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THE EFFECT OF THE FEEDING DIRECTION AND FEEDING SPEED OF PLANING ON THE SURFACE ROUGHNESS OF ORIENTAL BEECH AND SCOTCH PINE WOODS

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ABSTRACT

The objective of this study is to determine the effect of the feeding direction and feeding speed of planing on the surface roughness of the Oriental beech (*Fagus orientalis* L.) and Scotch pine (*Pinus silvestris* L.) wood species grown in the Black Sea Region of Turkey. When preparing the specimens, the wood was planed tangentially and radially to the annual rings at a cutting depth of 1.4 mm in a milling machine with 4 blades and an 85 mm diameter. The wood was planed in the direction of spindle rotation and in the direction opposite of the spindle rotation at feeding speeds of 6 m.min^{-1}, 9 m.min^{-1}, and 12 m.min^{-1} and a rotation speed of about 7200 rpm. The surface roughness values of the specimens were determined by using a stylus-type profilometer according to the ISO 4287 standards. The surface roughness was evaluated according to the R_a, R_z, and R_y principles, which are three basic parameters. The results showed that smoother surfaces could be obtained in the planing realized by feeding in spindle rotation. Furthermore, the tangential direction produced smoother surfaces compared to the radial direction and as the feeding speed increased, the surface roughness also increased.

KEY WORDS: wood, surface roughness, planing, feeding direction, feeding speed

INTRODUCTION

Wood, although light in weight, has many superior characteristics for widespread interior and exterior decoration. For example, it can be easily shaped using a low consumption of energy. It has a low sound, heat, and electrical transmission, and it has a high resistance to chemical substances. Moreover, wood can be finished aesthetically by staining and varnishing (Kurtoglu 2000, Kopac and Sali 2003, Aydin and Colakoglu 2005). Oriental beech and Scotch pine are the preferred species in the production of internal and external decoration elements in Turkey. Oriental beech is used in the production of interior space elements and furniture production. In contrast, Scotch pine is used primarily in the production of windows and external decoration elements subjected to outdoor weather conditions.

Wood is used in the production of desired dimensions and shapes for internal and external decorative elements by such processes as cutting, planing and sanding. However, when a piece of wood is processed repeatedly, production costs increase, and the quality of the product decreases as the result of the additional shaping, thus affecting the finishing quality. Consequently, it is necessary to specify the correct production parameters by using numerical data to provide for the sustainability of the selected processing conditions, the most effective being the determination of its surface roughness.

The methods for determining surface roughness and the standards developed were first of all used in the metal industry, and these studies were also used in the determination of the surface roughness of wood in various countries and at various times (Krisch and Csiha 1999, Elmendorf and Vaughan 1958).

Surface roughness can be determined by various methods, such as the optical, pneumatic, electrical, ultrasonic, photographic and stylus methods (Gurau et al. 2005, Sandak and Tanaka 2005). It has been stated that the stylus-type profilometer is suitable within the tested methods for the measurement of the surface roughness of wood (Sieminski and Skarzynska 1989). The surface roughnesses of Oriental beech (*Fagus orientalis* Lipsky) and Trembling aspen (*Populus tremula* L.) were determined with a stylus-type profilometer after the wood underwent the cutting, planing and sanding processes. It was determined at the conclusion of the study that as the processing parameters changed the surface roughnesses also changed. Furthermore, it was stated that the stylus method could be used successfully in the determination of the surface roughnesses of planed and sanded wood and in distinguishing the differences (Kilic et al. 2006).

Since cavities are formed among the vessels, tracheids, medullary rays, parenchyma, resin canals, and fibers as a result of cutting the cells with different cutters in the process of shaping the wood in machines, the processing systems, such as cutting, peeling and planing (Sulaiman 2009), further influence the surface roughness. The anatomic structure of the wood, especially the cell cavities, and the nonhomogeneous structure of the wood is influential in the size of these cavities (Strumbo 1963, Peters and Cumming 1970). Surface roughness is also influenced by the cross grain annual ring width, rays, knots, reaction wood, ratio of early wood and late wood (Taylor et al. 1999).

A tangential direction in the planing process produces a smoother surface compared to a radial direction. As the number of cutters is increased, the surface roughness values decrease, and as the feeding speed increases, the surface roughness also increases (Ors and Baykan 1999, Roger and Cool 2008). It has been confirmed in various studies that should variables such as the feeding speed not be selected correctly, then the desired surface quality is not obtained (Fujiwara et al. 2001).

It has been stated that when the Oriental beech (*Fagus orientalis* Lipsky) and Scotch pine (*Pinus silvestris* L.) wood specimens were prepared by planing, the surface roughness was less in the tangential cut compared to the radial cut. Furthermore, the surface roughness was less in the planing with 4 cutters compared to planing with 2 cutters and that the main effects of the cutting direction–number of cutters were statistically insignificant (Ors and Gurleyen 2002).

Surface roughness is an important factor in the quality of the internal and external decoration elements produced from wood and the fact that these are at low values not only positively affects the appearance of the finished product, it is also effective on both the upper surface requisites and the adhesion of the glues (Aslan et al. 2008, Richter et al. 1995, Malkocoglu 2007, Coelho et al. 2008).

The effect on the surface roughness of the wood species, cutting direction, feeding speed, number of cutters, and the types of processes were investigated in the previous studies. However, the aforementioned research did not study how the feeding in direction related to spindle rotation influenced the surface roughness in the process of planing Oriental beech (*Fagus orientalis* L.) and Scotch pine (*Pinus silvestris* L.) wood species which are grown and used in a widespread manner in Turkey. In this study, the effect of both the feeding direction and feeding speed in the planing process on the surface roughness of wood was investigated.

MATERIAL AND METHODS

Oriental beech (*Fagus orientalis* L.) and Scotch pine (*Pinus silvestris* L.), which grow naturally in Turkey, were used in the tests. The wood used in the tests was obtained with the *random selection* method from the Eastern Black Sea Region. Great care was taken when preparing the test specimens so that the wood was without knots, without fungal rot, and without growth faults and that they had smooth fibers. The average air-dried (12 % moisture content) densities of the wood used in the tests were 0.668 $g.cm^{-3}$ in the Oriental beech and 0.518 $g.cm^{-3}$ in the Scotch pine.

The preparation of the specimens conformed to the standards of the ASTM-D 1666-87, 1999. A total of 240 test specimens were prepared in the dimensions of 22 x 60 x 600 mm, 10 for each of the following variables: wood species (2), feeding direction (2), feeding speed (3) and cutting direction (2). The rough specimens were kept in a climatization chamber at a temperature of 20 ± 2 °C and a relative humidity of 65 ± 5 % until they reached an unchanging weight (12 % moisture content). The rough specimens were planed at feeding speeds of 6 $m.min^{-1}$, 9 $m.min^{-1}$, and 12 $m.min^{-1}$ in a tangential and radial direction to their annual rings by feeding in the direction of spindle rotation and in the direction opposite of the spindle rotation. The planing procedure was realized in a horizontal milling machine with 4 blades having a diameter of 85 mm. In this process, the cutting depth was adjusted to 1.4 mm, and the spindle rotation was at 7200 rpm. These conditions were not changed until the process was completed. The feeding direction and other factors were labeled with symbols on the back surfaces of the specimens.

Three parameters are commonly used in the evaluation of surface roughness. These are the arithmetical mean deviation of profile (R_a), ten-point height of irregularities (R_z) and the maximum height of profile (R_y). Ra is the average distance from the profile to the mean line over the length of assessment. R_z can be calculated from the peak-to-valley values of five equal lengths within the profile, while maximum roughness (R_y) is the distance between peak and valley points of the profile, which can be used as an indicator of the maximum defect height within the assessed profile (Korkut and Guller 2008, Hiziroglu 1996).

The surface roughness was determined by conforming to the ISO 4287, 1997 standards. The stylus-type profilometer (*TIME TR–200*) was used in the measurement of the surface roughness. This equipment has a 10 $mm.min^{-1}$ measuring speed, a 5 μm pin radius, and a 90° probe angle (TS 2495 EN ISO 3274, 2005). After adjusting the equipment to a 5 cut-off length (λ_c) and a 2.5 mm sampling length, the measurements were made on the specimens in a direction perpendicular to the fibers.

The analysis of variance was determined for the main effects among the wood species, cutting direction, feeding direction, and feeding speed factors for every surface roughness parameter (R_a, R_z, R_y). In cases where the difference among the groups was found to be statistically significant at the level of 0.01, they were separated into homogeneity groups according to the critical values of the least significant difference (*LSD*) by using the Duncan test. The data was evaluated at an 0.99 level of reliability in the MSTAT–C package program written for a PC.

RESULTS AND DISCUSSION

The average surface roughness values (R_a, R_z, R_y) for the wood species, feeding direction, feeding speed, and cutting direction have been given in Tab. 1.

Tab. 1: Arithmetic means (µm) of the surface roughness values according to test variables

Wood species	Feeding direction	Feeding speed m.min^{-1}	Cutting direction	Surface roughness parameters (µm)					
				R_a		R_z		R_y	
				$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
Oriental beech	DOSR	6	R	5.372	0.233	31.93	1.09	40.33	1.79
			T	4.971	0.162	30.34	1.12	37.06	1.05
		9	R	5.448	0.322	32.53	1.41	40.74	1.76
			T	5.216	0.279	30.83	1.35	39.00	0.72
		12	R	5.682	0.294	33.47	1.42	42.35	1.96
			T	5.534	0.322	31.83	1.65	41.71	3.48
	DSR	6	R	4.942	0.127	30.88	0.97	38.77	1.67
			T	4.805	0.132	29.46	0.64	36.91	0.96
		9	R	5.342	0.190	30.95	1.18	39.08	0.87
			T	5.092	0.120	30.39	0.83	38.23	1.06
		12	R	5.576	0.205	32.49	1.10	40.49	2.20
			T	5.383	0.137	31.78	0.66	39.55	1.03
Scotch pine	DOSR	6	R	4.481	0.400	23.94	1.21	32.73	1.94
			T	4.246	0.434	22.79	1.18	31.99	1.47
		9	R	4.583	0.318	25.97	1.51	33.48	1.90
			T	4.331	0.425	24.18	1.56	33.12	1.91
		12	R	4.714	0.245	27.15	1.53	36.27	1.99
			T	4.476	0.205	25.69	1.11	34.09	1.95
	DSR	6	R	4.304	0.308	22.60	0.92	31.59	087
			T	4.018	0.138	21.46	1.02	29.78	1.03
		9	R	4.469	0.289	24.35	1.12	33.47	1.67
			T	4.138	0.342	22.30	1.26	30.98	2.48
		12	R	4.612	0.299	26.26	1.28	35.33	1.87
			T	4.340	0.375	23.55	1.83	31.78	1.17

$\overline{X}$: Arithmetic means (µm); s: Standard deviation; R: Radial; T: Tangential
DSR: Direction of spindle rotation; DOSR: Direction opposite to spindle rotation

When Tab. 1 is examined, it is observed that there is a difference in the surface roughness values according to the process parameters. The results of the analysis of variance made to determine from which factors these differences stem from have been given in Tab. 2.

Tab. 2: Results of the variance analysis for the surface roughness values of processing parameters

Source		Sum of squares	df	Mean square	F	Sig.
R_a	Wood species (A)	47.438	1	47.438	574.266	0.000*
	Feeding direction (B)	1.690	1	1.690	20.462	0.000*
	A x B	0.008	1	0.008	0.108	0.743
	Feeding speed (C)	6.248	2	3.124	37.817	0.000*
	A x C	0.637	2	0.319	3.856	0.013**
	B x C	0.206	2	0.103	1.244	0.290
	A x B x C	2.118	2	1.059	0.348	0.643
	Cutting direction (D)	3.731	1	3.731	45.163	0.000*
	A x B x D	0.030	2	0.015	0.192	0.826
	A x C x D	0.086	2	0.043	0.051	0.950
	B x C x D	0.002	2	0.001	0.050	0.995
	A x B x C x D	0.003	2	0.002	0.220	0.980
	Error	17.843	216	0.083		
	Total	78.138	239			
R_z	Wood species (A)	3129.726	1	3129.726	2033.687	0.000*
	Feeding direction (B)	83.827	1	83.827	54.471	0.000*
	A x B	7.399	1	7.399	4.808	0.059
	Feeding speed (C)	222.367	2	111.184	72.247	0.000*
	A x C	16.819	2	8.410	5.465	0.000*
	B x C	1.362	2	0.681	0.443	0.643
	A x B x C	1.014	2	0.507	0.329	0.720
	Cutting direction (D)	133.683	1	133.683	86.867	0.000*
	A x B x D	5.891	1	5.891	3.8277	0.062
	A x C x D	4.900	2	2.450	1.592	0.206
	B x C x D	0.875	2	0.438	0.284	0.754
	A x B x C x D	2.573	2	1.287	0.836	0.635
	Error	332.411	216	1.539		
	Total	3947.049	239			

Source		Sum of squares	df	Mean square	F	Sig.
R_y	Wood species (A)	2674.339	1	2674.339	879.954	0.000*
	Feeding direction (B)	129.316	1	129.316	42.550	0.000*
	A x B	0.014	1	0.014	0.005	0.946
	Feeding speed (C)	302.038	2	151.019	49.691	0.000*
	A x C	2.547	2	1.028	0.337	0.714
	B x C	4.338	2	2.169	0.714	0.574
	A x B x C	1.659	2	0.845	0.277	0.758
	Cutting direction (D)	158.649	1	158.649	52.201	0.000*
	A x B x D	12.490	1	12.490	4.110	0.064
	A x C x D	21.286	2	10.643	3.502	0.082
	B x C x D	0.910	2	0.445	0.149	0.861
	A x B x C x D	2.470	2	1.235	0.405	0.667
	Error	656.463	216	3.039		
	Total	3976.480	239			

*: Significant at 99% confidence level; **: Significant at 95% confidence level.

When Tab. 2 is examined, it can been observed that the wood species, feeding direction, feeding speed, cutting direction and some main effects of these for the surface roughness parameters (R_a, R_z, R_y) are statistically significant at the level of 0.01 or 0.05.

The Duncan test comparison results made to determine the success orders and homogeneities of the process parameters were determined to be statistically significant at the level of 0.01 according to the surface roughness parameters and have been given in Tab. 3 for the wood species and in Tab. 4 for the feeding direction.

Tab. 3: Results of the Duncan test for the wood species

Surface roughness parameters (µm)	Wood species	Homogeneous subsets	
		1	2
R_a (LSD ± 0.026)	Scotch pine	4.391	
	Oriental beech		5.280
R_z (LSD ± 0.316)	Scotch pine	24.18	
	Oriental beech		31.41
R_y (LSD ± 0.443)	Scotch pine	32.89	
	Oriental beech		39.57

The surface roughnesses (R_a, R_z, R_y) were at lower levels in the Scotch pine compared to the Oriental beech. The fact that a smoother surface was obtained in the Scotch pine is in conformance with the studies in the literature (Krish and Csiha 1999, Kurtoglu 2000, Malkocoglu 2007, Ors and Baykan 1999). This situation could stem from the fact that the texture in the Scotch pine is finer than that in the Oriental beech.

Tab.4: Results of the Duncan test for the feeding direction

Surface roughness parameters (µm)	Feeding direction	Homogeneous subsets	
		1	2
R_a (LSD ± 0.073)	DSR	4.752	
	DOSR		4.920
R_z (LSD ± 0.316)	DSR	27.21	
	DOSR		28.38
R_y (LSD ± 0.443)	DSR	35.50	
	DOSR		36.96

DSR: Direction of spindle rotation;
DOSR: Direction opposite to spindle rotation

When Tab. 4 is examined, if the piece being worked in the planing process is advanced in the direction of spindle rotation, then it is observed that the roughness is at low values. This situation could stem from the fact that the blades are not breaking fibers from the surface of the wood during the removal of chips.

The Duncan test results made for feeding speed and cutting direction have been given in Tabs. 5 and 6.

Tab. 5: Results of the Duncan test for the feeding speed

Surface roughness parameters (µm)	Feeding speed ($m.min^{-1}$)	Homogeneous subsets		
		1	2	3
R_a (LSD ± 0.090)	6	4.642		
	9		4.828	
	12			5.037
R_z (LSD ± 0.386)	6	26.68		
	9		27.69	
	12			29.03
R_y (LSD ± 0.543)	6	34.97		
	9		36.02	
	12			37.69

According to the Duncan test results, as the feeding speed increases, the surface roughness values also increase. When the studies in the literature are examined, it can be stated that there is proportional relationship between the feeding speed and the surface roughness. The values obtained in this study are in conformance with the values in the literature (Krish and Csiha 1999, Malkocoglu 2007, Richter et al. 1995). Therefore, because feeding speed influences the average thickness of chips, that could be reason for different surface roughness when feeding speed increases.

Tab. 6: Results of the Duncan test for the cutting direction

Surface roughness parameters (µm)	Cutting Direction	Homogeneous subsets	
		1	2
R_a (LSD ± 0.732)	Tangential	4.711	
	Radial		4.960
R_z (LSD ± 0.316)	Tangential	27.05	
	Radial		28.54
R_y (LSD ± 0.443)	Tangential	35.42	
	Radial		37.04

When Tab. 6 is examined, it was found that the surface roughness values (R_a, R_z, R_y) were higher in a radial direction compared to a tangential direction. At the end of tests realized with similar conditions in the literature, it was stated that the radial direction produced rougher surfaces compared to the tangential direction. The findings obtained in this study support the information given in the literature (Krish and Csiha 1999, Kurtoglu 2000, Ors and Baykan 1999). The fact that the radial direction produced rougher surfaces compared to the tangential direction could stem from the fact that the structural configuration of the wood is different in this direction and from the fact that fibers break off from the springwood tissue (Kilic et al. 2006, Korkut and Guller 2008).

The Duncan test results for the surface roughness parameters (R_a, R_z) of the wood species-feeding speed main effects have been given in Tab. 7.

Tab. 7: Results of the Duncan test for the wood species-feeding speed

Wood species	Feeding speed $m.min^{-1}$	Homogeneous subsets									
		R_a (LSD± 0.127)					R_z (LSD± 0.733)				
		1	2	3	4	5	1	2	3	4	5
Scotch pine	6	4.262					22.70				
	9	4.380						24.20			
	12		4.531						25.66		
Oriental beech	6			5.022						30.66	
	9				5.275					31.17	
	12					5.544					32.99

The lowest surface roughness (R_a, R_z) was found in the Scotch pine at a 6 $m.min^{-1}$ feeding speed, whereas, it was the highest in the Oriental beech at a 12 $m.min^{-1}$ feeding speed. At the end of the planing processes, Ra values for Scotch pine between 6 $m.min^{-1}$ and 9 $m.min^{-1}$ feeding speeds and R_z for Oriental beech between 6 $m.min^{-1}$ and 9 $m.min^{-1}$ feeding speeds were statistically insignificant at a reliability level of 0.05. When the evaluation results within the group are examined (Tabs. 3 and 5), it is observed that the Scotch pine has lower surface roughness values compared to the Oriental beech and at the same time, as the feeding speed increases, the roughness also increases. This situation was also influential on the dual comparisons and showed a similarity to the studies in the literature (Krish and Csiha 1999, Malkocoglu 2007, Richter et al. 1995).

CONLUSIONS

According to the test results, in case the planing parameters are different, then the surface roughness values obtained are also acquiring a different character. In case the feeding direction of work piece in planing is in the direction of spindle rotation (cutting speed) the surface roughness values of R_a, R_z, and R_y were lower than in case when the feeding direction is opposite to spindle rotation (cutting speed). Furthermore, the radial direction produced rougher surfaces compared to the tangential direction and as the feeding speed increased, the surface roughness also increased. It was stated in the studies in the literature that the Scotch pine compared to the Oriental beech, the tangential cut compared to the radial cut and a lower feeding speed produced smoother surfaces. It is of importance that this study, however, has determined that feeding direction is an effective factor on surface roughness. Feeding speeds between 6 $m.min^{-1}$ and 9 $m.min^{-1}$ about R_a values for Scotch pine and R_z values for Oriental beech were statistically insignificant as seen in Tab. 7. This situation shows that the planing amount made in one minute can be increased from 6 $m.min^{-1}$ to 9 $m.min^{-1}$ provided that the surface roughness remains at the same values. It is a known fact that the priority target of commercial enterprises is to lower the production costs by increasing the production amounts made in a unit of time and consequently, to increase the ratio of profits and those enterprises are seeking different production processes in order to realize this. In conclusion, in addition to the information in the literature, it can be said that benefits would be provided by making the feeding in the direction of spindle rotation in planing, both from the aspect of decreasing the operating production costs and from the aspect of an increase in the amount of work done in a unit time. Furthermore, it would be beneficial for the literature and the woodworking industry to engage in studies that would examine the effects of feeding direction on surface quality and energy consumption by treating the different planing conditions of the different wood species.

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