Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (16): 2300-2306, 2007
ISSN 1812-5654

Effect of Wood Finishing and Planing on Surface Smoothness of Finished Wood

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Abstract: The effect of wood finishing and planning on surface smoothness of finished wood samples of Scots pine (*Pinus sylvestris* L.) eastern beech (*Fagus orientalis* L.) and oak (*Quercus petraea* L.), commonly used woods in the furniture industry in Turkey, was investigated for this study which was carried out in 2006 in the capital city of Ankara in Turkey. Two hundred and forty samples were prepared and processed by planing on the radial and tangential direction to annual rings with 2 and 4 blades. Surface smoothness of the samples was measured according to Turkish Standard (TS) 930. Following that, filling coat and topcoat of polyurethane varnish were applied to surfaces of the samples according to ASTM-D 3023. Then, samples were again subjected to measure for determining the surface smoothness. Statistical data were obtained for surface smoothness from varnished and unvarnished wood samples and it was concluded that finishing increases the surface smoothness.

Key words: Surface smoothness, surface roughness, finishing, planing, blades, wood material

INTRODUCTION

Wood structures exposed both indoors and outdoors need protection against a number of factors. Protection can be only achieved with a combination of product design and efficient finishing. The protection provided by finishes plays an important role during the service life of wood products, reducing or preventing damage from environmental conditions and every day use. One basic requirement for sufficient and long-lasting finishing performance is good adhesion of the coating product on the wood surface. The ability of a wood surface to accept and hold a coating is determined by the natural characteristics of the wood species and the manufacturing processes used (Cassens and Feist, 1991). Natural factors (anatomical, physical and chemical properties) vary considerably, not only between different species, but also even within the same species and tree. Their influence on finishing performance can only be predicted with a high range of variation and this influence is considered to some extent in grading and selection procedures. However, surface texture is not only determined by the inherent morphological structure of wood. According to a surface-texture system proposed by Marian *et al*. (1958), anatomic structure causes a first-degree texture (e.g., tracheid or vessel diameter and cell wall thickness). A second-degree texture results from the machining method itself (e.g., tooth marks from a saw and waves formed by a machine planer). Third-degree texture results from variation within the machining method (e.g., vibrations, misalignment and dull tools).

From these arguments, surface quality is an important concern in many areas of the woodworking industry because surfaces of wood are not smooth, even though they may have been well planed or sanded, because recesses due to the cell cavities appear on the surface. In other words, the quality of the surface of wood products is often characterized by surface irregularities. The height, width and shape of these irregularities establish the surface quality of a product. Such irregularities are evaluated as surface roughness, which is caused by the machining processes and the other factors. Irregularities caused by the machining can have a significant effect on the quality of finished surfaces and the effect is exacerbated on products for which a smooth finish is required.

A smooth surface is a key quality factor for woodworking industry. A number of authors Sadoh *et al*.

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(1983), Harada *et al.* (1983), Yasuda *et al.* (1983) and Sadoh and Nakato (1987) studied the surface properties of wood. The main purpose of these studies was to understand the relations among the physical, anatomical and sensory properties of wood surfaces. Some other studies dealt with effects of work materials on planing performance (Morita *et al.*, 1998) measurement methods of wood surfaces (Stumbo, 1963; Peter and Cumming, 1970; DeVries and Lemanster, 1991; Lemaster and Beal, 1996) surface roughness of wood composites or wood based panels (Oestman, 1993; Hiziroglu, 1996; Hiziroglu and Graham, 1998; Bekhta and Hiziroglu, 2002; Akbulut *et al.*, 2000) processing roughness of sanded wood surfaces (Ors and Baykan, 1999; Taylor *et al.*, 1999) effects of surface roughness on the performance of finishes (Williams and Feist, 1994; Richter *et al.*, 1995) and so on. However, a few studies focused on machining parameters on surface quality (Salles and Gonçalves, 2003; Lemaster and Taylor, 1999; Morita *et al.*, 2000; Buehlmann *et al.*, 2001) and the evaluation of machined surfaces of wood (Fujiwara *et al.*, 2003).

From a critical examination of the surface of the work piece, the manufacturers can determine the final product quality, general wear of the planing tools, as well as errors that are starting to arise in the machining centers themselves. Through monitoring of surface quality, feed speeds, spindle speeds and tools changes can be optimized and number of rejected parts can be minimized. This would be making adjustments in process variables such as feed speed and/or spindle speed to maintain acceptable levels of surface quality as the planing tools becomes worn. With the increased penetration of wood materials into applications for wide range of products, wood processing by machines is an important factor for achieving a smoother surface for finishing applications.

From this background, this study aims to quantify the surface smoothness of wood samples of Scots pine (*Pinus sylvestris* L.) eastern beech (*Fagus orientalis* L.) and oak (*Quercus petraea* L.) by planing the samples on radial and tangential direction to annual rings with 2 and 4 blades and then to determine the effect of wood finishing on the surface smoothness of the selected samples by applying a filling coat + topcoat (glossy) of polyurethane varnish.

MATERIALS AND METHODS

Wood material: The wood samples of Scots pine (*Pinus sylvestris* L.) eastern beech (*Fagus orientalis* L.) and oak (*Quercus petraea* L.) were used during experiment preparation due to common usage in the decoration and furniture industry in Turkey. Two hundred and forty samples were prepared according to 2×3×2×2×10 test pattern, composed of 10 per 2 application methods, 3 wood types, 2 planing direction and 2 number of blades. Experiment samples were selected according to the provisions of Turkish Standards TS 2470 (1976) from the randomly selected 1st class wooden material. The samples under air relative humidity were roughly cut into 180×45×10 mm size and conditioned until reaching permanent weight in a conditioning refrigerator with 20±2°C temperature and 50±5% relative humidity in order to obtain moisture value on internal environmental conditions according to TS 2471 (1976). Mean humidity of the samples was determined as 9±0.5% on 10 randomly selected samples.

Blades: For planing processes, samples were machined on a tangential or radial surface using a spindle-moulding machine with 2 and 4 blades as cutters. Usability of both sides of the blades, commercial availability of sharpened blades and easy adjustability of blades to the same flight axis has importance and prerequisite for surface smoothness. The machine, used in planing, was preferred as it is a common cutting type during forming to the wooden material in the Turkish massive furniture sector. Planing process was performed onto the sample surfaces with 100 mm diameter boring ball with 50×12×12 mm sizes and blades with 40°-wedge angle. Spindle speed for planing was fixed as 6000 rpm U min^{-1} and feed speed was fixed as 5 m min^{-1}. In this case, samples were sized to 170×43×8 mm.

Finishing: The glossy polyurethane varnish with two components was used during the preparation of experimental samples for this research. Polyurethane varnish was chosen because of common use in the decoration and furniture industry in Turkey.

For the amount of the varnish to be applied on the surfaces of the samples, the proportion of solid contents and manufactures' prospectuses were followed (Dewilux, 2002). Some of the characteristics of polyurethane varnish are given in Table 1.

At the period of spraying and drying, internal environmental conditions of 20±2°C temperature and 65±5% relative humidity were obtained according to TS 2471 (1976) before finishing.

The process of preparation for the proportion of second component (isocyanate) and thinner mixture was followed by the advice from manufacturer firm (Dewilux, 2002). Varnish application was performed by a spray gun complying with principles referred under ASTM.D-3023 (1998).

Filling coat of polyurethane varnish was applied both vertical and horizontal to the grains with the primary

Table 1: The characteristics of polyurethane varnish used in the experiments

Varnish type	pH	Density (g m^{-3})	Application viscosity DIN Cup/4 mm	Amount of finish application (g m^{-2})	Spray gun tip diameter (mm)	Air pressure (Bar*)
Polyurethane (Filling)	5.95	0.98	18	120	1.8	2
Polyurethane (Glossy)	4.01	0.99	18	120	1.8	2

*: 1 Bar = 10^5 pascal or 10^5 N/mm^2

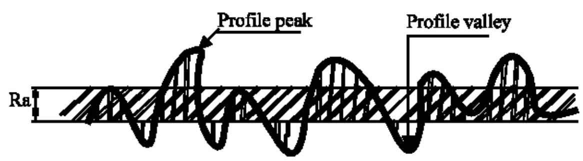

Fig. 1: Surface profile defined by the scanning pointer

purpose to stop the penetration of the succeeding topcoat. The filling-coated samples were left for drying in clean air circulation for 24 h. The dried samples of surfaces were smoothly planed and sanded uniformly with 220 and 320 grit (on Norton scale) sandpaper. Dusts on the surfaces were cleaned by a brush and vacuum method with the aim of topcoat finishing on the sample surfaces. After cleaning, samples were weighted with a sensitive analytical balance ±0.01 g. Following that, topcoat was applied on the surfaces of the samples.

Surface smoothness measurement: In this study, the measurement of surface smoothness was carried out by using TIME TR-200 surface smoothness tester (touch pointer), which consists of the main unit, the pick-up and a spindle-type diamond stylus with a 196 micro-inch. Measurement, as referred in the TS 930 (1989) was performed parallel and perpendicular to the grains on 5 primary profiles, marked on each sample via TIME TR-200 (2004), which has ability to detect profile change. Arithmetic means of these measurements were recorded as single values in terms of Ra (μm). The values were selected because smaller cut-off values exclude characteristic irregularities caused by both the cellular structure of the wood and the machining process (Fujiwara *et al*., 1998). Measurement stage of the equipment in test; was adjusted as 2, 5 mm and cut-off was adjusted as 3.

While the device measures the surface smoothness, it is profiling the zigzags of the surface with moving Ø 5 μm diamond tip of the scanning pointer upwards and downwards on sample surface. Central line between profile recesses (valleys) and salient (peaks) expresses the mean smoothness value (Ra) (Fig. 1).

Statistical method: In the evaluation of data, statistic package software called MSTATC was used. In the analysis, the values of factor effects based on the application method, wood type, planing direction and number of blades were determined as a result of multiple variance analysis, ANOVA and in cases where factor effects were significant with α = 0.05, error rate according to variance analysis ANOVA results, Least Significant Difference (LSD) critical values were used and causing factors were determined.

RESULTS

The value of surface smoothness in accordance with the effect of finishing and planing on the selected samples was determined. The results of multiple variance analysis to surface smoothness value concerned with defining the effect of finishing and planing on the surface of wood samples are given in Table 2.

According to Table 2, the factor of planing direction (C) and interaction (AC) were found to be not significant, while the interaction of BC, ABC and BCD was found statistically not meaningful (α = 0.05).

The results of Duncan test, carried out by using LSD critic values, single comparison for application method, wood types, planing direction and number of blades are given in Table 3.

During the single comparison for application method, the best surface smoothness value was found on the varnished sample surfaces. For wood types and number of blades, the best surface smoothness value was found on the samples of Scots pine while the best results were obtained in the samples, processed by 4 blades. For planing direction, the value of surface smoothness was found to be insignificant (α = 0.05) according to the results of variance analysis.

The results of Duncan test, double comparison for application method-wood type are given in Table 4.

According to Table 4, the best surface smoothness value was obtained from the varnished Scots pine and eastern beech samples while the worst value was obtained from the unvarnished oak.

The results of Duncan test, double comparison for number of blades and application method are given in Table 5.

The best surface smoothness value was obtained from the varnished samples after processing with 2 and 4 blades. The worst value was obtained from the samples of unvarnished after processing with 2 blades.

The results of Duncan test, double comparison for wood type and number of blades are given in Table 6.

Table 2: Multiple variance analysis results

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Prob.
Application method (A)	1	1801.199	1801.199	4264.2137	0.0000
Wood type (B)	2	129.029	64.515	152.7341	0.0000
Interaction AB	2	63.548	31.774	75.2228	0.0000
Planing direction (C)	1	0.153	0.153	0.3632	ns*
Interaction AC	1	0.408	0.408	0.9652	ns
Interaction BC	2	2.411	1.206	2.8543	0.0598**
Interaction ABC	2	2.556	1.278	3.0252	0.0506**
Number of blades (D)	1	8.852	8.852	20.9564	0.0000
Interaction AD	1	6.295	6.295	14.9022	0.0001
Interaction BD	2	9.157	4.578	10.8390	0.0000
Interaction ABD	2	11.525	5.763	13.6426	0.0000
Interaction CD	1	5.524	5.524	13.0770	0.0004
Interaction ACD	1	7.291	7.291	17.2600	0.0000
Interaction BCD	2	1.062	0.531	1.2575	0.2864**
Interaction ABCD	2	2.958	1.479	3.5010	0.0319
Error	216	91.238	0.422		
Total	239	2143.206			

*Not significant, **According to 0.05 not meaningful

Table 3: Application method, wood types, planing direction and number of blades, single comparison

Factors		$\bar{x}$ (Ra) µm	HG	LSD±
Application method	Unvarnished (control)	6.0300	B	0.1653
	Varnished	230.5508	A*	
Wood Methods	Scots Pine	2.3860	A	0.2024
	Eastern Beech	3.3030	B	
	Oak	4.1820	C	
Planing direction	Radial	3.3160	A	0.1653
	Tangential	3.2650	A	
No. of blades	2	3.4820	B	0.1653
	4	3.0980	A	

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

Table 4: Application method-wood type, double comparison

	Application method			
	Unvarnished (control)		Varnished	
Wood type	$\bar{x}$ (Ra) µm	HG	$\bar{x}$ (Ra) µm	HG
Scots pine	4.430	C	0.3421	A*
Eastern beech	6.205	D	0.4009	A
Oak	7.454	E	0.9094	B
LSD	0.2863			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

Table 5: Application method-number of blades, double comparison

	No. of blades			
	2		4	
Application method	$\bar{x}$ (Ra) µm	HG	$\bar{x}$ (Ra) µm	HG
Unvarnished (control)	6.384	C	5.676	B
Varnished	0.5809	A	0.5207	A*
LSD	0.2338			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

According to Table 6, the best surface smoothness value was obtained from Scots pine samples, processed with 2 and 4 blades. The worst value was obtained from oak samples, processed with 2 blades.

Table 6: Wood type-number of blades, double comparison

	No. of blades			
	2		4	
Wood type	$\bar{x}$ (Ra) µm	HG	$\bar{x}$ (Ra) µm	HG
Scots pine	2.528	A	2.244	A*
Eastern beech	3.285	B	3.321	B
Oak	4.634	D	3.370	C
LSD	0.2863			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

Table 7: Planing direction-number of blades, double comparison

	No. of blades			
	2		4	
Planing direction	$\bar{x}$ (Ra) µm	HG	$\bar{x}$ (Ra) µm	HG
Radial	3.356	B	3.275	B
Tangential	3.609	C	2.291	A*
LSD	0.2338			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

The results of Duncan test, double comparison for number of blades and planing direction are given in Table 7.

The best surface smoothness value was obtained from the samples, which were tangentially processed with 4 blades.

The results of Duncan test, trio comparison for application method, wood type and number of blades are given in Table 8.

According to Table 8, the best value for surface smoothness was obtained from Scots pine and eastern beech samples, varnished after processing by 2 and 4 blades. The worst value was obtained from oak samples, unvarnished and processed with 2 blades.

Table 8: Application method-wood types and number of blades, trio comparison

Wood type	No. of blades	Unvarnished (control) $\bar{x}$ (Ra) μm	HG	Varnished $\bar{x}$ (Ra) μm	HG
Scots pine	2	4.640	D	0.4166	A
	4	4.220	C	0.2676	A*
Eastern beech	2	6.140	E	0.4292	A
	4	6.270	E	0.3726	A
Oak	2	8.372	F	0.8969	B
	4	6.537	E	0.9219	B
LSD		4049			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

Table 9: Application method-planing direction and number of blades, trio comparison

Planing direction	No. of blades	Unvarnished (control) $\bar{x}$ (Ra) μm	HG	Varnished $\bar{x}$ (Ra) μm	HG
Radial	2	6.124	C	0.5875	A
	4	6.068	C	0.4822	A*
Tangential	2	6.643	D	0.5742	A
	4	5.283	B	0.5592	A
LSD		0.3306			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

Table 10: Application method-wood type-planing direction and number of blades, total comparison

Wood type	Planing direction	No. of blades	Unvarnished (control) $\bar{x}$ (Ra) μm	HG	Varnished $\bar{x}$ (Ra) μm	HG
Scots pine	Radial	2	4.360	F	0.3848	B
		4	4.180	E	0.3054	A
	Tangential	2	4.920	FG	0.4483	B
		4	4.260	E	0.2298	A*
Eastern beech	Radial	2	6.030	G	0.5830	C
		4	6.770	HI	0.4720	B
	Tangential	2	6.250	H	0.2754	A
		4	5.770	G	0.2732	A
Oak	Radial	2	7.983	IJ	0.7948	C
		4	7.255	HIJ	0.6691	C
	Tangential	2	8.760	J	0.9990	CD
		4	5.820	G	1.1750	DE
LSD			0.5726			

*: The best surface smoothness value, $\bar{x}$: Average value, HG: Homogeneous Group

The results of Duncan test, trio comparison for application method, planing direction and number of blades are given in Table 9.

The best value for surface smoothness was obtained from the varnished samples after radial and tangential processing with 2 and 4 blades.

The results of Duncan test, total comparison for application method, wood type, planing direction and number of blades are given in Table 10.

According to Table 10 the best surface smoothness value was obtained from Scots pine samples, varnished after tangential processing by 4 blades. The worst value was obtained from oak samples, unvarnished and tangentially processed with 2 blades.

DISCUSSION

In this study, the effect of wood finishing and planning on surface smoothness of finished wood samples of Scots pine (*Pinus sylvestris* L.) eastern beech (*Fagus orientalis* L.) and oak (*Quercus petraea* L.) was investigated. According to the results from the study, the highest value for surface smoothness was obtained from the varnished samples after processing by spindle-moulding machine with 2 and 4 blades. However, the lowest value for surface roughness was obtained from the unvarnished samples, which were processed by 2 blades. It is possible to argue that varnishing and machining processes cause significant effects on the smoothness of wood surfaces. From this argument, the smoothness quality depending on the machine processing can affect the performance of finishes in several ways. It has been quantified that good machine processing gives better adhesive performance that gives better quality of the finish and influences the level of finishing costs. This conclusion is compatible with the findings of several authors (Cassens and Feist, 1991; Williams and Feist, 1994; Richter *et al*., 1995).

The smoothness quality can also depend on the wood structure and wood types. For example, according to the results with respect to wood type, the highest value for surface smoothness was found on the varnished samples of Scots pine and eastern beech while the lowest results were obtained from the oak samples. The reason could be that the microscopic cellular structure of wood, including annual rings and rays, produces the characteristic grain patterns in different species of trees (Marian *et al*., 1958). For example, the anatomical structure of oak, which is different from the others, can play a significant role for the smoothness quality (Gurua *et al*., 2005).

The smoothness quality also varies depending on the number of blades used. According to the result from the study, the best value for surface smoothness was obtained from the samples, which were processed with 4 blades. Obviously, the high number of blades for cutting can give positively high results for the quality of surface smoothness. The reason might be the amount of work share for each blade. With respect to planing direction, the best result for surface smoothness was obtained on the samples after tangential processing while radial processing gives the lowest results. This result is compatible with the findings of several authors (Gurleyen, 1998; Baykan, 1995). This suggests that tangential processing for wood should be preferred to radial processing in woodworking industry. This fact may be useful when trying to achieve a specific target, to optimize the process or when searching for robust areas.

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