Determination of the Surface Roughness Values of Turkish Red Pine (*Pinus brutia* (Ten.)) Woods

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The aim of this study was to determine the surface roughness values of Turkish red pine samples obtained from the seven natural growth areas in Turkey. The samples were cut with a circular saw, planed with a thickness machine, and sanded with a sanding machine (with No. 80 sandpaper). After the samples were processed as radial and tangential surfaces in the machines, their surface roughness values (R_a, R_y, and R_z) were measured in accordance with ISO 4288 (1996). According to the statistical results, the lowest surface roughness values were in the samples obtained from the Muğla and Samsun areas on the tangential surfaces that were processed with the thickness machine.

Keywords: Surface roughness; Turkish red pine; Pinus brutia Ten woods; Wood machining; Cutting directions

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INTRODUCTION

Wood materials have many uses in construction and furniture production. While the most important aspects in the selection of wood materials for the construction sector are the mechanical properties, the aesthetic and mechanical properties are important for the material used in furniture (Aslan *et al.* 2008).

Surface roughness is the most important property in wood material used in furniture production. Surface roughness affects the quality of furniture because aesthetic concerns are significant in this industry (Ilter *et al.* 2002; Salca and Hiziroglu 2014; Söğütlü *et al.* 2016).

Among the methods used to minimize surface roughness, the most important one is increasing the number of machine cutters and processing wood materials in the low feed speed (Hiziroglu and Suchsland 1993; Hiziroglu 1996). Another successful method for processing wood in the direction of cutting involves usage of a down-milling machine. The results obtained in applications carried out tangentially are known to give better results compared to application carried out radially (Kılıç *et al.* 2006; Kılıç 2015; Kılıç 2016).

In the cutting, planing, and sanding processes of wood material, the accurate selection of processing conditions is very important to avoid undesired negative results, primarily surface roughness. Roughness on the wood surface can be minimized with additional precautions, such as increasing the knife and rotation numbers in the machines used to process wood (Pelit *et al.* 2015; Tiryaki *et al.* 2015).

The growth area of Turkish red pine *(Pinus brutia* (Ten.)) is expanding throughout the world and within Turkey. This species has a high economical value and is a principal tree species for Turkey. Forests covered an area of 21,678,134 hectares in Turkey in 2014, which was 27.6% of the country's total area. Turkish red pine has an expansion area of 5,854,673 hectares (General Directory of Forestry 2014). The Turkish red pine is one of

the most important primary tree species in Turkey. Therefore, the study of its basic wood properties is a top priority.

The surface roughness of wood material does not directly affect the surface roughness processes or the bonding resistance. Currently, there are no reports on the surface roughness values of Turkish red pine. For this reason, determining the surface roughness of the Turkish red pine wood is the subject of this study (Fig. 1).

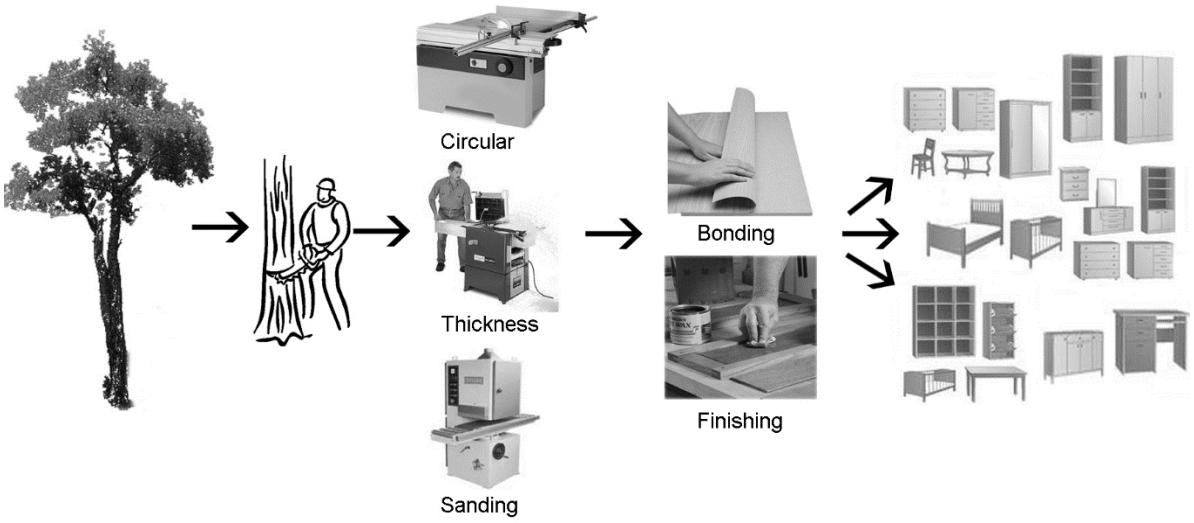

Fig. 1. The importance of surface roughness in the processing of furniture

In the evaluation of surface roughness, three parameters are widely used. These are R_a, which is the average deviation of the profile; R_z, which is the average of the height of the irregularity at 10 points, and R_y, which is the highest level of the profile.

EXPERIMENTAL

The experiment materials were selected from areas in Adana-Pos, Antalya-Düzlerçamı, Burdur-Bucak, Mersin-Silifke, Samsun-Bafra, Kahramanmaraş-Topçam, and Muğla-Kıyra, which are Turkish red pine natural growth areas in Turkey. For each region, a total of 21 trees from 7 different areas were selected (3 trees per area). The trees were cut in accordance with ISO 4471 (1982). Information about the areas is presented in Table 1.

The trial materials were cut to dimensions of 60 x 500 mm and placed in an environmental test chamber until air-dried humidity (12%) was reached. (Table 2).

The effect of three different surface processing types on Turkish red pine was determined using two cutting directions, tangential, and radial.

Two cutting directions (radial and tangential) and three surface treatment techniques (cutting by circular saw, planning, and sanding) were used in this work, and 300 measurements were taken with 50 test repetitions (2 x 3 x 50=300). In total, 2100 surface roughness measurements were performed for the seven different areas.

As the final process for the Turkish red pine, the samples were planed with a thickness machine three blades (4500 rev/min), cut with a 40-tooth circular saw machine (diameter 30 cm) (6000 rev/min), and sanded with a caliber sanding machine (with No: 80 sandpaper).

Table 1. Information Related to Origins

Origins	Antalya*	Adana	Muğla*	Samsun*	K. Maraş	Mersin	Burdur*
Regional Directorate	Antalya	Adana	Muğla	Amasya	K. Maraş	Mersin	Isparta
Forest District Directorates	Antalya	Pos	Ula	Bafra	K. Maraş	Silifke	Bucak
Forest Sub-district Directorates	Düzlerçamı	Soğukoluk	Kızılyaka	Yakakent	K. Maraş	Yeşilovacık	Pamucak
Region	370 368 371	215	14	5	143	138 139	182
Latitude	36°55’0’’N 37°15’28’’N	37°34’46’’N 37°34’73’’N	36°56’35’’N 37°06’37’’N	41°22’38’’N 41°41’06’’N	37°36’27’N 37°40’40’’N	36°15’38’’N 36°15’09’’N	37°27’N
Longitude	30°25’05’’E 30°37’56’’E	35°18’55’’E 35°18’25’’E	28°24’21’’E 28°34’10’’E	35°18’57’’E 35°48’10’’E	36°35’12’’E 36°55’12’’E	33°42’11’’E 33°42’06’’E	30°40’’E
Altitude(m)	150-250	796-812	700-800	30-160	861-900	400-460	800
Air-dried density (g/cm³)	0.580	0.557	0.608	0.588	0.532	0.595	0.602

*****(Ilter *et al.* 2011)

During sample processing, the feeding rate was fixed at 10 m/min. Surface roughness values were measured with a Mitutoyo SJ-301 device (Kawasaki, Japan), which measures with the stylus method, in accordance with ISO 4288 (1996) (Fig. 2). The surface roughness was measured on the fibers in a perpendicular direction with a ± 0.01 μm sensitivity (measurement speed 0.5 m/sec; cut-off wavelength (lc) 4 mm; measurement length (lt) 21 mm; diamond tip stylus; tip angle 90°/tip; and radius 2 μm) in accordance with ISO 4288 (1996).

Table 2. Properties of Experimental Trees

Region	Tree Number	1.30 m Diameter (cm)	Age	Length (m)
Antalya*	1	34	61	15.3
	2	30	76	20.1
	3	30	57	21
Samsun*	1	36	90	17.3
	2	38	111	13.8
	3	36	100	18.1
Muğla*	1	52	90	31.9
	2	50	105	32.5
	3	50	110	20.7
Burdur*	1	35	123	22.8
	2	38	115	22.2
	3	38	124	22.8
Adana	1	34	54	20
	2	37	60	20
	3	37	52	17.8
K. Maraş	1	33	45	17.3
	2	36	50	13.8
	3	38	59	18.1
Mersin	1	32	56	14
	2	34	50	13
	3	33	60	14.2

***(Ilter *et al.* 2011)

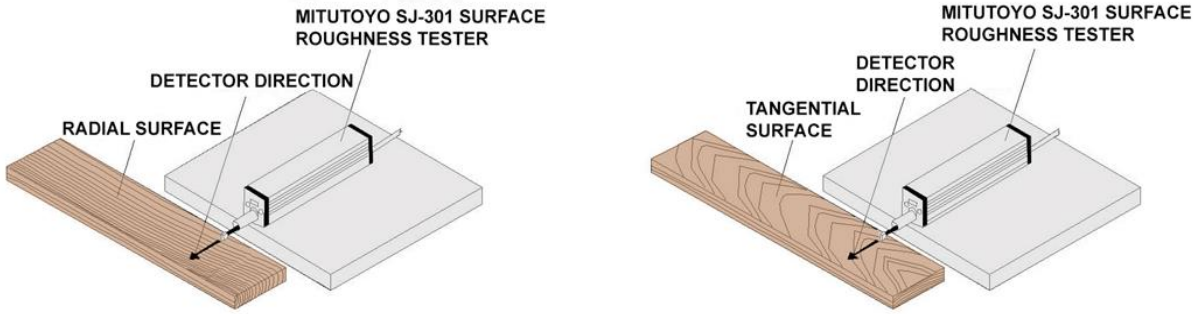

Fig. 2. Surface profilometer used in this study

With the purpose of presenting the effects of Region, Machine, and Cutting Direction (the main effect, double and triple interactions) on R_a, R_y, and R_z, the Univarite General Linear statistical model was used, and analysis was carried out. For the multiple

comparisons of the factors that were considered to be statistically important as a result of the overall F-test of each measurement, the Tukey HSD test was used. A statistical error with an importance level of type one has been determined as α=0.05. In terms of determining the difference effect level, Partial Eta squared statistics was used. The Partial Eta squared parameter indicates the level of effect and it is considered that as its value becomes closer to 1, the effect level increases.

RESULTS AND DISCUSSION

Evaluation of the Data Obtained for Ra (Average Roughness)

The statistical values and the results of the Tukey test according to the areas calculated for the average surface roughness (R_a) are presented in Table 3.

Table 3. Variance Analysis and Tukey's Test for Ra According to Region

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	P-value	Partial Eta Squared
Region (A)	563.140	6	93.857	127.939	0.00*	0.272
Machine (B)	2826.04	2	1413.02	1926.12	0.00*	0.652
Cutting Direction (C)	58.895	1	58.895	80.281	0.00*	0.038
A*B	314.238	12	26.186	35.695	0.00*	0.172
A*C	121.777	6	20.296	27.666	0.00*	0.075
B*C	46.844	2	23.422	31.927	0.00*	0.030
A*B*C	249.347	12	20.779	28.324	0.00*	0.142
Error	1509.764	2058	0.734			
Total	73876.647	2100				

ns : (not significant)
* : <0.05 important

Region	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Adana	300	6.4283	1.68589	2.54	9.98
Antalya	300	5.5365	1.52620	3.09	8.84
Burdur	300	5.8195	1.80622	2.67	9.86
K. Maraş	300	5.3039	1.55632	2.29	8.84
Muğla	300	5.1737	1.14806	3.01	7.94
Samsun	300	5.1623	1.41756	3.01	8.79
Mersin	300	6.4634	1.72141	3.06	9.92
Total	2100	5.6982	1.64646	2.29	9.98

		α = 0.05			
Region	N	1	2	3	4
Samsun	300	5.16			
Muğla	300	5.17			
K. Maraş	300	5.30			
Antalya	300		5.53		
Burdur	300			5.81	
Adana	300				6.42
Mersin	300				6.46

While the area, machine types, and cutting directions affected the R_a value, their double and triple effects were statistically significant in terms of the R_a value as well. In Table 3, the Partial Eta Squared effect value for R_a was found to be highest in Machine. According to the results of Tukey's tests for the areas, the lowest average surface roughness values were in Samsun (R_a = 5.16 μm), Muğla (R_a = 5.17 μm), and K. Maraş (R_a = 5.30 μm). There was no significant difference in the surface roughness values of these three areas.

The lowest average surface roughness value according to machine types was determined in the thickness machine (R_a = 4.54 μm), followed by the sanding machine (R_a = 5.26 μm), and the circular saw (R_a = 7.28 μm) (Table 4). When the statistical values were analyzed in terms of the cutting directions, the average surface roughness values of the tangentially cut samples were lower than the radially cut samples ($Ra_{Tangential}$ = 5.53μm, Ra_{Radial} = 5.86μm) (Table 4).

The R_a values determined in previous studies are lower in tangential surfaces than in the radial surfaces as well (Table 5).

Table 4. Statistical Values for Ra According to Machine Type and Cutting Direction

Machine	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Thickness	700	4.5412	1.62727	2.54	9.98
Sanding	700	5.2695	0.86382	2.29	7.93
Circular	700	7.2840	0.83850	4.98	9.84
Total	2100	5.6982	1.64646	2.29	9.98
Cutting Direction	**Number of Samples**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Radial	1050	5.8657	1.59912	3.01	9.98
Tangential	1050	5.5308	1.67658	2.29	9.92
Total	2100	5.6982	1.64646	2.29	9.98

Machine	N	α=0.05		
		1	2	3
Thickness	700	4.54		
Sanding	700		5.26	
Circular	700			7.28

Evaluation of the Data Obtained for R_y (R_{max}) (Maximum Roughness)

The statistical values and the results of the Tukey test according to areas calculated for R_y are presented in Table 6. Areas, machine types, and cutting directions affected the R_y value; however their double and triple effects were statistically significant in terms of the R_y value as well.

In Table 6, when the Partial eta squared value was analyzed for R_y, it was seen that the effect of machine was higher. According to the results of the Tukey's tests for the areas, the lowest average surface roughness values were in Muğla (R_y = 38.51 μm), Samsun (R_y = 39.04 μm), and K. Maraş (R_y = 39.04 μm). There was no statistical difference between the surface roughness of these three areas.

Table 5. The R_a Values Determined in Previous Studies

Wood Types	Cutting Direction	Machine		
		Thickness 2 Blade	Thickness 3 Blade	Sanding No.
		10 m/min	10 m/min	80
Eucalyptus camaldulensis Dehn. (İlter and Balkız 2005)	Radial	5.839	5.496	6.733
	Tangential	5.429	4.971	6.672
Bornmullerian Fir (İlter *et al.* 2002)	Radial	3.885	4.551	8.410
	Tangential	4.073	4.084	7.816
Pinus brutia Ten. (Burdurlu *et al.* 2006)	**Circular Saw**		-	-
	Radial	6.770	5.550	5.740
	Tangential	6.640	4.480	5.320
Pinus nigra Arnold. (Kılıç 2015)	Radial	7.17	5.11	5.48
	Tangential	6.86	4.41	4.63
Pinus brutia Ten.	Radial	7.28	4.68	5.63
	Tangential	6.90	4.39	4.90

The lowest average surface roughness value according to machine types was determined in the thickness machine (R_y = 35.84 μm), followed by the sanding machine (R_y = 40.78 μm), and the circular saw (R_y = 50.46 μm) (Table 7). When the statistical values were analyzed in terms of the cutting directions, the R_y surface roughness values of the tangentially cut samples were seen to be lower than the radially cut samples ($R_{y\ Tangential}$ = 41.58μm, $R_{y\ Radial}$ = 42.73μm) (Table 7).

Evaluation of the Data Obtained for Rz (Mean Peak-to-valley Height)

The statistical values and the results of the Tukey's test according to areas calculated for R_z are presented in Table 9. The areas, machine types, and cutting directions affected the R_z value; however, their double and triple effects were statistically significant in terms of the R_z value as well.

In Table 9, the Partial Eta squared effect for R_z was found the highest in Machine. According to Tukey's test for the areas, the lowest average surface roughness values were in Samsun (R_z = 30.44 μm) and Muğla (R_z = 30.48 μm). There was no statistical difference between these two areas' surface roughness values.

The lowest average ten-point height surface roughness values (R_z) in terms of machine types were found in the thickness machine (R_z = 27.59 μm), followed by sanding machine (R_z = 29.78 μm), and the circular saw (R_z = 41.19 μm) (Table 10). When the statistical values were analyzed in terms of the cutting directions, the R_z surface roughness values of the tangentially cut samples were lower than the radially cut samples ($R_{z\ Tangential}$ = 32.50 μm, $R_{z\ Radial}$ = 33.22 μm) (Table 8).

Table 6. Variance Analysis and Tukey's Test for Ry According to Region

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	P-value	Partial Eta Squared
Region (A)	20880.224	6	3480.037	78.591	0.00*	0.186
Machine (B)	83155.180	2	41577.590	938.966	0.00*	0.477
Cutting Direction (C)	684.389	1	684.389	15.456	0.00*	0.007
A*B	7374.962	12	614.580	13.879	0.00*	0.075
A*C	5337.211	6	889.535	20.089	0.00*	0.055
B*C	1235.546	2	617.773	13.951	0.00*	0.013
A*B*C	9927.495	12	827.291	18.683	0.00*	0.098
Error	91128.659	2058	44.280			
Total	3952296.87	2100				

* : <0.05 important

Region	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Adana	300	47.1800	9.68815	23.65	70.38
Antalya	300	41.0080	9.84699	24.13	65.17
Burdur	300	42.5842	10.26527	23.40	65.72
K. Maraş	300	40.4859	9.96464	20.24	69.63
Muğla	300	38.5169	7.50301	21.25	56.66
Samsun	300	39.0443	9.64871	20.31	67.00
Mersin	300	46.2965	10.96093	22.37	70.41
Total	2100	42.1594	10.23133	20.24	70.41

Region	N	α=0.05				
		1	2	3	4	5
Muğla	300	38.51				
Samsun	300	39.04	39.044			
K. Maraş	300		40.485	40.485		
Antalya	300			41.00	41.00	
Burdur	300				42.58	
Mersin	300					46.29
Adana	300					47.18

Table 7. Statistical Values for Ry According to Machine Type and Cutting Direction

Machine	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Thickness	700	35.23	7.15	20.24	67.0
Sanding	700	40.78	10.15	20.31	70.41
Circular	700	50.46	6.40	31.13	66.10
Total	2100	42.15	10.23	20.24	70.41
Cutting Direction	**Number of Samples**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Radial	1050	42.7303	9.70762	20.31	70.38
Tangential	1050	41.5885	10.70373	20.24	70.41
Total	2100	42.1594	10.23133	20.24	70.41
Machine		**N**	**α = 0.05**		
			1	2	3
Thickness		700	35.23		
Sanding		700		40.78	
Circular		700			50.46

Table 8. Statistical Values for R_z According to Machine Type and Cutting Direction

Machine	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Thickness	700	27.5977	4.11348	17.22	41.54
Sanding	700	29.7876	7.07630	17.04	57.59
Circular	700	41.1974	4.44540	41.1974	4.4454
Total	2100	32.8609	8.02844	41.1974	4.4454
Cutting Direction	**Number of Samples**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Radial	1050	33.2212	7.47205	17.25	57.59
Tangential	1050	32.5005	8.53707	17.04	58.30
Total	2100	32.8609	8.02844	17.04	58.30
Machine		**N**	**α = 0.05**		
			1	2	3
Thickness		700	27.59		
Sanding		700		29.78	
Circular		700			41.19

Table 9. Variance Analysis and Tukey's Test for R_z According to Region

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	P	Partial Eta Squared
Region (A)	9245.387	6	1540.898	82.045	0.00*	0.193
Machine (B)	74650.155	2	37325.077	1987.365	0.00*	0.659
Cutting Direction (C)	272.686	1	272.686	14.519	0.00*	0.007
A*B	4689.437	12	390.786	20.807	0.00*	0.108
A*C	1868.435	6	311.406	16.581	0.00*	0.046
B*C	581.612	2	290.806	15.484	0.00*	0.015
A*B*C	5333.353	12	444.446	23.664	0.00*	0.121
Error	38651.678	2058	18.781			
Total	2402952.80	2100				

* : <0.05 important

Region	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
Adana	300	35.7636	8.09175	17.04	54.34
Antalya	300	32.1755	7.68763	20.33	48.81
Burdur	300	33.9825	8.44534	18.30	57.59
K. Maraş	300	31.5715	7.97003	17.22	53.02
Muğla	300	30.4821	6.12042	17.39	47.04
Samsun	300	30.4478	7.33294	17.25	50.46
Mersin	300	35.6032	8.42082	19.62	58.30
Total	2100	32.8609	8.02844	17.04	58.30

Region		α=0.05			
	N	1	2	3	4
Samsun	300	30.44			
Muğla	300	30.48			
K. Maraş	300		31.57		
Antalya	300		32.17		
Burdur	300			33.98	
Adana	300				35.60
Mersin	300				35.76

CONCLUSIONS

1. Turkish red pine trees were selected from areas in Adana, Antalya, Burdur, Mersin, Samsun, Kahramanmaraş, and Muğla, which are natural growth areas in Turkey. The lowest surface roughness values were obtained from the samples taken from the Muğla and Samsun areas.
2. The samples obtained from the Turkish red pine were processed with the most common surface processing techniques in the wood processing sector: sawing with a circular saw, planing with a thickness machine, and sanding with a sanding machine (No. 80 sandpaper). After the samples were processed radially and tangentially, their roughness values (R_a, R_y, and R_z) were determined. When the statistical results of surface roughness values were analyzed, the lowest surface roughness values were obtained in the Turkish red pine samples that were processed with the thickness machine.

3. The Partial Eta Squared effect level values for R_a, R_y, and R_z were the highest in Machine type. The variable with the second highest value level after Machine type was Region.
4. In Muğla and Samsun regions, the reason why the lowest surface roughness values were obtained might be related to density and the growth area of the samples. In future studies, it might be useful to analyze the red pine trees in these areas anatomically.
5. The roughness values of the tangentially cut surfaces were determined to be lower than the radially cut surfaces. Burdurlu *et al.* (2006) have also determined that the R_a values of tangentially cut samples of red pine trees were lower than the values of radially cut surfaces. In the same manner, the R_a values of surfaces processed with the thickness machine were found to be lower compared to surfaces sanded with no: 80 sandpaper (Table 5). The results are in line with this study.
6. An important aspect of this study lay in determining the surface roughness of Turkish red pine samples selected from the seven natural growth areas in Turkey and introducing these results to literature.

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