Turk J Agric For
29 (2005) 315-321

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

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Received: 25.03.2004

Abstract: The effect of the number of blades and the abrasive grain size of sandpaper on the surface roughness in wood materials obtained from Lombardy poplar (*Populus nigra* L.) and European black pine (*Pinus nigra* A.) were examined. A total of 220 samples were prepared for this purpose. The samples were subjected to roughness measurements according to TS 6212 EN ISO 4288. The values obtained were statistically analyzed and the results were interpreted. The best results among the sanded surfaces in roughness were obtained with 180-grit sandpaper on tangential cut surfaces for Lombardy poplar and with 220-grit sandpaper on tangential cut surfaces for European black pine. In the planed surfaces, the best result was obtained on tangential cut surfaces with 2 blades and a 5 m min^{-1} feeding rate for Lombardy poplar and European black pine.

Key Words: Surface roughness, Wood sanding, Wood planing, European black pine, Lombardy poplar

Karaçam ve Karakavak'ın Rendelenmesi ve Zımparalanmasında Bıçak Sayısı ve Zımpara Tanecik Büyüklüğünün Yüzey Pürüzlülüğüne Etkisi

Özet: Bu çalışmada, Karakavak (*Populus nigra* L.) ve Karaçam (*Pinus nigra* A.) 'dan elde edilmiş ahşap malzemenin, planya ve zımpara makinesinde işlenmesinde bıçak sayısı ve zımpara tanecik büyüklüğünün yüzey pürüzlülüğüne etkisi araştırılmıştır. Bu amaçla, farklı numaralı (Farklı tanecik büyüklüklü) zımparaların pürüzlülüğe etkisinin belirlenebilmesi için 5 x 2 x 10 (zımpara türü x kesiş yönü x ölçüm sayısı) = 100 ve bıçak sayısı ve besleme oranının pürüzlülüğe etkisinin belirlenmesi için 3 x 2 x 2 x 10 (bıçak sayısı x kesiş yönü x besleme oranı x ölçüm sayısı) = 120 adet olmak üzere toplam 220 adet numune hazırlanmıştır. Numuneler TS 6212 EN ISO 4288'ye göre pürüzlülük ölçümüne tabi tutulmuştur. Elde edilen değerler istatistiksel analize tabi tutularak sonuçlar yorumlanmıştır. Pürüzlülük açısından zımparalanmış yüzeylerde en iyi sonuç Karakavak'ta teğet kesit yüzeylerde 180 numara zımpara ile, Karaçam'da teğet kesit yüzeylerde 220 numara zımpara ile elde edilmiştir. Rendelenmiş yüzeylerde ise en iyi sonuç Karakavak ve Karaçam'da 2 bıçak ve 5 m dak^{-1} besleme oranı ile teğet kesit yüzeylerde elde edilmiştir.

Anahtar Sözcükler: Yüzey pürüzlülüğü, Zımparalama, Rendeleme, Karaçam, Karakavak

Introduction

Different methods of cutting are applied in the wood products industry depending on the use of the wood and purpose of operation. These can be listed as follows:

i) Non-rotating cutting (hand planer, veneer cutting machine-slicer)
ii) Sawing (circular and band sawing)
iii) Knife cutting (planing, thicknessing, routing, etc.)
iv) Boring (boring machines)
v) Sanding

In all of these cutting methods, the quality of surface obtained as the result of the processing is affected by factors related to the piece being processed (tree species, quality of materials, moisture contents of the materials, etc.), factors related to the cutter (number of cutters, cutting angle, bluntness of cutters, etc.) and factors related to the machinery (technological level, feeding rate, cutting speed, etc.). The surface value obtained under these conditions affects the resulting performances of gluing (assembly) and finishing activities, which are the most important procedures of woodworking. Smoothness is one of the most important factors in the

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determination of the surface value of materials. While our perception of a surface evokes a sense of smoothness, it is better defined and measured as “roughness”. Roughness is defined as deviations in elevation from a true plane. We would say a surface is perfectly smooth if there were no deviations. Since roughness is of such great importance, a large number of research studies have been carried out on this subject in Turkey and abroad.

With the decrease of the surface roughness values, bonding and finishing problems are reduced and much more satisfying surfaces are obtained in terms of aesthetics. To decrease the surface roughness, surface filling can be applied during the finishing process. (Elmendorf and Vaughan, 1958; Stumbo, 1960; Richter et al., 1995; Yiğit, 1999).

Factors like angle of grain direction, feeding rate, cutting speed, cutting depth, moisture content, cutting direction, number of blades (or teeth in ripsawing) and kind of wood directly affect the surface roughness of the wood while planing and ripsawing. There is no generalization on account of the kind of the wood and cutting direction. When other factors are kept constant, different smoothness values arise on the different kinds and in radial or tangential sections of wood. To decrease the roughness, it is necessary to decrease the moisture content, the angle of grain direction, feeding rate and cutting depth and to increase the number of blades (or number of teeth) and cutting speed. According to the length of planing and ripsawing process, the cutter wear causes an increment in roughness (McMillan and Lubkin, 1959; Steward, 1970; Steward, 1976; Kamata et al, 1994; Baykan, 1995; Yalçınkaya, 1997; Dereli, 1997; Örs and Demirci, 1999; Aguilera and Martin, 2001; Örs and Gürleyen, 2002; Hernandez et al. 2002; Kılıç and Demirci, 2003).

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. To use silicon carbide abrasive mineral instead of aluminum oxide abrasive mineral decreases the roughness (Dereli, 1997; Taylor et al, 1999).

In measuring the roughness values, systems like laser scatter/optical imaging and acoustic emission count rate are used, in addition to traditional stylus tracing systems (Funck et al., 1993; Tanaka et al., 1994).

As can be seen from previous studies, the tree species, cutting direction, and type and number of cutters have a significant effect on surface roughness. Therefore, it is necessary to conduct roughness studies related to domestic tree species and to determine the most suitable type and number of cutting tools. This was the starting point of this study and the determination of the roughness values in European black pine and Lombardy poplar was the objective.

Materials and Methods

The pieces to be used in the experiments were produced from Lombardy poplar (*Populus nigra* L.) and European black pine (*Pinus nigra* A.) lumber obtained from Siteler, Ankara, Turkey, and randomly selected. Special attention was paid in the selection of the sample lumber in order to avoid defects such as cracks, knots, cross grain and change in color and to ensure that the wood had a natural color.

The lumber obtained in this manner was dried in a drying kiln until 10% moisture content was achieved. After drying, the pieces of lumber were cut to the dimensions of 36 x 2.5 x 2.5 cm by paying attention to their tangential and radial surface formation. Twenty flawless pieces were selected from among the pieces cut taking into consideration the defects stemming from cutting and materials. Then 220 cubic samples were prepared in dimensions of 20 x 20 x 20 mm from these pieces. Of these, 5 x 2 x 10 (grit number of sandpaper x cutting directions x number of measurements) = 100 each were prepared to determine the effect of the sanders on surface roughness and 3 x 2 x 2 x 10 (number of blades x cutting directions x feeding rates x number of measurements) = 120 each were prepared to determine the effect of the number of blades and feeding rate on surface roughness. These samples were put in a climatization chamber at 20 °C and relative humidity of 65% and kept there until their weights did not change (until reaching a rate of 12% moisture content). After this stage, the samples were put into plastic bags to prevent loss of moisture and were left until the experiments.

A roughness measurement instrument (Mitutoya Surftest-301 Series) was used to obtain measurements by the Contact Stylus Tracing Method for determining the effect of the type of cutters, number of cutters, cutting directions and feeding rates on surface roughness.

Of the over 50 different parameters that can be used in the determination of surface roughness values, the Ra parameter, which is used extensively because it gives a simple value for acceptance and rejection decisions, was used. The Ra value is the average arithmetic height (mm) from the average roughness value of the roughness values measured within the length (l) of one sample (TS 6956). The TS 6212 EN ISO 4288 principles were complied with in the determination of the surface roughness on the samples.

The needle of the surface roughness measurement instrument, with values of 0.5 mm s^{-1} speed, 2.5 mm cut-off length limit (lc) and 12.5 mm sampling length, was moved perpendicular to the grain of samples prepared and the Ra value of each piece was determined and recorded.

Results and Discussion

The Ra values obtained according to the samples and the principles mentioned above are given in Table 1.

Variance analysis was used for the statistical analysis of the Ra values obtained in 2 different three species, 2 different cutting directions and 10 different surface operations. The results of ANOVA are given in Table 2.

As can be seen from Table 2, the tree species, cutting directions and surface operations affected the surface roughness values; the tree species and cutting direction processes had a joint effect, but a 0.05 error in the cutting direction did not create a difference and the joint interaction of each of 3 factors created a difference. The Lombardy poplar material had rougher results than the European black pine material (European black pine: 5.298 mm, Lombardy poplar: 7.843 mm).

Table 1. Arithmetic means (mm) of the surface roughness values according to the test variables.

Test Variables				Arithmetic Means Ra (mm)	
Cutting Direction	Operation	Feeding Rate ($m\ min^{-1}$)	Grit Number Blade	Lombardy Poplar	European Black Pine
RADIAL	Sanding		Grit Number		
			60	15.8460	12.2660
			80	8.0430	4.7810
			120	4.1620	6.0260
			180	5.1460	3.9970
			220	5.4210	4.7690
	Planing	5	# Blade		
			2	8.8450	4.5090
			3	7.3950	5.2100
			4	8.5550	4.9300
		9	2	7.6590	5.0170
			3	8.5850	4.5290
			4	-	-
TANGENTIAL	Sanding		Grit Number		
			60	15.6050	13.4770
			80	10.3210	6.9640
			120	6.2670	4.2260
			180	3.7360	3.6770
			220	4.2410	3.1760
	Planing	5	# Blade		
			2	6.7240	4.1860
			3	6.7930	4.4070
			4	7.5640	4.5610
		9	2	8.4850	4.2050
			3	7.4590	4.2410
			4	-	-

Table 2. Variance analysis for Ra (DF-Degree of Freedom, SS- sum of squares, MS- mean of squares, P-precision).

Sources	DF	SS	MS	Fsum	P
Wood Species	1	647.65	647.65	741.25*	0.000
Surface Operations	9	3113.56	345.95	395.95*	0.000
Cutting Direction	1	10.81	10.81	12.37*	0.000
Wood Species-Surface Operations	9	128.02	14.22	16.28*	0.000
Wood Species- Cutting Direction	1	0.68	0.68	0.78Ns	0.377
Surface Operations-Cutting Direction	9	117.81	13.09	14.98*	0.000
Wood Species-Surface Operations- Cutting Direction	9	68.11	7.57	8.66*	0.000
Error	360	314.54	0.87		
Total	399	4401.18			

Ns: Nonsignificant *Significant at 95% confidence level

Table 3. Duncan's multiple range test for surface operation variables.

RA
Duncan's Multiple Range Test

Variables	N	Subsets					
		A	B	C	D	E	F
180-grit Abrasive	40	3.6815					
220-grit Abrasive	40		4.1268				
120-grit Abrasive	40			5.1702			
3 Blades & 5 m min^{-1} Feeding Rate	40				5.9513		
2 Blades & 5 m min^{-1} Feeding Rate	40				6.0035		
3 Blades & 9 m min^{-1} Feeding Rate	40				6.2035		
2 Blades & 9 m min^{-1} Feeding Rate	40				6.3365		
4 Blades	40				6.4025		
80-grit Abrasive	40					7.5273	
60-grit Abrasive	40						14.2985

It was determined in the evaluation with regard to cutting direction that there was a difference with a 5% error between the radial and tangential cuts and that the tangential cuts produced a smoother surface than did the radial cuts (tangential cut: 6.406 mm, radial cut: 6.735 mm).

Duncan's multiple range test was applied to find the difference between the operations tested in the evaluation with regard to surface operations (Table 3). According to this, the smoothest surface was obtained from sanding with a 180-grit abrasive (Ra: 3.6815 mm).

The Duncan's multiple range test related to the joint effects of cutting direction and surface operations is given in Table 4.

Table 4 shows that the smoothest surface in the tangental cut was obtained with a 180-grit abrasive (Ra: 3.1585 mm), and the smoothest surface in the radial cut was also obtained with a 180-grit abrasive (Ra: 4.0715 mm). No significant difference was observed among the blades. The 60-grit abrasive produced the roughest surface. The joint effects of tree species, cutting directions and surface operations are given in Table 5. The smoothest surface was obtained with tangential cut European black pine and with a 220-grit abrasive (Ra: 3.1760 mm). The smoothest surface in the Lombardy poplar material was obtained in a tangential cut with a 180-grit abrasive (Ra: 3.7360 mm). The best result on

Table 4. Duncan's multiple range test for surface operation variables and cutting directions.

Surface Operation Variables	N	RA Duncan's Multiple Range Test									
		Radial Direction				Tangential Direction					
		Subsets				Subsets					
		A	B	C	D	A	B	C	D	E	F
180-grit Abrasive	20	4.0715				3.1585					
120-grit Abrasive	20		5.0940			3.2915					
220-grit Abrasive	20		5.0950				5.2465				
3 Blades & 4 m min^{-1} Feeding Rate	20			6.3025			5.3300				
2 Blades& 9 m min^{-1} Feeding Rate	20			6.3380			5.6000	5.6000			
80-grit Abrasive	20			6.4120				5.8500	5.8500		
3 Blades & 9 m min^{-1}. Feeding Rate	20			6.5570				6.0625	6.0625		
2 Blades & 5 m min^{-1} Feeding Rate	20			6.6770					6.3350		
4 Blades	20			6.7425						8.6425	
60-grit Abrasive	20				14.056						14.5410

the radial cut surface of European black pine was obtained with a 180-grit abrasive (Ra: 3.9970 mm). The best result on the radial cut surface of Lombardy poplar was obtained with a 120-grit abrasive (Ra: 4.1620 mm). There was no significant difference on the radial cut pine surface of all the blades or between the 80-grit and 220-grit abrasives. Furthermore, there was no significant difference on the surface with 3 blades at a 5 m min^{-1} feeding rate and with a 120-grit abrasive. There was also no significant difference in the tangential cut pine surface with different blades.

Conclusion

In this study, the effect of tree species, cutting directions, number of blades, feeding rates and grain sizes of abrasive on the surface roughness of wood materials was examined.

According to the analyses tree species has an effect on the surface roughness value. Under the same conditions, European black pine produces smoother surfaces than does Lombardy poplar. The fact that the fibers of the European black pine are long and the fiber diameters are smaller, as a characteristic of the species, could be influential in this. As the grain size of the abrasive used becomes smaller (as the sander number increases) smoother surfaces are obtained. However, in this study, sanding with the 180-grit abrasive produced a smoother surface compared to the surfaces sanded with the 220-grit abrasive. This indicates that as the sizes of the abrasive grains become smaller, the effectiveness of breaking off wood shavings from the wood is decreased. In practice, the 180-grit or higher grit number abrasives are used for sanding varnished surfaces. From this, it can be proposed that in the sanding of wood surfaces the maximum grit number should be 180. It is necessary to use less filling varnish for smoother surfaces.

According to the joint interaction of tree species, cutting directions and surface operation types, the best result is obtained on surfaces sanded with the 220-grit abrasive.

The surfaces obtained with tangential cuts become smoother compared to the surfaces obtained with radial cuts. This could stem from an increase or decrease in the tissue voids stemming from the fiber cutting angle connected with the cutting method.

As the number of blades increases and the feeding rate decreases, the roughness decreases. The increase in the number of blades or decrease in the feeding rate with

Table 5. Duncan's multiple range test for surface operation variables, cutting directions and species.

RA Duncan's Multiple Range Test for European Black Pine

Variables	N	Radial Cut				Variables	Tangential Cut				
		Subsets					Subsets				
		A	B	C	D		A	B	C	D	E
180-grit Abrasive	10	3.997				220-grit Abrasive	3.176				
Feeding Rate											
2 Blades & 5 m min^{-1}	10		4.509			180-grit Abrasive		3.677			
3 Blades & 9 m min^{-1}	10		4.529			2 Blades & 5 m min^{-1}			4.186		
Feeding Rate						Feeding Rate					
220-grit Abrasive	10		4.769			2 Blades & 9 m min^{-1}			4.205		
						Feeding Rate					
80-grit Abrasive	10		4.781			120-grit Abrasive			4.226		
4 Blades	10		4.930			3 Blades & 9 m min^{-1}			4.241		
						Feeding Rate					
2 Blades & 9 m min^{-1}	10		5.017			3 Blades & 5 m min^{-1}			4.407		
Feeding Rate						Feeding Rate					
3 Blades & 5 m min^{-1}	10		5.210	5.210		4 Blades			4.561		
Feeding Rate											
120-grit Abrasive	10			6.026		80-grit Abrasive				6.964	
60-grit Abrasive	10				12.266	60-grit Abrasive					13.477

RA Duncan's Multiple Range Test for Lombardy Poplar

Variables	N	Radial Cut						Variables	Tangential Cut					
		Subsets							Subsets					
		A	B	C	D	E	F		A	B	C	D	E	F
120-grit	10	4.162						180-grit	3.736					
Abrasive								Abrasive						
180-grit	10	5.146	5.146					220-grit	4.241					
Abrasive								Abrasive						
220-grit	10		5.421					120-grit		6.267				
Abrasive								Abrasive						
3 Blades &								2 Blades &						
5 m min^{-1}	10			7.395				5 m min^{-1}		6.724	6.724			
Feeding Rate								Feeding Rate						
2 Blades &								3 Blades &						
9 m min^{-1}	10			7.659	7.659			5 m min^{-1}		6.793	6.793			
Feeding Rate								Feeding Rate						
80-grit								3 Blades &						
Abrasive	10			8.043	8.043	8.043		5 m min^{-1}			7.459			
								Feeding Rate						
4 Blades	10				8.555	8.555		4 Blades			7.564			
3 Blades &								2 Blades &						
9 m min^{-1}	10			8.585	8.585			9 m min^{-1}				8.485		
Feeding Rate								Feeding Rate						
2 Blades &								80-grit						
5 m min^{-1}	10					8.845		Abrasive					10.321	
Feeding Rate														
60-grit	10						15,846	60-grit						15.605
Abrasive								Abrasive						

the same number of blades decreases the cutting wavelengths and this also causes a decrease in surface roughness.

It is thought that various factors, such as the anatomic structure of the wood, which affects the surface roughness of the wood material, its specific gravity, hardness, spring-summer wood and heartwood-sapwood ratios, could have significant effects. It is proposed that these characteristics be taken into consideration in studies to be conducted in the future.

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