Determination of the Surface Roughness of Heat-Treated Wood Materials Planed by the Cutters of a Horizontal Milling Machine

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The aim of the present study was to determine the surface roughness of heat-treated Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.), and sessile oak (*Quercus petraea* L.) wood material samples following planing by the cutters of a horizontal milling machine. The samples that were heat-treated at 140 ºC or 160 ºC for 3, 5, or 7 hours were then processed by star blades or razor blades, which are the most frequently used blade types in a milling machine. The surface roughness of the samples was determined by a touch (spined) scan device (TIME TR200), as indicated by the ISO 4287 principle. The results of the study indicate that heat treatment decreases the surface roughness value of the wood material and a significant difference in surface roughness cannot be detected between planing using the razor blade or the star blade.

Keywords: Wood material; Heat treatment; Criteria of cutting theory; Surface roughness; Cutters of milling machine

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INTRODUCTION

Along with advances in technological development worldwide, the preservation of wood using impregnated or toxic chemicals is currently being restricted or banned completely. The environmental awareness aiming for the traditionally used wood impregnating materials has triggered the onset of a number of scientific studies on the development of novel chemical materials, methods, and novel products to replace traditional methods.

Heat treatment of woods has attracted attention in Europe and more recently in the Northern America in recent years as an environmentally friendly wood preservation method (Mayes and Oksanen 2002; Wikberg 2004; Enjily and Jones 2006; Boonstra 2008; Korkut and Kocaefe 2009). The wood material gains a hydrophobic (water repellant) structure with increasing temperature during heat treatment. The wood thus becomes more resistant to the harmful effects of the biohazards. In addition, the material achieves improved dimensional stability and its properties, including hardness mechanical resistance, resistance against flammability, appearance, workability, dye affinity, and fusability, gain importance (Millett and Gerhards 1972; Viitanen *et al.* 1994; Suttie and Thompson 2001; Yıldız 2002; Sernek *et al.* 2008; Akyıldız and Ateş 2008; Sevim Korkut *et al.* 2008; Korkut and Budakçı 2010; Dizman Tomak and Yıldız 2010;

Budakçı *et al.* 2011).

As in other engineering fields, research on surface roughness has been increasing in the wood processing industry owing to its direct effect on product quality (Jakub and Martino 2005). The ability to quantify and control the surface roughness, which ranges on a wide scale as a result of the methodological differences in the processing of the wood using tools or machinery, is very important in various applications (Yıldız 2002).

Every object has a surface comprised of miniature hills and valleys. The dimensional and areal distribution of these hills and valleys affect the surface properties. Many international standards have been developed for the numerical parameters that describe the surface roughness measurement methods or the surface texture. Interestingly, elementary difficulties and misunderstandings still occur in many studies. This problem is more apparent in the woodworking industry, for which there is still the need for improvement in the description of surfaces (Jakub and Martino 2005).

The surface of the woods is not smooth due to the cellular voids on the surface despite being planed away, milled, lathed, and sandpapered using the suitable techniques. Because of the anisotropic structure of the wood, high quality processing of the timber is reported to depend on the use of suitable processing techniques, the feed speed, the geometry of the cutter, and the proper technical attendance of these cutters in terms of sharpening and maintenance (Yıldız 2002). Recent studies reported that smoother surfaces could be obtained on tangential edges compared to radial edges and that the direction of cutting and type of cutter interactions were insignificant. In addition, lower surface roughness values have been determined for summer wood than in spring wood (Malkoçoğlu 2007); smoother surfaces were obtained as the number of blades in planing was increased and surface roughness increased with increasing feed speed and cutting depth (Stumbo 1960; Stewart 1970; Örs and Baykan 1999; Örs and Gürleyen 2002; Efe *et al.* 2003; Efe and Gürleyen 2003; Söğütlü 2004; Efe and Gürleyen 2007; Usta *et al.* 2007).

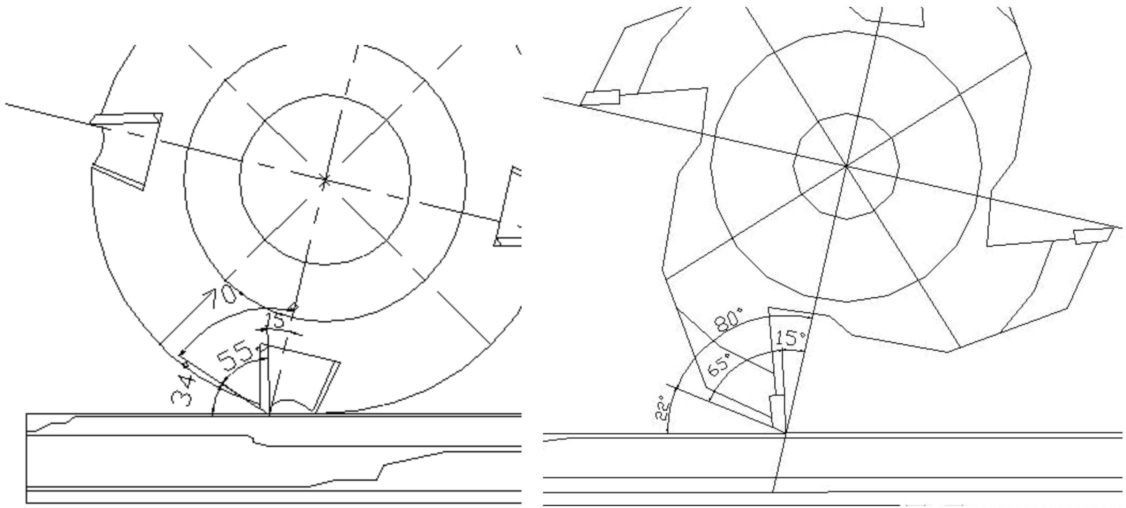
Within the context of the available information, the present study aimed to determine the surface roughness of heat-treated Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.), and sessile oak (*Quercus petraea* L.) samples following planing by the cutters of a horizontal milling machine.

EXPERIMENTAL

Preparation of the Test Samples

Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), Uludağ fir (*Abies bornmülleriana* Mattf.), and sessile oak (*Quercus petraea* L.) were selected in this study owing to their frequent utilization in Turkey. The mean oven-dried density of specimens was 0.49 gr/cm^3, 0.63 gr/cm^3, 0.40 gr/cm^3, and 0.65 gr/cm^3, respectively. The humidity of the samples was as allowed by stagnant air drying, and the samples were selected randomly from 1st grade wood materials. The samples were prepared such that they had regular fiber structure without knots or cracks, they were of uniform color and density, and they were cut from fresh parts such that the annual rings were perpendicular to the surface as indicated by the TS 2470 standards. The dimensions of the samples were 18 × 110 × 350 mm (TS 2470 1976). The samples were first kept at 103 ± 2 ºC until their weight was constant, and then they were treated with heat at 140 ºC and 160 ºC for 3, 5, or 7 h. They were then treated in the conditioning cupboard at 20 ± 2 ºC and 65 ± 5% relative humidity (TS 2471 1976; Korkut and Bakangil 2007).

Four anti-blunt carbon steel razor blades of dimensions 1.5 × 12 × 50 mm and four flat formed star blades of 200 mm diameter with diamond cutters were attached to the collet of 90 mm diameter in the present study. The angular positioning of the blades is displayed in Fig. 1.



Razor blade Star blade

Fig. 1. Cutters used in the milling machine

The samples were prepared for the experiment in a horizontal milling machine using the star and razor blades with the following parameters; 6000 rpm cutting speed, 4 m/min feed speed, and 1 mm planing (Fig. 2).

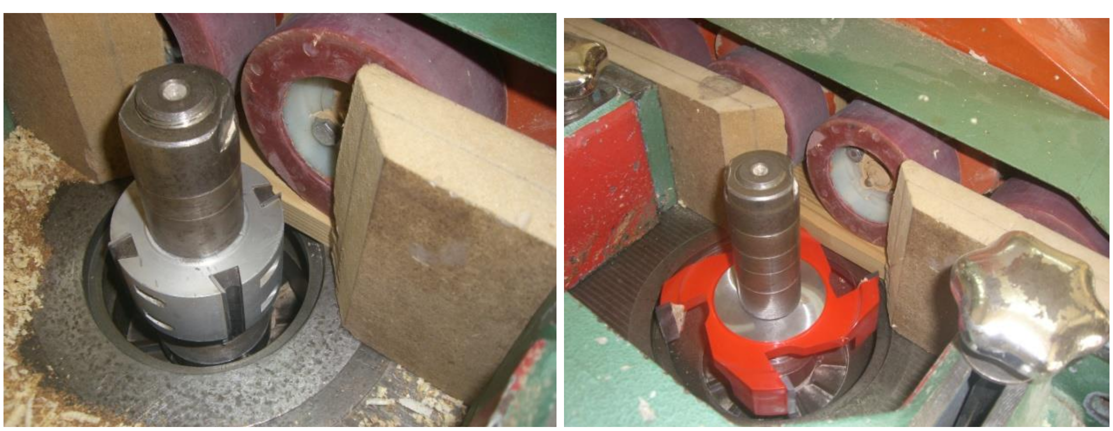


Fig. 2. Sample preparation using razor and star blades

Surface Roughness Test

The surface roughness of the samples was determined using a touch scan (spined) device (TIME TR200) as stated in the ISO 4287 (1997) standard. Measurements were made at 10 different positions perpendicular to the fibers on each sample as marked in Fig. 3. The measurements were made at 20 ± 2 °C and a relative humidity of 65 ± 3% in a sound-proof and vibration-proof environment. The device parameters were set to a 0.25 mm measurement step and 5 measurements as the cut-off, and the measurement arm was placed between 2 lines 5 mm apart. The measurements were made after both the sample and the device were checked to be parallel to the ground. Measurements were repeated if the tip of the scanning needle got stuck in the cellular voids. The calibration of the device was re-checked after each 100 measurements to maintain reproducibility.

Fig. 3. Measurement of the sample surfaces

The device measures the surface roughness by obtaining the dent-ridge profile of the surface by moving the 5 µm diameter diamond tip of the scanning needle up and down on the surface of the sample. The central line between the profile dents (valleys) and the ridges (hills) shows the mean roughness (*Ra*) in µm (Fig. 4). The surface roughness was evaluated in terms of *Ra* in the present study.

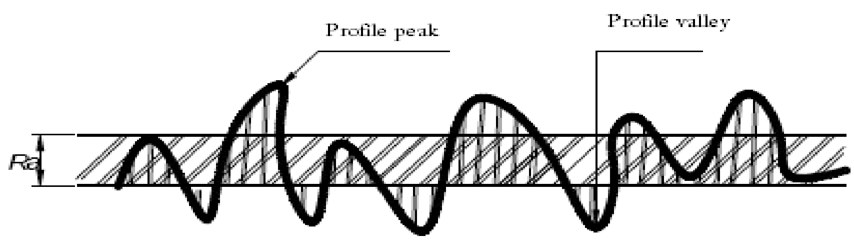


Fig. 4. Surface profile determined by the scanning needle (Söğütlü 2005).

Statistical Analysis Method

MSTATC statistical software package was used for the statistical evaluation of the results and to show the effects of the type of wood material, the type of cutter blade, the temperature of heat treatment, and duration of the heat treatment on surface roughness. The interactions between these factors were determined using multivariate (ANOVA) analysis. The comparisons were made using the critical values obtained from the Duncan test and LSD (least square difference) and the factors causing the differences were identified.

RESULTS AND DISCUSSION

The results of the multivariate analysis (ANOVA) of the surface roughness measurements for the heat-treated and untreated (control) wood materials processed by different cutter blades in the horizontal milling machine are displayed in Table 1.

Table 1. Results of the Analysis of Variance

Factors	Degree of freedom	Sum of squares	Mean square	F-number	Level of Significance (P<0.05)
Wood type (A)	3	338.576	112.859	162.6923	0.0000*
Cutter blade type (B)	1	0.800	0.800	1.1534	ns**
Interaction (AB)	3	23.243	7.748	11.1685	0.0000
Temperature of heat treatment (C)	1	0.103	0.103	0.1484	ns
Interaction (AC)	3	2.760	0.920	1.3264	0.2648
Interaction (BC)	1	0.006	0.006	0.0089	ns
Interaction (ABC)	3	0.974	0.325	0.4682	ns
Duration of heat treatment (D)	3	5.474	1.825	2.6302	0.0204
Interaction (AD)	9	20.786	2.310	3.3294	0.0006
Interaction (BD)	3	6.658	2.219	3.1993	0.0230
Interaction (ABD)	9	15.048	1.672	2.4103	0.0109
Interaction (CD)	3	2.006	0.669	0.9641	ns
Interaction (ACD)	9	8.397	0.933	1.3450	0.2104
Interaction (BCD)	3	1.043	0.348	0.5014	ns
Interaction (ABCD)	9	6.160	0.684	0.9866	ns
Fault	576	399.568	0.694		
Total	639	831.602			

*: significant at 95% confidence level; **: not significant

The results of the analysis of variance indicate that the interactions AC and ADC were meaningless and the factors B and C along with the interactions BC, CD, ABC, BCD, and ABCD were insignificant. The remaining factors and their interactions were determined to be significant at a level of α=0.05. The results of the comparative wood type Duncan test are presented in Table 2.

Table 2. Comparative Results of Wood Type: Duncan Test (μm)

Wood type							
Pine		Beech		Oak		Fir	
$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*
2.941	C	4.133	A*	2.188	D	3.596	B
LSD ± 0.1829							

$\bar{x}$, arithmetic mean; *HG*, homogeneity group; *, the greatest roughness value

The results provided in the table indicate that the greatest roughness value was obtained for the Eastern beech and the lowest value was obtained for the oak, as indicated by the measurements conducted on the wood material surfaces that were processed by different blade cutters. The fact that the surface roughness value of oak was the lowest was not in accordance with its ringed tracheids and coarse-textured anatomical structure. A considerable difference was identified between the summer wood and the spring wood in terms of roughness. The reason for this difference is the fact that the surface roughness of the spring wood zone could not be measured accurately and therefore only the summer wood was used in the study. Previous studies reported lower surface roughness values for the summer wood than for spring wood (Malkoçoğlu 2007). Another study reported that different cells of the wood material are machine processed differently, and ridges form between tracheids, xylem, parenchyma, resin ducts, and fibers during cutting. Moreover, the type of wood, ratio of the summer wood to spring wood, and horizontal, radial, or tangential cutting affected the formation of these ridges, which changed surface roughness (Söğütlü 2005).

The very high roughness value measured for the Eastern beech was thought to stem from the effect of the heat treatment on the wood samples. As previously reported in the literature, heating the wood will cause a decrease in the mass and the volume of the wood, depending on the method of application, temperature, and the duration of the heat treatment. The heat treatment associated weight loss would increase fibrousness, moisture loss in wood structure due to the reduction of the present hydroxyl groups, material loss in cell membrane, and the degradation of the hemicellulose structures, which in turn would be effective in increasing surface roughness (Fengel and Wegener 1989; Viitanen *et al.* 1994; Korkut and Kocaefe 2009). The direction of cutting was also another effect accounting for differences in the surface roughness measurements for these two types of wood. The fact that the radial and the tangential cuts were not distinctively used during cutting would have caused this outcome. Kantay and Ünsal (2002) reported surface roughness values of 5.18 µm for oak and 4.73 µm for beech that were cut tangential to the annual rings and values of 5.07 µm for oak and 5.19 µm for beech that were cut radial to the annual rings. The roughness value of the radially-cut beech samples was higher than that of the oak samples. The present results are in accordance with the results available in the literature (Kantay and Ünsal 2002).

The results of the comparative cutter blade type Duncan test are presented in Table 3.

Table 3. Comparative Results of the Cutter Blade Type: Duncan Test (µm)

Cutter blade type			
Razor		Star	
$\bar{x}$	*HG*	$\bar{x}$	*HG*
3.179	A	3.250	A*
LSD ± 0.1294			

$\bar{x}$, arithmetic mean; *HG*, homogeneity group; *, the greatest roughness value

The comparison of the type of cutter blade used shows that the differences in surface roughness values were insignificant, as indicated by the results of the analysis of variance. The razor and star blade cutters did not cause any difference in surface roughness. This might stem from the fact that the number of blades (4) and the normal rake angles (15^o) were equal for both types of cutters. Previous studies reported smoother surfaces with an increasing number of blades used in the application (Stumbo 1960; Stewart 1970; Örs and Baykan 1999; Örs and Gürleyen 2002; Efe *et al.* 2003; Efe and Gürleyen 2003; Söğütlü 2004; Efe and Gürleyen 2007; Usta *et al.* 2007).

The results of the temperature of the heat treatment Duncan test are presented in Table 4.

Table 4. Comparative Results of the Temperature of Heat Treatment: Duncan Test (µm)

Temperature of heat treatment ºC			
140		160	
$\bar{x}$	*HG*	$\bar{x}$	*HG*
3.202	A	3.227	A*
LSD ± 0.1294			

$\bar{x}$, arithmetic mean; *HG*, homogeneity group; *, the greatest roughness value

The comparison of the temperature of heat treatment showed that the differences in surface roughness values were insignificant, as indicated by the results of the analysis of variance. Heat treatment at 140 ^{o}C or 160 ^{o}C did not cause any difference in surface roughness. However, the surface roughness values of both heat-treated samples were higher than the control samples. A similar result was obtained in a previously conducted study using circular saws (Budakçı *et al.* 2011). This situation was associated with the fact that the thermal degradation of wood begins at temperatures as low as 100 ^{o}C and that above 200 ^{o}C, the structural damage involves the total conversion of wood components and the release of gas phase degradation products (Fengel and Wegener 1989; Boonstra and Tjeerdsma 2006). Additionally, the formation of condensable particles due to the loss of water and volatile extracts below 140 ^{o}C and the formation of cellular degradation products formed by loose structures connected to the cell wall polymers above that temperature were previously observed. This condition would specifically be the result of the formation of acetic acid as a degradation by-product of hemicellulose. In addition, as the wood is further heated, the formic acid and methanol would also cause similar effects as well as the condensed gases (specifically CO_2). At temperatures above 140 °C, dehydration reactions commence, causing a decrease in the hydroxyl content; this increases the surface roughness with increasing temperature (Bourgois *et al.* 1991).

Table 5. Comparative Results of the Duration of Heat Treatment: Duncan Test (µm)

Duration of heat treatment (hours)							
Control		3		5		7	
$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*
3.056	B	3.288	A*	3.263	A	3.251	A
LSD ± 0.1829							

$\bar{x}$, arithmetic mean; *HG*, homogeneity group; *, the greatest roughness value

The results displayed in Table 5 indicate that the lowest surface roughness value was achieved in the untreated samples. The three different durations of heat treatment (3, 5, and 7 h) were determined to be effective in increasing the surface roughness value. Previous studies also reported a loss in the physical properties depending on the duration of the heat treatment and the temperature at which the treatment was applied (Yıldız *et al.* 2006; Korkut *et al.* 2008; González-Peña *et al.* 2009; Gündüz *et al.* 2009; Korkut and Budakçı 2009; Korkut and Hızıroğlu 2009; Korkut and Budakçı 2010; Budakçı *et al.* 2011). The results of the present study are in accordance with the results available in the literature.

The results of the comparative Duncan test conducted to determine the interactive effects of the type of wood, the type of cutter blade, the heat treatment temperature, and the duration of heat treatment factors are presented in Table 6.

The surface roughness values were determined to be insignificant relative to the interaction effect of the type of wood, the type of cutter blade, the heat treatment temperature, and duration of heat treatment. Also, the factor interactions were determined to be negligible.

Table 6. Comparative Results of Wood Type, Cutter Blade Type, Heat Treatment Temperature, and Duration of Heat Treatment: Duncan Test (µm)

Factor ABCD**			140 °C				160 °C			
			Control	3 h	5 h	7 h	Control	3 h	5 h	7 h
Pine	Razor	$\overline{x}$	2.470	2.435	3.096	2.030	2.470	2.860	2.907	2.869
		HG	J-O	J-O	F-L	MNO	J-O	H-M	H-M	H-M
	Star	$\overline{x}$	3.308	3.070	3.098	3.493	3.308	3.424	3.344	2.879
		HG	E-K	G-L	F-L	C-I	E-K	D-I	E-J	H-M
Beech	Razor	$\overline{x}$	4.326	4.354	3.957	4.360	4.326	3.972	4.512	4.701
		HG	ABCD	ABC	A-G	ABC	ABCD	A-G	AB	A*
	Star	$\overline{x}$	4.142	3.848	3.642	3.768	4.142	4.045	3.859	4.167
		HG	A-E	A-G	B-H	B-H	A-E	A-E	A-G	A-E
Oak	Razor	$\overline{x}$	2.231	1.708	2.148	2.236	2.231	1.872	1.666	2.379
		HG	LMNO	O	MNO	LMNO	LMNO	NO	O	LMNO
	Star	$\overline{x}$	2.003	2.427	3.120	1.788	2.003	2.910	2.244	2.048
		HG	MNO	K-O	F-L	NO	MNO	H-M	LMNO	MNO
Fir	Razor	$\overline{x}$	3.324	4.003	3.875	4.059	3.324	3.497	3.656	3.878
		HG	E-K	A-F	A-G	A-E	E-K	C-I	B-H	A-G
	Star	$\overline{x}$	2.644	4.285	3.679	3.530	2.644	3.905	3.402	3.826
		HG	I-N	ABCD	B-H	C-I	I-N	A-G	D-I	A-G
LSD ± 0.7317										

$\overline{x}$, arithmetic mean; *HG*, homogeneity group; *, the greatest roughness value
**: A: Wood type; B: Cutter blade type; C: Temperature of heat treatment; D: Duration of heat treatment

CONCLUSIONS

1. Heat treatment has been recommended for the stabilization of wood material and the increase in resistance against pest and fungi (Wikberg 2004; Enjily and Jones 2006; Boonstra 2008; Korkut and Kocaefe 2009; Yıldız *et al.* 2006; Kocaefe *et al.* 2007; Korkut *et al.* 2008; González-Peña *et al.* 2009; Gündüz *et al.* 2009; Korkut and Budakçı 2009; Korkut and Hızıroğlu 2009; Korkut and Budakçı 2010; Budakçı *et al.* 2011). Heat treatment was shown to have a roughness-increasing effect in the present study as a result of giving the wood material a crisp structure, thereby increasing its hardness. In addition, the color changes associated with the oxidation of the secondary metabolites in the wood material at elevated temperatures was another issue that drew attention.
2. The results of the study indicate that the use of star or razor blades in planing did not cause any difference in surface roughness values. Therefore, either type of blade can be used effectively in the planing of heat-treated or untreated wood material surfaces.
3. Moreover, the use of touch scan (spiny) methods as a generally accepted evaluation technique for measuring two dimensional surface roughness was criticized for its poor reliability due to the erroneous measurements that were obtained, specifically in the evaluation of anisotropic surfaces such as wood materials. As an alternative to this method, Laser Displacement Sensors (LDS) that enable a three dimensional characterization of the surfaces through non-touch optical reader-based techniques would be preferred to obtain the measurements to achieve more objective results.

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REFERENCES CITED

Akyıldız, M. H., and Ateş, S. (2008). "Effect of heat treatment on equilibrium moisture content (EMC) of some wood species in Turkey," *Research Journal of Agriculture and Biological Sciences* 4(6), 660-665.

Boonstra, M. J., and Tjeerdsma, B. (2006). "Chemical analysis of heat treated softwoods," *Holz als Roh- und Werkstoff* 64, 204-211.

Boonstra, M. J. (2008). "A two-stage thermal modification of wood," Ph.D. Dissertation Cosupervised at Ghent University and Université Henry Poincaré – Nancy 1, 297 p. ISBN 978-90-5989-210-1.

Bourgois, J., Janin, G., and Guyonnet, R. (1991). "Measuring colour: A method of studying and optimising the chemical transformations of thermally-treated wood," *Holzforschung* 45(5), 377-382.

Budakçı, M., İlçe, A. C., Sevim Korkut, D., and Gürleyen, T. (2011). "Evaluating the surface roughness of heat-treated wood cut with different circular saws," *BioResources* 6 (4), 4247-4258.

Dizman Tomak, E., and Yıldız Ü. C. (2010). "The chemical modification of wood," III. National Karadeniz Forestry Conference, Book: IV, 1681-1690.

Efe, H., Demirci, S., and Kılıç, Y. (2003). "Effect of cutter direction, number of cutter, recharge rate and depth of cut to surface smoothness on the wood of Fagus Orientalis Lipsky for planning," Gazi University, Journal of Kastamonu Faculty of Forestry, 3(1), 77-87.

Efe, H., and Gürleyen, L. (2003). "The effects of cutting direction, number of cutter and the rotation value on surface smoothness for some wood species," *The Journal of the Industrial Arts Education Faculty of Gazi University*, 11(12), 34-35.

Efe, H., and Gürleyen, L. (2007). " The effects of cutter direction, number of cutter and the rotation value on surface smoothness for planning wood material," *Kastamonu University, Journal of Kastamonu Faculty of Forestry*, 7(1), 1-12.

Enjily, V., and Jones, D. (2006). "The potential for modified materials in the panel products industry," *Wood Resources and Panel Properties* Conference, Spain, 12-14 June, COST Action E44/E49.

Fengel, D., and Wegener, G. (1989). *Wood: Chemistry, Ultrastructure, Reactions*, Walter De, Germany.

González-Peña, M. M., Curling, S. F., and Hale, M. D. C. (2009). "On the effect of heat on the chemical composition and dimensions of thermally-modified wood," *Polymer Degradation and Stability* 94(12), 2184-2193.

Gündüz, G., Korkut, S., Aydemir, D., and Bekar, İ. (2009). "The density, compression strength and surface hardness of heat treated hornbeam (*Carpinus betulus* L.) wood," *Maderas Cienciay Tecnologia* 11(1), 61-70.

ISO 4287. (1997). "Geometrical product specifications surface texture profile method terms, definitions and surface texture parameters," *International Standards Organization*.

Jakub, S., and Martino, N. (2005). "Wood surface roughness-what is it?", Trees and timber research institute, Ivalsa/Cnr. (http://www.boku.ac. at/physik /coste35/Rosenheim/article/art_Sandak_COST_E35_Rosenheim_2005.pdf.)

Kantay, R., and Ünsal, O. (2002). "Investigation of surface roughness of oak and beech wood parquets produced in Turkey," *Istanbul University Review of the Faculty of Forestry, Series: A* 52(1), 81-97.

Kocaefe, D., Younsi, R., Poncsak, S., and Kocaefe, Y. (2007). "Comparison of different high temperature wood heat treatment models," *International Journal of Thermal Sciences* 46(7), 707-716.

Korkut, S., and Bakangil, O. (2007). "Heat treatment methods," *Woodwork Furniture, Furniture Industry, Architecture, Decoration and Research Magazine*, 28-34.

Korkut, S., Kök, M. S., Sevim Korkut, D., and 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.

Korkut, S., and Budakçı, M. (2009). "Effect of high-temperature treatment on the mechanical properties of rowan (*Sorbus aucuparia* L.) wood," *Drying Technology* 27(11), 1240-1247.

Korkut, S., and Hızıroğlu, S., (2009). "Effect of heat treatment on mechanical properties of hazelnut wood (*Corylus Colurna L.*)," *Materials & Design* 30 (5), 1853-1858.

Korkut, S., and Kocaefe, D. (2009). "Effect of heat treatment on wood properties," *Düzce University, Journal of Forestry* 5(2), 11-34.

Korkut, S., and Budakçı, M. (2010). "The effects of high-temperature heat-treatment on physical properties and surface roughness of rowan (*Sorbus aucuparia* L.) wood," *Wood Research* 55(1), 67-78.

Malkoçoğlu, A. (2007). "Machining properties and surface roughness of various wood species planed in different conditions," *Building and Environment* 42(7), 2562-2567.

Mayes, D., and Oksanen, O. (2002). *ThermoWood Handbook*, Finnforest, Finland.

Millett, M. A., and Gerhards, G. C. (1972). "Accelerated aging: Residual weight and flexural properties of wood heated in air at 115 °C to 175 °C," *Journal of Wood Science* 4 (4), 193-201.

Örs, Y., and Baykan, I. (1999). "The effects of planning and sanding on surface roughness for solid wood material," *Turkish Journal of Agriculture and Forestry* 23(3), 577-582.

Örs, Y., and Gürleyen, L. (2002). "Effect of the cutting direction, number of cutter and cutter type to surface smoothness on wood material for planning," Gazi University, Technical Education Faculty, *Journal of Polytechnic* 5(4), 335-339.

Sernek, M., Boonstra, M., Pizzi, A., Despres, A., and Gérardin, P. (2008), "Bonding performance of heat treated wood with structural adhesives," *European Journal of Wood and Wood Products* 66(3), 163-242.

Sevim Korkut, D., Korkut, S., Bekar, İ., Budakçı, M., Dilik, T., and Çakıcıer, N. (2008). "The effects of heat treatment on the physical properties and surface roughness of Turkish hazel (*Corylus colurna* L.) wood," *International Journal of Molecular Sciences* 9, 1772-1783.

Söğütlü, C. (2004). "Using feasibility of some local wood species in making kündekâri," *Ph.D. Thesis*, Gazi University Institute of Science and Technology, 67-82.

Söğütlü, C. (2005). "The effect of some factors on surface roughness of sanded wood material," Gazi University, Technical Education Faculty, *Journal of Polytechnic* 8(4), 345-350.

Stewart, H. A. (1970). "Cross-grain knife planing hard maple produces high quality surfaces and flakes," *Forest Products Journal* 20(20), 39-42.

Stumbo, D. A. (1960). "Surface texture measurement for quality and production control", *Forest Products Journal* 10(12), 122-124.

Suttie, E., and Thompson, J. H. R. (2001). "Opportunites for UK grown timber: Wood modification state of the art review," DTI Contruction Industry Directorate and Forestry Commission, Project Report Number 203-343.

TS. 2470. (1976). "Methods of sampling for physical and mechanical testing of wood and general properties," Turkish Standards Institution.

TS. 2471. (1976). "Determination of moisture content for physical and mechanical tests of wood," Turkish Standards Institution.

Usta, İ., Demirci, S., and Kiliç, Y. (2007) "Comparison of surface roughness of locust acacia (*Robinia pseudoacacia* L.) and European oak (*Quercus petraea (*Mattu.) Lieble.) in terms of the preparative process by planing," *Building and Environment*, 42, 2988-2992.

Viitanen, H., Jämsä, S., Paajanen, L., Nurmi, A., and Viitaniemi, P. (1994). "The effect of heat treatment on the properties of spruce, A preliminary report," *International Research Group On Wood Preservation*, IRG/WP 94-40032, 03-06 May, Nusa Dua, Bali, Indonesia.

Wikberg, H. (2004). "Advanced solid state NMR spectroscopic techniques in the study of thermally modified wood," Academic Dissertation, University of Helsinki, Department of Chemistry, Laboratory of Polymer Chemistry, Helsinki, Finland.

Yıldız, S. (2002). "Physical, mechanical, technological and chemical properties of beech and spruce wood treated by heating," Ph.D. Thesis, Karadeniz Technical University, Trabzon.

Yıldız, S., Gezer, E. D., and Yıldız, Ü. C. (2006). "Mechanical and chemical behavior of spruce wood modified by heat," *Building and Environment* 41(12), 1762-1766.

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