district in Ankara, Turkey. Particular importance was placed on selecting lumber that was of high quality, undamaged, and naturally colored. The selected lumber had annual rings that were regular and parallel to each other, did not include defects, and had not been subjected to attack by insects or fungi.

Densification press

A 100-ton HURSAN laboratory press was used with a capacity to heat up to a temperature of 250 °C. The press was equipped with a plate surface of 60 × 60 cm^2 for the densification of the Scots pine using the open system thermomechanical method. The pressure and temperature of plates and stocks could be controlled and monitored automatically.

Preparation of the stocks for the densification process

The process given below was followed to prepare the test stocks that were used in the densification process:

1. The lumber was stacked and kept in a manner suitable for air-drying in a ventilated environment with a central heating system that did not receive direct sunlight.
2. Stocks were cut from the lumber in dimensions of 560 × 80 × 60 mm (length × width × thickness) in order to conform to the measurements specified in the standards for the tests that would be conducted. The stocks were stacked and left to dry naturally.
3. The stocks were machined to the finished dimensions of 550 × 70 × 50 mm (length × width × thickness) via circular sawing and planing processes.
4. The stocks were kept in an acclimatization chamber at a temperature of 20 ± 2 °C and a relative humidity of 65% ± 5% until they reached equilibrium weight at a 12% air-dried moisture level.
5. The stocks were wrapped with plastic sheets to prevent changes in moisture content that could occur prior to the densification process.

Densification

The following process was applied for the densification of Scots pine using the open system thermomechanical method:

1. The press was operated and the thermostats were adjusted so that the platens reached the temperatures of 120 °C, 140 °C, and 160 °C with a sensitivity of ±5 °C.
2. The stocks were placed on the lower platen in a manner such that the pressure would be applied in a radial direction. Furthermore, to check if the internal temperature of the stocks had reached the planned temperature, three temperature control stocks with thermometers were placed so they would reach both sides and the middle of the lower platen of the press. The thermometers were in the middle and side parts of the stocks.
3. To ensure heat transfer to both sides, the upper flat surface was placed in contact with the stock surfaces without applying pressure.
4. The stocks were kept in the press until they reached internal temperatures of 120 °C, 140 °C, and 160 °C. The internal temperature of the stocks was monitored from the temperature control stocks with a thermometer.
5. The pressure gauge of the press was adjusted to 6 MPa, providing a densification ratio of 50%. The stocks were densified by being compressed with a 3 m/min loading speed under automatic control. The thickness of the stocks was decreased from 50 mm to 25 mm in the radial direction after the densification process.
6. The press was kept closed for 10 min to prevent an increase in the volume of the stocks due to the spring effect. A residence time of 10 min after densification was the best time for achieving the lowest spring effect and was determined in preliminary tests.
7. The stocks were removed from the press and kept in a closed environment for a period of 10 days.
8. Steam or heat treatment was not applied to the stocks after densification process.
9. The average moisture content of the stocks was determined according to standard TS 2471 ISO 3130 (1976). It was 4%.

Preparation of the specimens for the surface roughness measurement

The process given below was followed in the preparation of the test specimens that would be used in the roughness measurements:

The densified stocks were kept in an acclimatization chamber at a temperature of 20±2 ºC and a relative humidity of 65%±5% until they reached unchanged masses in order for them to reach a 12% air-dried moisture content. The stocks were wrapped with plastic sheets after the acclimatization to prevent a change in moisture content that could occur prior to the surfacing processes.

Table 1 shows the measurements and numbers of the specimens prepared to be used in the determination of the surface roughness connected to the different variables of densified Scots pine on which the planing, circular sawing, and sanding processes were applied. The general principles stated in the TS 2495, EN ISO 3274, and TS 6212 EN ISO 4288 standards were followed for the preparation of the specimens.

Table 1. Measurements and Numbers of Specimens Prepared for Use in the Determination of Surface Roughness Connected to Different Variables of Densified Scots Pine on Which the Planing, Circular Sawing, and Sanding Processes Were Applied

Process	Dimensions of specimen (mm) (L × W × T)	Number of samples	
		Densified	Control
Planing	160 × 50 × 10	240	80
Circular sawing	160 × 50 × 10	360	120
Sanding	160 × 50 × 10	180	60

After bringing the densified Scots pine stocks to the test measurements at different temperatures to determine the roughness of the planed surfaces, the planing process was applied on the radial and tangential surfaces at 2000 and 4000 revolutions/minute by using 2 each and 4 each cutters with a feeding speed of 7 m/min and 14 m/min and a cutting depth of 1.6 mm. The planing process of a total of 320 each specimens was realized with the NETMAK Model KA500 thickness machine.

After bringing the densified Scots pine stock to the test measurements at different temperatures in order to determine the roughness of the circular cut surfaces, the circular sawing process was applied on the radial and tangential surfaces at 3000 and 6000 revolutions/minute by using 22 and 30 tooth circular saws at a feeding speed of 6 m/min. The circular sawing process of a total of 480 each specimens was realized with the YONMAK circular sawing machine.

After bringing the densified Scots pine stocks to the test measurements at different temperatures to determine the roughness of the sanded surfaces, the sanding process was applied on the radial and tangential surfaces with Number 60, 80, and 100 grit sanders. The sanding process of a total of 240 specimens was realized with the MAKITA Model 9404 disc sanding machine. The feeding speed of 9 m/min and cutting speed of 440 m/min was selected for the sanding.

Prior to the roughness measurements, the specimens underwent another acclimatization process to reach an air-dried humidity level. The specimens were kept in an acclimatization chamber at a temperature of 20 ± 2 °C and a relative humidity of 65% ± 5% until they reached equilibrium weight. The specimens were wrapped with plastic sheets after the acclimatization to prevent a change in moisture content that could occur prior to the roughness measurement.

Methods

Density determination

The density of Scots pine on which the densification process was implemented or not implemented was determined in accordance with the TS 2472 (1976) ISO 3131(1975) standard. The density value was the ratio of the oven-dry mass of a specimen to the volume of the specimen at the oven-dry moisture.

Surface Roughness measurement

The average surface roughness (*Ra*) of the Scots pine specimens on which the densification process was implemented or not implemented was determined in accordance with the TS 6212 EN ISO 4288 standards. The Mitutoyo Surftest SJ-301 touch (needle) surface roughness test equipment was used in the measurements. The measurements were made in a direction perpendicular to the fibers and in a position parallel to the plane at 5 separate points on each specimen (Figs. 1 and 2).

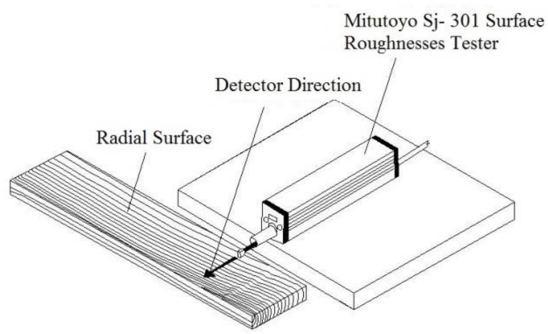

Fig. 1. Measurement of radial surface roughness

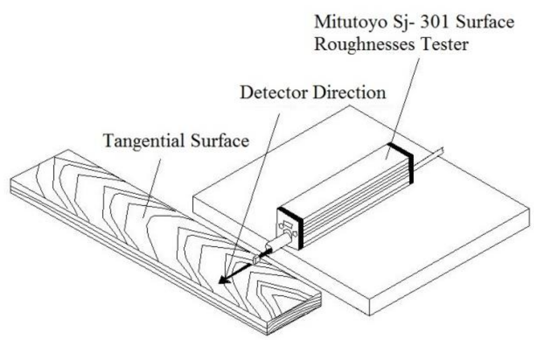

Fig. 2. Measurement of tangential surface roughness

Experimental data analysis

The obtained data were statistically analyzed. A multi-variance analysis was applied to test whether the densification temperature and some of the surfacing variables affected the surface roughness of Scots pine. If the obtained p-value was less than 5%, then the variable was judged to have had an effect on the roughness. If not, the variable had no effect. Duncan's multiple range test was used to determine whether the differences among the surface roughness values of the variables were significant, and the results were interpreted. The MSTAT - C package program was used for the analysis.

RESULTS AND DISCUSSION

Density

The density values of densified Scots pine are given in Table 2 according to the method explained above at a pressure of 6 MPa/cm^2 and different temperatures.

Table 2. Density Values of Densified Scots Pine at a Pressure of 6 MPa / cm^2 and Different Temperature Levels

Specimens	Statistical value		
	Average (kg/m^3)	**Standard deviation**	**Variation coefficient**
Control (undensified)	430	0.01	1.23
Densified at 120 °C	790	0.07	8.46
Densified at 140 °C	810	0.02	2.05
Densified at 160 °C	800	0.02	2.81

After the densification process, the density of Scots pine rose from 430 kg/m^3 to 800 kg/m^3, which was an 86% increase in density. Increasing the densification temperature at a fixed pressure of 6 MPa did not affect the density.

Effects of Some Variables on Surface Roughness in Planing

The surface roughness values after the planing of densified Scots pine are given in Table 3.

An analysis of variance was performed to determine whether some variables in planing had an effect on surface roughness. According to the results, the densification temperature, the number of blades, the rotational speed, and the cutting direction had an effect in the dual and triple interactions on surface roughness ($p < 0.05$).

The homogeneity test connected to different variables in planing is given in Table 4. The densification process and the temperature applied during densification affected the surface roughness in the planing of Scots pine. Because the roughness value of undensified Scots pine was the highest (5.02 µm), the densification process decreased the surface roughness after planing. Raising the densification temperature from 120 °C to 140 °C decreased the surface roughness (3.67 µm). However, raising it from 140 °C to 160 °C increased the surface roughness. In the planing process, the use of 4 blades instead of 2 (4.55 µm and 3.86 µm, respectively) and planing at 14 m/min instead of 7 m/min (4.34 µm and 4.07 µm, respectively) both decreased the roughness. Furthermore, tangentially cut surfaces had smoother surfaces than radially cut surfaces (4.50 µm and 3.91 µm, respectively). The lowest roughness (3.07 µm) from the interaction of densification temperature and number of blades was obtained at 140 °C in densified surfaces planed with 4 blades, followed by surfaces (3.96 µm) densified at 120 °C and planed with 2 blades. The highest roughness (5.69 µm and 4.35 µm) occurred in the undensified specimens. In the interaction between densification temperature and feeding speed, the lowest roughness (3.59 µm, 3.66 µm, and 3.74 µm) were obtained in the specimens densified at 140 °C, while the feeding speed connected to the densification temperature had no effect on the surface roughness.

Table 3. Roughness Values Connected to Densification Temperature, Number of Blades, Feeding Seeped, and Cutting Direction in Densified Scots Pine

DT (°C)	NB	FS	CD	Roughness value (R_a) (µm)		
				Mean	Standard deviation	Variation coefficient
Control (undensified)	2	7 m/min	Radial	6.38	1.06	16.68
			Tangential	5.19	1.06	20.45
		14 m/min	Radial	6.03	1.07	17.75
			Tangential	5.14	0.68	13.32
	4	7 m/min	Radial	5.29	1.14	21.59
			Tangential	4.35	0.58	13.30
		14 m/min	Radial	4.25	0.75	17.60
			Tangential	3.50	0.98	27.94
120 °C	2	7 m/min	Radial	4.44	1.15	25.92
			Tangential	4.30	0.83	19.20
		14 m/min	Radial	4.05	0.68	16.91
			Tangential	3.40	0.87	25.48
	4	7 m/min	Radial	4.36	0.67	15.26
			Tangential	4.29	0.97	22.69
		14 m/min	Radial	4.05	0.56	13.85
			Tangential	3.16	0.67	21.29
140 °C	2	7 m/min	Radial	4.75	0.79	16.62
			Tangential	4.34	0.75	17.19
		14 m/min	Radial	4.30	1.04	24.05
			Tangential	3.67	0.73	19.92
	4	7 m/min	Radial	3.00	0.32	10.69
			Tangential	2.28	0.34	14.83
		14 m/min	Radial	3.54	0.49	13.70
			Tangential	3.44	0.61	17.74
160 °C	2	7 m/min	Radial	4.51	0.86	18.97
			Tangential	4.09	1.30	31.76
		14 m/min	Radial	4.19	1.12	26.62
			Tangential	3.94	0.58	14.70
	4	7 m/min	Radial	4.23	0.94	22.11
			Tangential	3.61	0.36	9.98
		14 m/min	Radial	4.55	0.39	8.60
			Tangential	3.83	0.89	23.30

The densification process, the temperature applied in densification, the number of blades, the feeding speed, and the cutting direction affected the surface roughness in the planing of Scots pine. While densification provided a 26% decrease in surface roughness, the use of 4 blades instead of 2 blades during planing provided a 15% decrease, and an increase in feeding speed from 7 m/min to 14 m/min provided a 6% decrease. The roughness was 13% lower in the tangentially cut surfaces than in the radially cut surfaces. The lowest roughness was obtained in densified Scots pine at 140 °C (a decrease of 26% compared to undensified samples). Raising the densification temperature from 120 °C to 140 °C decreased the surface roughness by 8%, and raising the temperature from 140 °C to 160 °C increased the roughness by 12%. According to these values, the most suitable densification temperature for Scots pine was judged to be 140 °C.

Table 4. Homogeneity Test Related to the Determination of the Roughness Values that Create a Difference Connected to Different Variables

DT (°C)	**Roughness value (R_a) (µm)**	**HG**
Control	5.02	C
120	4.01	B
140	3.67	A
160	4.12	B
NB	**Roughness value (R_a) (µm)**	**HG**
2	4.55	B
4	3.86	A

DT (°C)	**Number of blades (NB)**			
	2		4	
	Roughness value (*Ra*) (µm)	**HG**	**Roughness value (*Ra*) (µm)**	**HG**
Control	5.69	E	4.35	D
120	4.05	C	3.96	B
140	4.27	C	3.07	A
160	4.18	C	4.06	C

FS	**Roughness value (R_a) (µm)**	**HG**
7 m/min	4.34	B
14 m/min	4.07	A

DT (°C)	**FS**			
	7 m/min		14 m/min	
	Roughness value (R_a) (µm)	**HG**	**Roughness value (R_a) (µm)**	**HG**
Control	5.30	D	4.73	C
120	4.35	B	3.66	A
140	3.59	A	3.74	A
160	4.11	B	4.13	B

DT (°C)	**Number of blades (NB)**							
	2				**4**			
	FS							
	7 m/min		14 m/min		7 m/min		14 m/min	
	Roughness value (R_a) (µm)	**HG**	**Roughness value (R_a) (µm)**	**HG**	**Roughness value (R_a) (µm)**	**HG**	**Roughness value (R_a) (µm)**	**HG**
Control	5.79	I	5.59	I	4.82	H	3.87	D
120	4.37	F	3.73	D	4.33	F	3.60	C
140	4.55	G	3.99	D	2.64	A	3.49	B
160	4.30	F	4.06	E	3.92	D	4.19	E

CD	**Roughness value (*Ra*) (µm)**	**HG**
Radial	4.50	B
Tangential	3.91	A

In planing, a circular path is followed by knives mounted on the cutterhead of the machine. Consequently, the knife engages the wood in brief circular passes, leaving a surface with elevated blips. Depending upon the rotation speed of the cutterhead, the number of blades, the depth of cut and feeding speed of wood, the cutting action produces scallops of varying elevation and distance between them (Marra 1992). At the moment of planing, increasing the number of blades or feeding speed when the other variables are fixed decreases the distance between scallops. This, therefore, results in the cutting of smaller wood shavings and it also decreases the roughness.

Effect on Surface Roughness of Some Variables Related to Densification Temperature and Cutting with a Circular Saw

The roughness values connected to some variables related to densification temperature and cutting in densified Scots pine are given in Table 5.

Table 5. Surface Roughness Values Connected to Densification Temperature, Number of Teeth on a Circular Saw, RPM, and Cutting Direction in Densified Scots Pine

DT (°C)	Number of teeth on C. Saw	CS RPM	CD	Roughness value (R_a) (µm)		
				Mean	**Std. Dev.**	**Variation coefficient**
Control (undensified)	22	3000	Radial	7.18	1.06	14.73
			Tangential	5.71	1.13	19.88
		6000	Radial	6.43	0.91	14.13
			Tangential	5.39	0.83	15.40
	30	3000	Radial	4.28	0.62	14.39
			Tangential	3.80	0.64	16.88
		6000	Radial	4.93	1.37	27.88
			Tangential	3.90	0.68	17.47
120°	22	3000	Radial	4.30	1.19	27.76
			Tangential	4.28	0.84	19.51
		6000	Radial	4.04	0.77	19.17
			Tangential	3.22	0.96	29.97
	30	3000	Radial	2.68	0.78	29.20
			Tangential	3.62	1.14	31.34
		6000	Radial	3.67	0.52	14.13
			Tangential	3.40	0.76	22.45
140°	22	3000	Radial	4.15	0.73	17.51
			Tangential	3.30	0.59	17.75
		6000	Radial	3.28	0.55	16.66
			Tangential	2.87	0.43	14.94
	30	3000	Radial	3.19	0.48	15.14
			Tangential	3.56	0.18	5.12
		6000	Radial	3.34	0.64	19.12
			Tangential	3.44	0.95	27.74
160°	22	3000	Radial	3.91	0.52	13.42
			Tangential	4.09	1.30	31.76
		6000	Radial	3.49	0.47	13.37
			Tangential	3.18	0.35	10.97
	30	3000	Radial	3.43	0.36	10.51
			Tangential	3.47	0.23	6.70
		6000	Radial	3.97	0.50	12.64
			Tangential	3.56	0.63	17.72

An analysis of variance was performed to determine whether the temperature and number of teeth on the circular saw or the rpm and the cutting direction had an effect on surface roughness. According to the results, the densification temperature in the circular cutting of Scots pine, the number of teeth on the cutter, and the cutting direction each had a significant effect ($p < 0.05$) on surface roughness. Rpm did not have an effect ($p > 0.05$)

on the surface roughness. Furthermore, the interactions between densification temperature and rpm, densification temperature and cutting direction, rpm and cutting direction, as well as the triad interaction of densification temperature × tooth number of the cutter × rpm did not have an effect on surface roughness ($p > 0.05$).

While the densification process, temperature, number of teeth on the circular saw, and the cutting direction in the circular sawing of Scots pine affected the surface roughness, the rpm of the circular saw did not. Densification provided a 38% decrease in the surface roughness in the circular sawing of Scots pine, and using a 30-tooth circular saw instead of a 22-tooth circular saw provided a 15% decrease. Increasing the rpm from 3000 to 6000 did not affect the roughness. The roughness of tangentially cut surfaces was 4% lower than radially cut surfaces. The lowest roughness was obtained with Scots pine densified at 140 °C (a decrease of 38% compared to undensified). Raising the densification temperature from 120 °C to 140 °C decreased the surface roughness 12%, whereas raising the densification temperature from 140 °C to 160 °C increased the roughness 8%. According to these values, the most suitable densification temperature is 140 °C in the circular sawing of Scots pine.

The homogeneity test connected to different variables in circular cutting is given in Tables 6, 7, and 8.

Table 6. Homogeneity Test Connected to DT, NT on CS and CD in Circular Sawing

DT (°C)	**Roughness value (R_a) (μm)**	**HG**
Control	6.24	C
120	4.39	B
140	3.87	A
160	4.19	B
N. of teeth on C. Saw	**Roughness value (R_a) (μm)**	**HG**
22	4.30	B
30	3.64	A
CD	**Roughness value (R_a) (μm)**	**HG**
Radial	*4.78*	B
Tangential	4.57	A

Table 7. Homogeneity Test Connected to DT x NT on CS, NT on CS x RPM, and NT on CS x CD in Circular Sawing

DT (°C)	**Number of Teeth on Circular Saw**			
	22		30	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**
Control	6.18	E	4.23	D
120	3.97	C	3.34	A
140	3.40	A	3.38	A
160	3.67	B	3.61	B
NT on CS	**RPM**			
	3000		6000	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**
22	4.62	D	3.99	C
30	3.51	A	3.78	B
NT on CS	**Cutting Direction**			
	Radial		**Tangential**	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**
22	4.60	C	4.00	B
30	3.69	A	3.59	A

Table 8. Homogeneity Test Connected to NT on CS x RPM x CD, DT x NT on CS x RPM, and DT x RPM x CD in Circular Sawing

NT on CS	**RPM**							
	3000				6000			
	Cutting Direction							
	Radial		**Tangential**		**Radial**		**Tangential**	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**
22	4.89	E	4.35	D	4.31	D	3.66	B
30	3.39	A	3.61	B	3.98	C	3.57	A
DT (°C)	**Number of teeth on C.Saw**							
	22				30			
	CD							
	Radial		**Tangential**		**Radial**		**Tangential**	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**
Control	6.81	J	5.55	I	4.61	H	3.85	F
120	4.17	G	3.75	F	3.18	B	3.51	D
140	3.72	E	3.09	A	3.27	C	3.49	D
160	3.70	E	3.63	E	3.70	E	3.52	D
DT (°C)	**RPM**							
	3000				6000			
	CD							
	Radial		**Tangential**		**Radial**		**Tangential**	
	Roughness (R_a) (μm)	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**	**Roughness (R_a) (μm)**	**HG**
Control	6.44	G	6.26	G	6.19	G	6.06	G
120	4.46	F	4.38	F	4.33	F	4.40	F
140	4.35	F	3.77	B	3.83	C	3.54	A
160	4.08	D	4.28	E	4.57	B	3.84	C

Because the highest roughness value was found in the control specimen (6.239 µm), circular sawing after the densification process decreased the surface roughness. Additionally, the densification temperature significantly affected the surface roughness in the circular sawing of the Scots pine. The lowest roughness (3.87 µm) was obtained from circular sawing of Scots pine densified at 140 °C. While raising the densification temperature from 120 °C to 140 °C decreased surface roughness, raising it to 160 °C increased surface roughness. The use of a 30-tooth saw instead of a 22-tooth saw in the circular sawing process decreased roughness (from 4.30 µm to 3.64 µm). Furthermore, tangentially cut surfaces were smoother than radially cut surfaces (4.78 µm and 4.57 µm, respectively). In the interaction of densification temperature and number of teeth on the saw, the lowest roughness (3.40 µm, 3.38 µm, and 3.34 µm) were obtained on the cut surfaces densified at 140 °C with the 22- and 30-tooth circular saw and the surfaces densified at 120 °C with the 30-tooth circular saw, respectively. This was followed by the cut surfaces densified at 160 °C with the 22- and 30-tooth circular saws (3.67 µm and 3.61 µm, respectively). The highest roughness (6.18 µm) appeared in the undensified specimens. In the interaction of tooth number of saw and rpm, the lowest roughness (3.51 µm) was obtained from the specimens cut with a 30-tooth circular saw at 3000 rpm, followed by the specimens cut with a 30-tooth circular saw at 6000 rpm (3.78 µm). The highest roughness appeared on the surfaces cut with the 22-tooth circular saw at 3000 rpm. In the triad interaction of densification temperature, tooth number of saw, and cutting direction, the lowest roughness (3.09 µm) was obtained in the specimens densified at 140 °C cut tangentially with a 22-tooth saw, followed by the specimens densified at 120 °C cut radially with a 30-tooth saw (3.18 µm). The highest roughness (6.81 µm) appeared in the specimens that were cut radially with a 22-tooth saw.

Circular saws used for rip sawing have teeth that attack the end grain of the wood, but also dress the side grain during the cut. Varying surface qualities are produced depending upon the configuration of teeth, sharpness, rim speed of the saw, feeding speed of the wood, and stability of the saw against vibration and wobble (Marra 1992). Connected to increasing the tooth number of the circular saws and increasing the saw diameter, the cutting speed also increases. When the other variables, which are effective in cutting, are kept constant, increasing the cutting speed decreases the size of the wood shavings cut and a decrease in the size of the wood shavings also decreases roughness. Furthermore, increasing the diameter of the saw increases the angle between the cutting teeth entering and exiting the wood. Increasing the entry-exit angle decreases the difficulty of shearing the fibers at the moment of cutting, and smoother surfaces with more uniform cuts are obtained.

Effect on Surface Roughness of Some Variables Related to Densification Temperature and Sanding

Roughness values connected to some variables in sanding have been given in Table 9.

An analysis of variance was done to determine whether the temperature applied in densification, the size of the sanding grit, and the cutting direction had an effect on surface roughness. According to the results, the interaction of the densification temperature × size of the sanding grit × cutting direction, and the interaction of the densification temperature × size of the sanding grit had an effect on the sanding of densified Scots pine ($p < 0.05$). The interactions between densification temperature × cutting direction, size of the sanding grits × cutting direction, and densification temperature × size of the sanding grits × cutting direction did not have an effect on surface roughness ($p > 0.05$). The homogeneity test connected to different variables in sanding is given in Table 10.

The densification process, the temperature applied in densification (DT), the grit number on sand-paper (GNS-P), and the cutting direction (CD) of Scots pine in sanding affected the surface roughness. Densification provided a 32% decrease in the surface roughness in the sanding of Scots pine.

The use of an 80-grit sander instead of a 60-grit sander provided a decrease of 20%, and the use of a 100-grit sander provided a decrease of 38%. The roughness of the tangentially cut surfaces was 10% lower than that of the radially cut surfaces. Raising the densification temperature from 120 °C to 140 °C decreased the surface roughness by 12%, resulting in the lowest roughness value (a 38% decrease compared to undensified wood). However, raising the temperature from 140 °C to 160 °C increased the roughness by 8%.

Table 9. Roughness Values Connected to Different Variables in Sanding

DT (°C)	G. Number	CD	Roughness values		
			Mean	Standard deviation	Variation coefficient
Control	60	Radial	7.02	1.33	18.90
		Tangential	6.28	1.11	17.71
	80	Radial	6.99	0.58	8.37
		Tangential	6.11	1.26	20.58
	100	Radial	4.33	0.53	12.30
		Tangential	3.95	0.92	23.18
120	60	Radial	4.23	0.98	23.17
		Tangential	3.89	0.72	18.48
	80	Radial	4.65	0.63	13.57
		Tangential	3.77	0.51	13.65
	100	Radial	3.67	0.52	14.13
		Tangential	3.49	0.89	25.57
140	60	Radial	7.49	0.59	7.82
		Tangential	7.08	0.96	13.49
	80	Radial	4.64	0.38	8.26
		Tangential	4.25	0.99	23.21
	100	Radial	4.74	0.88	18.58
		Tangential	4.26	0.68	15.94
160	60	Radial	7.53	1.25	16.58
		Tangential	6.53	1.84	28.13
	80	Radial	5.21	0.42	8.09
		Tangential	4.66	1.08	23.16
	100	Radial	3.59	0.55	15.40
		Tangential	3.22	0.59	18.28

Table 10. Homogeneity Test Connected to Different Variables in Sanding

DT (°C)	**Roughness value (*Ra*) (µm)**	**HG**				
Control	5.78	C				
120	3.95	A				
140	5.43	B				
160	5.12	B				
GNS-P	**Roughness value (*Ra*) (µm)**	**HG**				
60	6.27	C				
80	5.04	B				
100	3.91	A				
DT (°C)	**Grit number of sandpaper**					
	60		80		100	
	Roughness (*Ra*) (µm)	**HG**	**Roughness (*Ra*) (µm)**	**HG**	**Roughness (*Ra*) (µm)**	**HG**
Control	6.65	F	6.55	F	4.14	C
120	4.06	C	4.21	C	3.58	B
140	7.33	E	4.44	D	4.50	D
160	7.03	G	4.93	E	3.41	A
CD	**Roughness value (*Ra*) (µm)**	**HG**				
Radial	5.35	B				
Tangential	4.79	A				

Sanding is basically a process of cutting and tearing parts of fibers, whole fibers, or clumps of fibers out of the wood surface by abrasive action of sharp stonelike grits drawn along the grain. The quality of a sanded surface depends upon grit size and sharpness, grit speed, pressure, and wood moisture content (Marra 1992). As the grit size increases (as the grit number decreases) in the sanding process, the size of the wood shavings broken off from the wood increases and consequently, the surface roughness increases by forming deeper holes. Thus, sanding should be done several times with a gradually decreasing grit size.

Chemical degradations arise in the structural (cell wall) elements of the wood above certain temperature levels in the radial densification process with the thermo-mechanical method. These degradations emerge in the hemicellulose from 120 ºC, in the lignin from 160 ºC, and in the cellulose from 230 ºC, and the level of degradation undergoes a change according to the temperature value and the period of heating. With these degradations, the degree of polymerization of hemicelluloses is decreased 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 (Kocaefe *et al.* 2008. LeVan *et al.* 1990; Korkut and Kocaefe 2009). The weakening or breaking of the bonds between the structural elements of the wood negatively affects all the resistance characteristics. Raising the densification temperature increases the roughness following processes such as planing, circular sawing, and sanding. These effects stem from a decrease in the resistance characteristics. Surfacing of densified wood with these techniques at relatively higher temperatures also increases the surface roughness formed from cutting the cell wall elements as well as breaking off and fracturing due to the weak structure stemming from degradation.

Roughness of the tangential cut surfaces in all surfacing techniques (planning, circular sawing and sanding) were less than those of radial cut surfaces. This result may be due to free molecular motion along the tangential direction, resulting in a denser structure.

CONCLUSIONS

1. The densification process, the temperature level applied in densification, the number of blades, the feeding speed, and the cutting surface all affect the surface roughness in the planing of Scots pine. While densification provided a 26% decrease in surface roughness in the planing process, the use of 4 blades instead of 2 blades provided a 15% decrease, and the increase of the feeding speed from 7 m/min to 14 m/min provided a 6% decrease. The roughness was 13% lower in the tangential cut surfaces compared to the radial cut surfaces. While the lowest roughness was obtained in densified Scots pine at 140 ºC (a decrease of 26% compared to undensified), raising the densification temperature from 120 ºC to 140 ºC decreased the surface roughness 8%, whereas, raising the temperature from 140 ºC to 160 ºC increased the roughness 12%. According to these values, the most suitable densification temperature is 140 ºC for the lowest roughness in the planing of Scots pine.
2. The densification process, the temperature level applied in densification, the tooth number of the circular saw, and the cut surface in the circular sawing of Scots pine all affect the surface roughness, while the number of revolutions/minute of the circular saw does not affect surface roughness. Densification provided a 38% decrease in the surface roughness in the circular sawing of Scots pine; the use of a 30-tooth circular saw instead of a 22-tooth circular saw provided a 15% decrease. Increasing the revolutions/minute from 3000 to 6000 did not affect roughness. The roughness of tangential cut surfaces was 4% lower compared to radial cut surfaces. While the lowest roughness was obtained in Scots pine densified at 140 ºC (a decrease of 38% compared to undensified), raising the densification temperature from 120 ºC to 140 ºC decreased the surface roughness 12%. Raising the densification temperature from 140 ºC to 160 ºC increased the roughness 8%. According to these values, the most suitable densification temperature is 140 ºC for the lowest roughness in the circular sawing of Scots pine.
3. The densification process, the temperature level applied in densification, the sander grit number, and the cut surface of Scots pine in sanding all affect the surface roughness. While densification provided a 32% decrease in the surface roughness in the sanding of Scots pine, the use of an 80 grit sander instead of a 60 grit sander provided a decrease of 20%, whereas the use of a 100 grit sander provided a decrease of 38%. The roughness on the tangential cut surfaces was 10% lower compared to the radial cut surfaces. While the lowest roughness was obtained in Scots pine densified at 140 ºC (a 38% decrease compared to undensified), raising the densification temperature from 120 ºC to 140 ºC decreased the surface roughness 12%, whereas, raising the temperature from 140 ºC to 160 ºC increased the roughness 8%. According

to these values, the most suitable densification temperature is 140 ºC for the lowest roughness in the circular sawing of Scots pine.

4. In all of the surfacing techniques, the roughness values in tangential cut surfaces were less than those of radial cut surfaces.

REFERENCES CITED

Aguilera, A., and Martin, P. (2001). "Machining qualification of solid wood of *Fagus sylvatica* L. and *Picea excelsa* L.: Cutting forces, power requirements and surface roughness," *Holz Roh- Werkst.* 59(6), 483-488.

Blomberg, J., Persson, B., and Blomberg, A. (2005). "Effects of semi-isostatic densification of wood on the variation in strength properties with density," *Wood Sci. Technol.* 39(5), 339-350.

Bucur, V., Garros, S., and Barclow, C. Y. (2000). "The effect of hydrostatic pressure on physical properties and microstructure of spruce and cherry," *Holzforschung* 54(1), 83-92.

Burdurlu, E., Usta, I., Kilic, Y., and Ulupinar, M. (2007). "The effect on shear strength of different surfacing techniques in Oriental beech (*Fagus orientalis* Lipsky) and Scotch pine (*Pinus sylvestris* L.) bonded joints," *J. Adhes. Sci. Technol.* 21(3-4), 319-330.

Burdurlu, E., Usta, İ., Ulupınar, M., Aksu, B., and Erarslan, T. Ç. (2005). "The effect of the number of blades and the grain size of abrasives in planing and sanding on the surface roughness of European black pine and Lombardy poplar," *Turk. J. Agr. Forest.* 29(4), 315-321.

Dereli, Ü. (1997). "Kızılçam (*Pinus brutia* Ten) ve orta yoğunluklu lif levhalarda (MDF) yüzey pürüzlülüğünün tayini üzerine araştırmalar (Studies on the determination of the surface roughness of Calabrian pine (*Pinus brutia* Ten.) and medium density fiberboards (MDF)," M.S. Thesis, Hacettepe University, Institute of Science, Ankara, Turkey.

Hernández, R. E., and Cool, J. (2008). "Evaluation of three surfacing methods on paper birch wood in relation to water and solvent-borne coating performance," *Wood Fiber Sci.* 40(3), 459-469.

Hernández, R. E., and de Moura, L. F. (2002). "Effects of knife jointing and wear on the planed surface quality of northern red oak wood," *Wood Fiber Sci.* 34(4), 540-552.

Hillis, W. E., and Rozsa, A. N. (1978). "The softening temperatures of wood," *Holzforschung* 32(2), 68-73.

Iskra, P., and Hernández, R. E. (2009). "The influence of cutting parameters on the surface quality of routed paper birch and surface roughness prediction modeling," *Wood Fiber Sci.* 41(1), 28-37.

Kamata, H., and Kanauchi, T. (1994). "Analysis of roughness of cutting surface with NC router (influence of grain direction in solid wood)," *Trans. Jpn. Soc. Mech. Eng.* 60 (569), 303-307.

Kamke, F. A., and Sizemore, H. (2005). "Viscoelastic thermal compression of wood," *US Patent 7404422 B2*.

Kennedy, R. W. (1968). "Wood in transverse compression," *Forest Prod. J.* 18(3), 36-40.

Keturakis, G., and Juodeikiene, I. (2007). "Investigation of milled wood surface roughness. – Materials science," *Technologija* 13(1), 47-51.

Kilic, Y., and Demirci, S. (2003). "Research on surface roughness values of Scotch pine (*Pinus sylvestris*) and chestnut (*Castanea sativa*) wood," *Gazi Univ. J. Sci.* 16, 553-558.

Kilic, M., Hiziroglu, S., and Burdurlu, E. (2006). "Effect of machining on surface roughness of wood," *Build. Environ.* 41(8), 1074-1078.

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

Kocaefe, D., Shi, L. J., Yang, D. Q., and Bouazara, M. (2008b). "Mechanical properties, dimensional stability, and mold strength of heat-treated jack pine and aspen," *Forest Prod. J.* 58(6), 88-93.

Kollmann, F. F. P., and Cote, W. A. (1984). *Principles of Wood Science and Technology, Vol. 1: Solid Wood*, Springer-Verlag, New York.

Kollmann, F. P., Kuenzi, E. W., and Stamm, A. J. (1975). *Principles of Wood Science and Technology, Vol. II: Wood Based Materials*, Springer-Verlag, New York.

Korkut, S., and Kocaefe, D. (2009). "Isıl işlemin odun özellikleri üzerine etkisi (Effect of heat treatment on wood properties)," *Düzce Univ. Ormancılık D.* 5(2), 11-34.

Kultikova, E. V. (1999). "Structure and properties relationships of densified wood," M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Kunesh, R. H. (1968). "Strength and elastic properties of wood in transverse compression," *Forest Prod. J.* 18(1), 65-72.

Kutnar, A., and Kamke, F. A. (2012). "Compression of wood under saturated steam, superheated steam, and transient conditions at 150 ºC, 160 ºC, and 170 ºC," *Wood Sci. Technol.* 46(1-3), 73-88.

Kutnar, A., and Sernek, M. (2007). "Densification of wood," *Zbornik Gozdarstva in Lesarstva* 82, 53-62.

Lenth, C. A., and Kamke, F. A. (2001). "Moisture dependent softening behavior of wood," *Wood Fiber Sci.* 33(3), 492-507.

LeVan, S. L., Ross, R. J., and Winandy, J. E. (1990). "Effects of fire retardant chemicals on bending properties of wood at elevated temperatures," *Res. Pap. FPL-RP498*, USDA Forest Service, Forest Products Laboratory, Madison, WI.

Magoss, E. (2008). "General regularities of wood surface roughness," *Acta Silv. Lign. Hung.* 4, 81-93.

Marra, A. A. (1992). *Technology of Wood Bonding: Principles in Practice*, Van Nostrand Reinhold, New York.

Morsing, N. (2000). "Densification of wood - The influence of hygrothermal treatment on compression of beech perpendicular to the grain," Department of Structural Engineering and Materials. Technical University of Denmark. Series R. 79, 138 pp.

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

Pinkowski, G., Szymanski, W., Gilewicz, A., and Warcholinski, B. (2011). "Surface roughness of beechwood following milling using modified cutters," *Ann. Warsaw Univ. Life Sci. – SGGW For. Wood Technol.* 75, 210-215.

Ratnasingam, J, Ma, T. P., Manikam, M., Farrokhpayam, S. R. (2008). "Evaluating the machining characteristics of oil palm lumber," *Asian J. Appl. Sci.* 1(4), 334-340.

Reiterer, A., and Stanzl-Tschegg, S. E. (2001). "Compressive behaviour of softwood under uniaxial loading at different orientations to the grain," *Mech. Mater.* 33(12), 705-715.

Reynolds, M. S. (2004). "Hydro-thermal stabilization of wood-based materials," Master Thesis, Virginia Tech., Blacksburg, Virginia, 155 pp.

Sandak, J., and Negri, M. (2005). "Wood surface roughness – What is it?" Proceedings of the 17th International Wood Machining Seminar, Rosenheim, Germany, 26-28 September, 242-250.

Santos, J. A. (2000). "Mechanical behaviour of eucalyptus wood modified by heat," *Wood Sci. Technol.* 34(1), 39-43.

Seborg, R. M., Millet, M., and Stamm, A. J. (1945). "Heat-stabilized compressed wood. Staypak," *Mech. Eng.* 67(1), 25-31.

Skaljic, N., Beljo, L. R., Cavlovic, A., and Obujina, M. (2009). "Effect of feed speed and wood species on roughness of machined surface," *Drvna Ind.* 60(4), 229-234.

Sogutlu, C., and Togay, A. (2011). "The effect of the process parameters in the planing processes on the surface roughness of cherry and pear woods," *Afr. J. Biotechnol.* 10(21), 4392-4399.

Stamm, A. J., Burr, H. K., and Kline, A. A. (1955). "Heat-stabilized wood (Staybwood)," Rep. No. 1621, U.S. Department of Agriculture Forest Service, Forest Products Laboratory, Madison, WI, USA.

Tabarsa, T., and Chui, Y. H. (2001). "Characterizing microscopic behavior of wood under transverse compression. Part II. Effect of species and loading direction," *Wood Fiber Sci.* 33(2), 223-232.

Taylor, J. B., Carrano, A. L., and Lemaster, R. L. (1999). "Quantification of process parameters in a wood sanding process," *Forest Prod. J.* 49(5), 41-46.

Trenard, Y. (1977). "Study of isostatic compressibility of some timbers," *Holzforschung* 31(5), 166-171.

TS 2471. ISO 3130 (1976). "Odunda, Fiziksel ve Mekaniksel Deneyler İçin Rutubet Miktarı Tayini" (Determination of the amount of humidity for physical and mechanical tests in wood.) Türk Standartları Enstitüsü (Turkish Institute of Standards), Ankara (in Turkish).

TS 2495, EN ISO 3274. (2005). "Geometrik mamul özellikleri (GMÖ) - Yüzey yapısı: profil metodu - Temas uçlu (iğneli) ölçme cihazlarının anma karakteristikleri" (Geometrical product specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments.) Türk Standartları Enstitüsü (Turkish.Institute.of.Standards), Ankara.

TS 6212 EN ISO 4288. (1999). "Mamulün Geometrik Özellikleri (GMÖ)- Yüzey Yapısı: Profil Metodu-Yüzey Yapısının Değerlendirilmesi İçin Kurallar ve İşlemler" Geometrical product specifications (GPS) surface texture: Profile method-Rules and procedures for the assessment of surface texture.) Turkish Institute of Standards (TSE), Ankara.

Wilkowski, J., Zerebiec, B., and Czarniak, P. (2010). "Analysis of surface roughness in wood milling," *Ann. Warsaw Univ. Life Sci.– SGGW For. Wood Technol.* 72, 474-479.

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