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Effect of Feed Speed and Wood Species on Roughness of Machined Surface

Utjecaj posmične brzine i vrste drva na hrapavost obrađene površine

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ABSTRACT • *In this study, the surface roughness values of planed beech-wood (Fagus L.), oak-wood (Quercus L.) and fir-wood (Abies alba Mill.) specimens were examined. The samples of beech-wood were cut from steamed beech-wood and from thermally modified beech-wood (212°C). The specimens were machined by planing in radial directions with two knives at 6, 12, 18 and 24 m/min feed speed. The cutting depth of 2.0 mm was constant and knife rake angle was 15°. The machining experiments were carried out using a single cutter-block of a Weinig Powermat 400. The cutter-block with a diameter of Ø 125 mm rotated at 6000 revolutions per minute (RPM). Surface roughness was measured from the radial face of each sample according to DIN 4768 (1990) by using Mitutoyo SJ-201 stylus scanner. Comparison between the results of surface roughness of four species showed that surface roughness increases with the increase of feed rate. The surface quality of samples of planed beech-wood, oak-wood and fir-wood were significantly different. The samples of planed surface of oak-wood had the best quality and the samples of fir wood had the highest values of surface roughness. There were no significant differences in the surface quality of thermally modified and steamed beach-wood samples despite the significant difference in mechanical and physical properties of thermally modified and steamed wood.*

Key words: *surface roughness, wood planing, feed speed, wood species*

SAŽETAK • *Rad predstavlja istraživanja kvalitete blanjane površine bukovih, hrastovih i jelovih uzoraka. Bukovi su uzorci izrađeni od parene bukovine i termički modificirane bukovine (212 °C). Istraživanja su provedena na uzorcima blistača, koji su blanjani u radijalnom smjeru. Alat za blanjanje imao je dvije oštrice, a blanjano je pri posmičnim brzinama 6, 12, 18 i 24 m/min. Dubina blanjanja bila je konstantna i iznosila je 2,0 mm, a prsni je kut oštrica alata bio γ = 15°. Eksperiment je proveden na četverostranoj blanjalici Weinig Powermat 400. Promjer putanje rezne oštrice bio je 125 mm, a broj okretaja radne osovine 6 000 min^{-1}. Hrapavost površine mjerena je po duljini obrade, u skladu sa normom DIN 4768 (1990) upotrebom elektromehaničkog profilometra Mitutoyo SJ-201. Usporedbom dobivenih rezultata za sve četiri vrste uzoraka može se zaključiti da se s povećanjem posmične brzine povećava hrapavost površine. Kvaliteta blanjane površine za različite je vrste drva različita u jednakim uvjetima obrade. Najmanju hrapavost imali su uzorci hrasta, a najveću uzorci jele. U istraživanjima nije zabilježena značajna razlika između kvalitete površine uzoraka od parene bukovine i termički modificirane bukovine usprkos mnogo lošijim mehaničkim svojstvima termički modificiranog drva u odnosu prema parenom drvu.*

Ključne riječi: *hrapavost površine, blanjanje, posmična brzina, vrsta drva*

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1 INTRODUCTION
1. UVOD

Besides physical, mechanical, and anatomical properties of wood, the surface quality of details and finished products is influenced by numerous factors like: direction of cutting, geometry of the blade and its sharpness, thickness of the cut part, lack of precision of the sharpening tool, technological parameters (speed of cutting, speed of movement, etc.) (Richter *et al*, 1995). The quality of processing includes the precision of processing and quality of the machined surface. These two mutually dependent indicators of the processing quality, which depend on numerous factors, represent the most important conditions in achieving the required product quality. Morphologic properties of the surface that was created through mechanical processing of wood carries a lot of information on the quality of technological procedure with which the surface came to existence. Full understanding and evaluation of the geometric condition of the wood surface and wood material provides mostly technical information in solving the problems like capabilities of gluing, impregnation, strength of joints, control of blade sharpness, and decrease of waste. The relation between surface roughness and wearing of the tools is well known. It is assumed that surface roughness of sawed surfaces of softwoods and hardwoods increases with the increase of wedge radius (Keturakis, 2007). Monitoring of the roughness can provide valuable information on the condition of the blade and vice versa. The strength of the glued joints and other mechanical properties of wood products are also dependent of surface roughness (Malkoçoğlu, 2007). Studies show that smooth surfaces require relatively small amount of paint for surface protection (Marian *et al*, 1958).

In the manufacturing process the occurrence of fault in processing is inevitable. If the quality deviations of the actual properties are within the limit values, then the detail is considered to be properly processed in terms of technological requirements. However, it often happens that the dimensions of the detail are within the limit values, and the details are different in the quality of the machined surface. Sanding is the most common and most influential operation for achieving surface quality during the phase of surface preparation.

This paper presents the research of the influence of the planing regime on the quality of the machined surface and possibilities to leave out the sanding operation by replacing it with planing in the preparation of the surface. Also, the aim of the research was to compare the surface quality of the samples of different wood species and different wood treatment.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Testing was conducted on samples of beech-wood (steamed and thermally modified), oak-wood and fir-wood. Dimensions of samples were 70x21x600 mm for steamed beech-wood, oak-wood and fir-wood and 70x21x500 mm for thermally modified beech-wood at 212°C. Samples of wood elements were radial texture with moisture content and density according to Table 1. Before planning, samples were kept in the conditioning room at 20°C temperature and 65 ±5 relative humidity. For each type of timber the average density and humidity of wood were determined. Wood density is determined in accordance with ISO 3131, and wood moisture is determined by gravimetrical method according to the ISO 3130 of 1975.

Table 1 Data of density and moisture content for the studied species of wood
Tablica 1. Podaci za gustoću i sadržaj vode istraživanih vrsta drva

Wood species *Vrsta drva*	**Properties** *Svojstvo*	**Number of samples** *Broj uzoraka*	**Minimum** *Minimum*	**Maximum** *Maksimum*	**Mean** *Srednja vrijednost*	**Std. Dev.** *Standardna devijacija*
Steamed beech-wood *parena bukovina*	density/ *gustoća* g/cm^3	30	0,600	0,718	0,664	0,034
	moisture/*sadržaj vode*, %	30	8,85	9,63	9,18	0,070
Thermally modified beech-wood *termički modificirana bukovina*	density/ *gustoća* g/cm^3	30	0,607	0,673	0,639	0,023
	moisture/*sadržaj vode*, %	30	4,14	4,76	4,47	0,151
Oak-wood *hrastovina*	density/ *gustoća* g/cm^3	30	0,603	0,720	0,655	0,035
	moisture/*sadržaj vode*, %	30	8,67	9,95	9,31	0,401
Fir-wood *jelovina*	density/ *gustoća* g/cm^3	30	0,412	0,471	0,434	0,019
	moisture/*sadržaj vode*, %	30	17,37	19,17	18,27	0,541

Figure 1 Cabinet planer (Weinig Powermat 400)
Slika 1. Četverostrana blanjalica (Weinig Powermat 400)

Machining process was conducted with a cabinet planer (Weinig Powermat 400). Only the top spindle of the machine with two knives was used at 125 mm tool diameter. The knives were made of industry standard high-speed steel. The used feed speeds were 6 m/min, 12 m/min, 18 m/min and 24 m/min. The used knife rake angle was 15^o and the depth of cut was 2.0 mm.

For each testing conditions a total of 10 samples were used. Measurements in five different randomly selected surface spots at each sample were averaged. Surface roughness tests were conducted using a Mitutoyo Surftest SJ 201, and carried out according to DIN 4768, 1990. Table 2 lists the characteristics of the tracing process. The values of roughness were determined with a precision of ±0,01 μm.

Table 2 Characteristics of stylus tracing for surface roughness measurements
Tablica 2. Karakteristike mjernog postupka određivanja hrapavosti površine

Tracing length (L_t) / *mjerna duljina*	12,5 mm
Tracing speed / *brzina mjerenja*	0,5 mm/s
Pick-up length (λ_c) / *duljina uzorkovanja podataka*	2,5 mm
Stylus tip radius / *radijus zaobljenja mjerne igle*	5 μm
Stylus tip angle / *kut mjerne igle*	90^o

Figure 2 shows the Mitutoyo Surftest SJ 201 which was used for the current research. Surface roughness was measured on one side of the sample.

Descriptive statistics (mean, minimum, maximum, variance, standard deviation) was made for all analysed variables. The differences between the obtained values of roughness parameter *R*a for different feed speed were tested by the Student's t-test, under assumption that the condition of homogeneity of variance was met (McClive et al., 1988). If the homogeneity of variance were not met, nonparametric comparison of two independent groups would be made by Mann-Whitney u-test. The error of type I (α) of 5 % was considered statistically significant. All statistical analyses have been made by use of the statistics software - STATISTICA 6.0.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

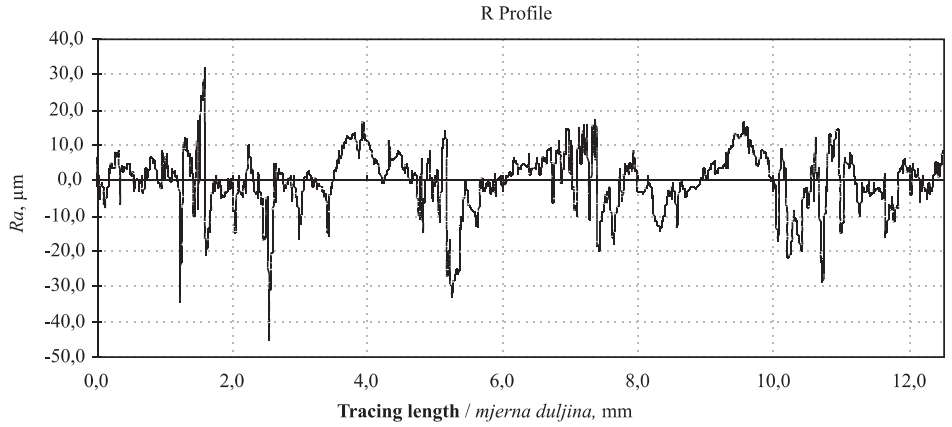
An example of the *R* profiles obtained with our device is presented in Figure 3. The given examples present surface roughness of samples obtained by processing with tool rake angle of 15^o and feed speed of 18 m/min.

Research results are shown in Table 3. The arithmetical mean deviations of the profile (*R*a) present the average roughness value in each group of samples. In order to obtain more accurate results for each sample, measuring of the value *R*a was performed by five measurements and hence we had in total 50 measurements in each group of samples. Mean values of these measurements of arithmetical mean deviation of the profile *Ra*, are presented by the diagram in Figure 4.

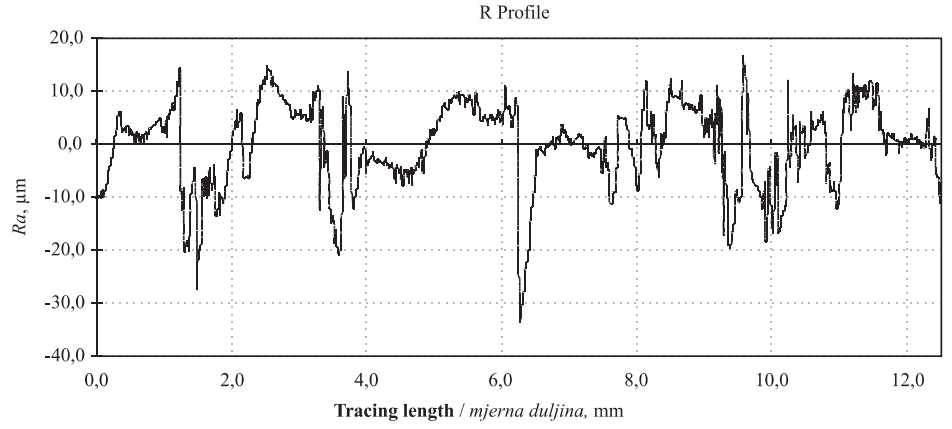
The surface quality of samples of planed beech-wood, oak-wood and fir-wood were significantly different. The best quality of planed surface was achieved by samples of oak-wood, while the samples of fir wood had the highest values of surface roughness. There is no significant difference in surface quality of thermally modified and steamed beach-wood samples despite the significant difference in mechanical properties of the thermally modified and steamed wood.

The results clearly show that the physical and mechanical properties and anatomical structure of wood affect the surface roughness. Resistance to penetration blade cutting edge in the wood depends on the size, shape of cells, as well as thickness and strength of cell

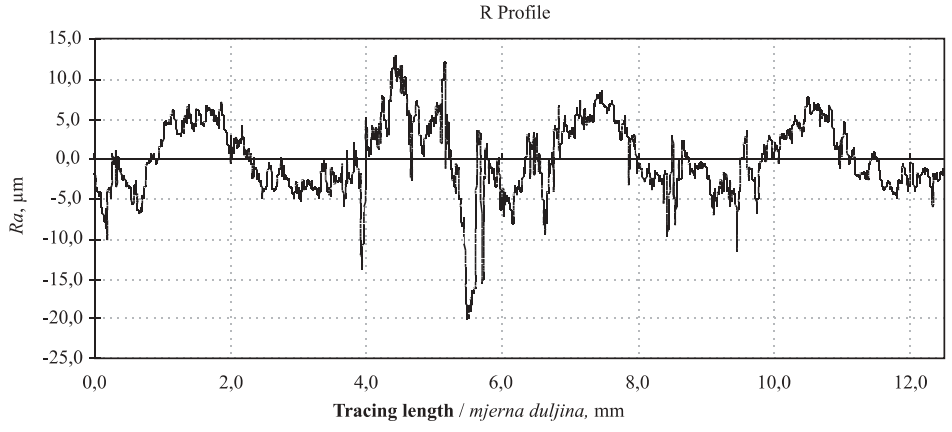
Figure 2 Surface profilometer-Mitutoyo Surftest SJ-201 used in this study
Slika 2. Profilometar Mitutoyo Surftest SJ-201 upotrijebljen u istraživanju



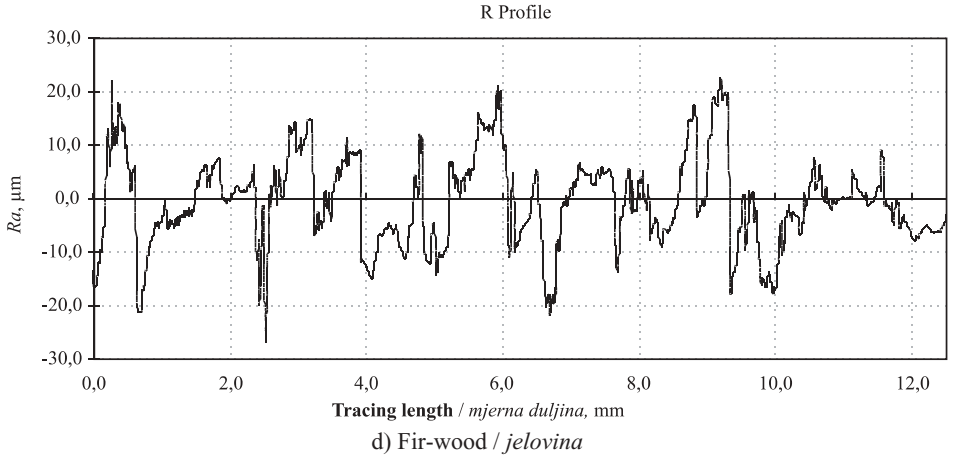
a) Steamed beech-wood / *parena bukovina*



b) Thermally modified beech-wood / *termički modificirana bukovina*



c) Oak-wood / *hrastovina*



d) Fir-wood / *jelovina*

Figure 3 Surface roughness profiles of steamed beech-wood, thermally modified beech-wood, oak-wood and fir-wood
Slika 3. Profil hrapavosti površine parene bukovine, termički modificirane bukovine, hrastovine i jelovine

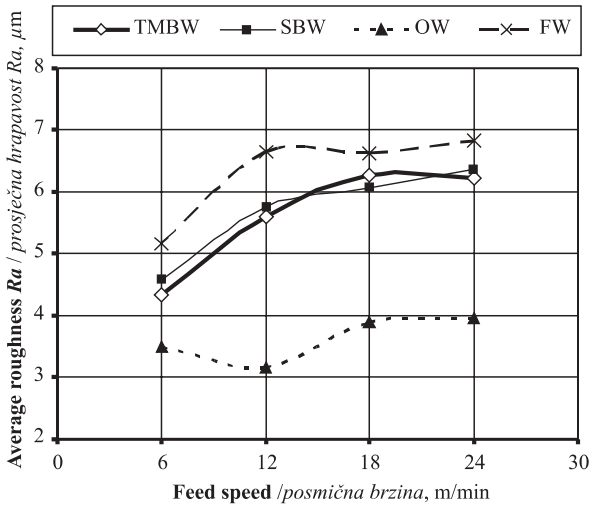


Figure 4 Effect of wood species and feed speed on surface quality (TMBW – Thermally modified beech-wood; SBW - Steamed beech-wood; OW – Oak-wood; FW - Fir-wood)
Slika 4. Utjecaj vrste drva i posmične brzine na kvalitetu obrađene površine (TMBW – termički modificirana bukovina; SBW – parena bukovina; OW – hrastovina; FW – jelovina)

walls. Wood of conifers (fir) has a simpler structure, lower mechanical properties and lower density than deciduous trees (oak and beech). In their researches Malkoçoğlu and Özdemir (2006) and Malkoçoğlu (2007) showed that under the same parameters of processing the surface of conifers (spruce-wood) is of lower quality that the surface of hardwood species (beech wood). It is known from literature that mechanical properties of thermally modified wood are not as good as those of unmodified wood. This research showed that different mechanical properties of steamed and thermally modified beech wood had no effect on the quality of the machined surface of samples under given processing conditions. The samples of thermally modified beech wood, despite mechanical properties of lower quality, had an equally good quality of planed surface as the samples of steamed beech wood.

In their researches Usta *et al* (2007), Örs and Baykan (1999) and Keturakis (2007) showed that the decrease of feed speed results in a better quality of the machined surface. The researches by Malkoçoğlu (2007) also show that the decrease of feed speed and rake angle result in a better quality of the machined surface.

Statistical significance of differences between arithmetic mean values of roughness parameter *Ra*, of individual value pairs for different feed speeds, was tested by use of *t*-test. Table 4 presents the data obtained for *p*. There are significant differences between arithmetic mean values of roughness parameters *Ra* for $p<0.05$.

The axial tool leaves kinematic irregularities on the finished surface in the form of slot cycloid which is characterized by the length and depth of the wave. These parameters directly depend on the feed rate which is proportional to feed speed. As the surface roughness parameter *R*a was measured in direction of fibre length, lower feed rate caused smaller depth of wave, and smal-

Table 3 Statistical processing of measured parameter of surface roughness *Ra*
Tablica 3. Statistička obrada izmjerenih vrijednosti parametra hrapavosti *Ra*

Feed speed *Posmična brzina* m/min	**Wood species** *Vrsta drva*	**Hrapavost *Ra*, µm** / *Surface roughness Ra, µm*					
		Number of samples *Broj uzoraka*	Minimum *Minimum*	Maximum *Maksimum*	Mean *Srednja vrijednost*	Variance *Varijanca*	Std.Dv. *Standardna devijacija*
6	TMBW*	50	2,03	6,72	4,342	1,571	1,253
	SBW	50	2,11	6,71	4,581	1,176	1,085
	OW	50	1,99	6,57	3,490	1,289	1,135
	FW	50	2,11	9,11	5,157	2,743	1,656
12	TMBW	50	2,99	7,34	5,605	1,424	1,193
	SBW	50	2,91	7,95	5,756	1,739	1,319
	OW	50	2,20	4,53	3,154	0,328	0,573
	FW	50	3,58	9,03	6,641	1,585	1,259
18	TMBW	50	3,19	8,83	6,259	1,843	1,358
	SBW	50	4,43	8,05	6,067	1,041	1,020
	OW	50	2,43	5,43	3,896	0,576	0,759
	FW	50	4,24	8,43	6,626	0,953	0,976
24	TMBW	50	4,23	7,97	6,229	1,256	1,121
	SBW	50	3,98	8,45	6,348	1,300	1,140
	OW	50	2,26	5,36	3,960	0,479	0,692
	FW	50	5,05	8,95	6,831	0,894	0,945

*TMBW – Thermally modified beech-wood / *termički modificirana bukovina*; SBW – Steamed beech-wood / *parena bukovina*; OW – oak-wood / *hrastovina*; FW – Fir-wood / *jelovina*

Table 4 Comparison of values of roughness parameter *R*a for different feed speeds
Tablica 4. Usporedba vrijednosti parametra hrapavosti *R*a za različite posmične brzine

Wood species *Vrsta drva*	***p***											
	Feed speed / *posmična brzina*, m/min											
	6	12	6	18	6	24	12	18	12	24	18	24
TMBW*	0		0		0		0		0		0,75	
SBW	0		0		0		0,34		0,05		0,21	
OW	0,43		0		0		0		0		0,77	
FW	0		0		0		0,89		0,66		0,67	

*TMBW – Thermally modified beech-wood / *termički modificirana bukovina*; SBW – Steamed beech-wood / *parena bukovina*; OW – oak-wood / *hrastovina*; FW – Fir-wood / *jelovina*

ler average value of the arithmetical mean deviation of the profile *R*a was estimated at lower feed speed.

Meanwhile, it can be concluded from the presented results that neither of four groups of samples (steamed beech-wood, thermally modified beech-wood, oak-wood and fir-wood) shows any significant difference at a 5% level between mean values of roughness parameter *Ra* of samples planed at feed speeds of 18m/min and 24 m/min. In machining fir-wood samples, with the increase of feed speed above 12 m/min, the obtained data of mean values of roughness parameter *Ra* show no significant difference at a 5% level.

4 CONCLUSIONS
4. ZAKLJUČAK

The research of the surface quality of samples of beech-wood (steamed and thermally modified), oak-wood and fir-wood was conducted on samples planed at different feed speed.

In the group of sixteen samples, oak-wood samples showed the lowest value of mean deviation profiles while fir-wood samples showed the highest value of surface roughness parameter. The average value of the arithmetical mean deviation of the profile *R*a of the thermally modified beech-wood was very close to the same values of steamed beech-wood samples. It can be concluded that in all four types of samples the increase of feed rate results in the increase of the average value of the arithmetical mean deviation of the profile *R*a. This particularly applies to feed speed up to 18 m/min. No significant change of roughness parameter *Ra* was recorded at feed speed ranging between 18 and 24 m/min.

In general, better results of the machining performance have been obtained with the decreasing feed speed. In the literature, it has been reported that increasing feed speed caused strong machining defects (Koch, 1964); (Malkoçoğlu, 2007).

Further research of the surface quality of planed samples should be carried out on samples planed at higher revolutions (higher cutting speed) with more knives on the planing tool.

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