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Effects of CNC Processing Parameters on Surface Quality of Wood-Based Panels Used in Furniture Industry

Utjecaj parametara CNC obrade na kvalitetu površine drvnih ploča koje se upotrebljavaju u industriji namještaja

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ABSTRACT • *The processing of wood-based panels such as plywood, particleboard and fiberboard, which are widely used in the furniture industry, with CNC (Computer Numerical Control) milling machines has been increasing recently. Even though CNC milling machines have many advantages for furniture producers, it is difficult to set process parameters to obtain the desired surface quality of the material. Therefore, it is necessary to determine the most suitable of these parameters for the surface quality of each wood-based panel. This study aimed to determine the effects of processing parameters on the surface quality of plywood, particleboard and medium density fiberboard (MDF) panels processed in CNC milling machines. Furthermore, the average surface roughness values of these panels were compared after CNC processing. Three spindle rotational frequencies (10.000, 14.000 and 18.000 rpm), three feed rates (5, 7, and 9 m/min) and two cutting tool diameters (2 and 5 mm) were selected as CNC processing parameters. To determine the surface quality of wood-based panels, the surface roughness measurements were performed according to DIN 4768 standard and three surface roughness parameters (R_a, R_{max} and R_z) were determined. According to the results of this study, it can be concluded that the surface roughness values of wood-based panels decreased with increasing spindle rotational frequency and feed rate, while they increased with increasing cutting tool diameter. Among the wood-based panels used in this study, the lowest average roughness values were obtained for plywood samples.*

KEYWORDS: *wood-based panel; CNC milling machine; surface roughness; processing parameters*

SAŽETAK • *Za obradu ploča na bazi drva kao što su furnirske ploče, iverice i vlaknatice, koje imaju široku primjenu u industriji namještaja, u posljednje se vrijeme sve češće primjenjuju CNC (Computer Numerical Control) glodalice. Iako CNC glodalice imaju mnoge prednosti za proizvođače namještaja, teško je odrediti parametre procesa za postizanje željene kvalitete površine obrađivanog materijala. Stoga je potrebno odrediti najprikladnije parametre obrade za svaku vrstu ploče na bazi drva. Cilj ovog istraživanja bio je utvrditi utjecaj parametara obra-*

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de CNC glodalicama na kvalitetu površine furnirske ploče, iverice i ploče vlaknatice srednje gustoće (MDF ploče). Nadalje, uspoređene su srednje vrijednosti hrapavosti površine tih ploča nakon CNC obrade. Kao parametri CNC obrade odabrane su tri frekvencije vrtnje vretena (10 000, 14 000 i 18 000 okr./min), tri posmične brzine (5, 7 i 9 m/min) te dva promjera reznog alata (2 i 5 mm). Za određivanje kvalitete površine ploča na bazi drva provedena su mjerenja hrapavosti površine prema normi DIN 4768, a hrapavost je iskazana trima parametrima hrapavosti površine (R_a, R_{max} i R_z). Prema rezultatima ovog istraživanja može se zaključiti da su se vrijednosti hrapavosti površine ploča na bazi drva smanjivale s povećanjem frekvencije vrtnje vretena i posmične brzine, dok su se povećavale s povećanjem promjera reznog alata. Među pločama na bazi drva na kojima je provedeno ovo istraživanje najniže srednje vrijednosti hrapavosti dobivene su za uzorke furnirske ploče.

KLJUČNE RIJEČI: *ploče na bazi drva; CNC glodalica; hrapavost površine; parametri obrade*

1 INTRODUCTION
1. UVOD

Wood-based panels such as plywood, particleboard and fibreboard, especially medium density fiberboard (MDF), are intensely used in furniture production and interior decoration (Akbulut and Ayrilmis, 2019). The production of wood-based panels in Europe (+EFTA) grew by 3 % in 2018 to 57.6 million cubic metres. The fastest growth was in plywood, and particleboard was the largest category by volume (32 million cubic metres), followed by MDF (12.3 million cubic metres) (European Panel Federation, 2018). Turkey is now one of the world's top wood-based panel manufacturers. Turkey is ranked first in the production of MDF in Europe and second in the world, and third in Europe and fourth in the world in the production of particleboard (ORSIAD, 2019). In 2018, the production quantity of particleboard, MDF and plywood in Turkey was 4.36, 4.91 million cubic metres, and 112.000 cubic metres, respectively (FAO, 2020). It is known that among the panels produced every year, approximately 80 % of the particleboard and 70 % of the MDF panels are used in the furniture industry, and the furniture market in Turkey is growing rapidly due to the increase in the amount of wood-based panel production. Furthermore, it was stated that plywood panels are frequently used in both construction and furniture industries (Ferreira *et al.*, 2017).

The application of high technology such as CNC machines and automation systems is one of the main reasons of the growth of the furniture industry. In the furniture industry, CNC machines have been preferred considerably in the processes such as patterning, milling, drilling and grooving (Sofuoglu, 2017). As the integration of CNC machines with other automation systems is very flexible, time loss in furniture production decreases and productivity increases 2.5 times (Koc *et al.,* 2017). Moreover, they improve surface quality of the materials and reduce labour cost (Sutcu, 2013). The surface quality of the processed materials is one of the most important factors affected by finishing processes such as coating, painting and varnishing, machining properties, mechanical properties such as adhesion strength and bending strength of wood-based panels (Sofuoglu, 2017; Zhong *et al.,* 2013). Surface roughness measurement is the most important quality control tool that determines the surface quality of the processed materials. The surface roughness of wood and wood-based panels is affected by many factors. The most important of these factors are the anatomical and physical properties of wood materials such as wood species, density, hardness, moisture content, fiber direction (Tabarsa *et al*., 2011). Moreover, the main operational machining parameters such as spindle rotational frequency, depth of cut, tool sharpness, cutting circle radius, cutting direction, cutting angle and vibration are among the factors that significantly affect surface roughness values (Csanády *et al*., 2015).

Many different parameters have to be adjusted on the CNC machines for the processing of material using code file. These are the spindle rotational frequency, feed rate, cutter step over, cutter plunge speed, tool strategy, etc. (Bal and Akcakaya, 2018). Most of the problems that occur in the processing of wood and based panels are caused by errors in setting the appropriate parameters. Processing parameters adjusted correctly are the most important factors that increase the surface quality of wood and wood-based boards (Koc *et al.,* 2017). For this reason, many researchers have studied the effects of CNC processing parameters such as spindle rotational frequency, step over, feed rate, cutting tool diameter and depth of cut on surface roughness of solid wood (Gawronski, 2013; Hazir and Koc, 2019; Iskra and Hernández, 2009; Sofuoglu, 2017; Sutcu and Karagoz, 2013) and MDF (Koc *et al.,* 2017; Bal, 2018; Davim *et al.,* 2009; Deus *et al.,* 2018; İşleyen and Karamanoğlu, 2019) processed with CNC machines. In general, it was found in these studies that higher values of spindle rotational frequency caused smoother surface of material whereas higher values of feed rate, step over and depth of cut resulted in the increased surface roughness of materials.

There is no information about the influence of CNC processing parameters on the surface quality of plywood and particleboard while there are many studies on solid wood and MDF in the literature. The aim of this study was to determine the effects of processing parameters on the surface quality of plywood, particleboard and MDF panels processed in CNC milling machines. In addition, the average values of surface roughness of these panels were compared after CNC processing.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Particleboard and MDF panels with the thickness of 18 mm and five-ply birch plywood panels with the thickness of 10 mm have been obtained from a supplier as research materials in the study, because these wood-based panel products are largely used as raw materials in the furniture industry in Turkey. Test samples with the dimensions of 50 cm × 110 cm (width × length) were prepared from the particleboard, MDF and plywood panels. Before the processing with CNC machine, the samples of panels were conditioned at (20 ± 2) °C and (65 ± 5) % relative humidity until they reached a moisture content of (12 ± 1) % in a climate chamber.

2.2 CNC machine and cutting conditions
2.2. CNC stroj i uvjeti obrade

The samples of panels were processed on Megatron 2128, four-axis CNC Milling Machine with 9 kW spindle power, and a maximum rotational frequency of 24.000 rpm. The processing of panel samples with CNC machine is shown in Figure 1.

Three spindle rotational frequencies (10.000, 14.000, and 18.000 rpm) and feed rates (5, 7, and 9 m/min) were applied for CNC processing. Solid carbide barrel milling cutters in conical form were also used with two different diameters (2 mm and 5 mm). The tool dimensions of cutters are presented in Figure 2. The cutting depth for plywood was 2 mm and 10 mm for particleboard and MDF.

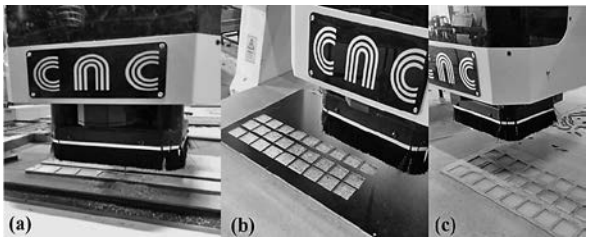

Figure 1 Grooving of plywood (a), particleboard (b) and MDF (c) panels with CNC machine
Slika 1. Izrada utora na furnirskoj ploči (a), ploči iverici (b) i MDF-u (c) CNC strojem

2.3 Surface roughness measurements
2.3. Mjerenje hrapavosti površine

Five specimens (5 cm × 5 cm) were obtained from panel groups and five measurements were made for each specimen. Mitutoyo Surftest SJ-301 Surface Roughness Tester was used for the surface roughness tests. Cut-off length was 2.5 mm, sampling length was 12.5 mm and detector tip radius was 5 µm in the surface roughness measurements. The measurements were made perpendicular to the fiber direction of the plywood samples, whereas the fiber direction was not taken into account in the particleboard and MDF samples due to their homogeneous structure. Three roughness parameters R_a (absolute arithmetic mean), R_{max} (maximum two-point height of profile) and R_z (arithmetic mean of the 10-point height of irregularities) were measured to evaluate surface roughness of the sample surfaces according to DIN 4768 standard (1990).

Analysis of variance (ANOVA) was performed for the statistical evaluation of changes in the surface

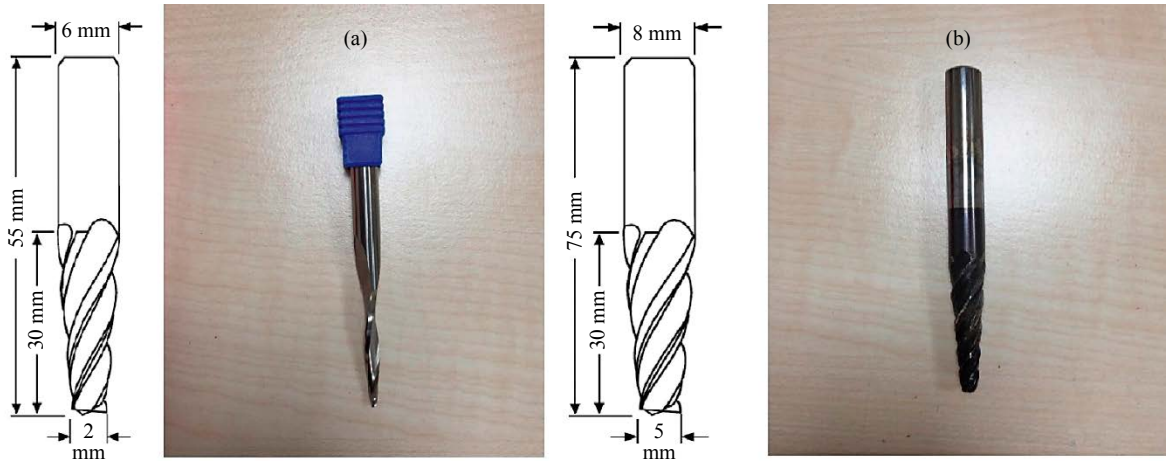

Figure 2 Cutting tool dimensions of 2 (a) mm and 5 (b) mm diameters
Slika 2. Dimenzije reznog alata promjera 2 mm (a) i 5 mm (b)

roughness parameters (R_a, R_{max} and R_z) depending on the cutting tool diameter, spindle rotational frequency and feed rate. After ANOVA, Student–Newman–Keuls test with 95 % confidence level was used to compare the mean values of variance sources.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The average values and standard deviation of R_a, R_{max}, and R_z parameters of surface roughness are given in Figures 3 and 4. The lowest R_a, R_{max}, and R_z values

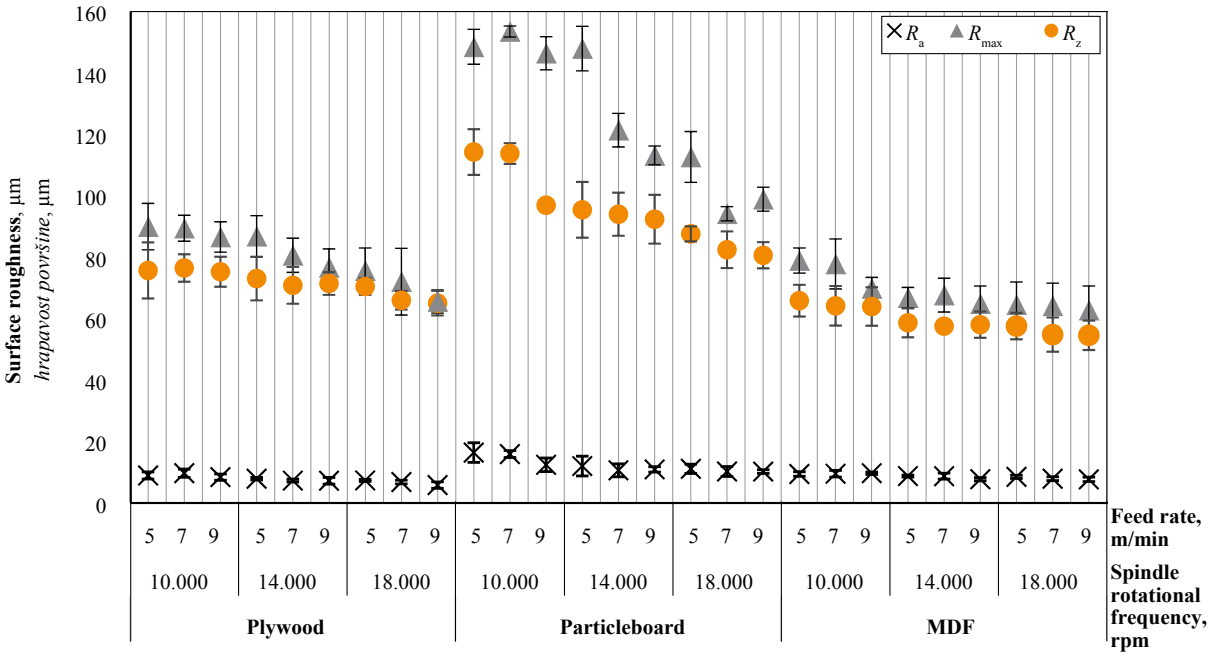

Figure 3 Variation of surface roughness values of wood-based panels processed with 2 mm diameter cutting tool according to CNC cutting parameters
Slika 3. Odstupanja vrijednosti hrapavosti površine ploča na bazi drva obrađenih reznim alatom promjera 2 mm s obzirom na parametre CNC obrade

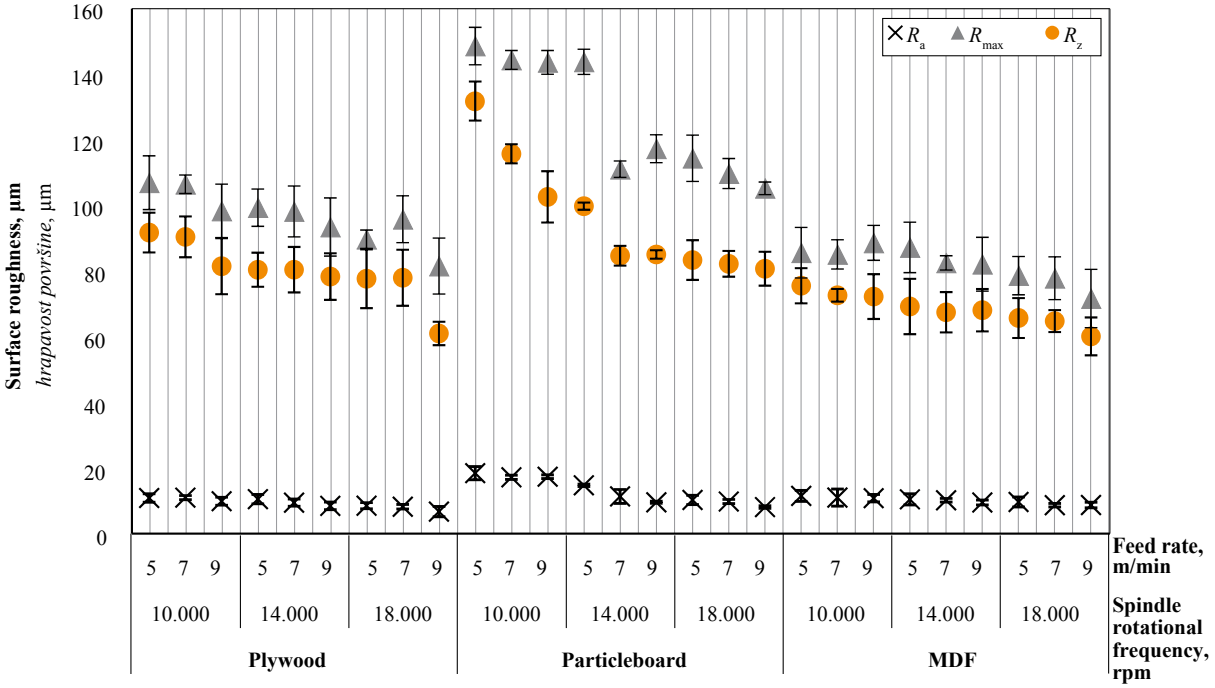

Figure 4 Variation of surface roughness values of wood-based panels processed with 5 mm diameter cutting tool according to CNC cutting parameters
Slika 4. Odstupanja vrijednosti hrapavosti površine ploča na bazi drva obrađenih reznim alatom promjera 5 mm s obzirom na parametre CNC obrade

were obtained with 2 mm diameter cutting tool, 18.000 rpm spindle rotational frequency and 9 m/min feed rate for all three panel samples. However, the highest values were obtained with 5 mm diameter cutting tool, 10.000 rpm spindle rotational frequency and 5 m/min feed rate for all panel groups. When the data of surface roughness were analysed, higher surface roughness values were obtained with 5 mm diameter cutting tool than with 2 mm diameter cutting tool.

ANOVA tables have been compiled with the average surface roughness obtained from the experiments. The effects of related parameters on surface roughness have been determined. The results of F and Significant Levels (Sig.) of variance analysis are given in Table 1. The Sig. values lower than 0.05 show that the factors and interaction of the factors are statistically significant. Multiple comparison test results (Student–Newman–Keuls) for surface roughness parameter values (R_a, R_{max} and R_z) are given in Table 2.

When analysing the results of Table 2, it can be seen that the surface roughness values (R_a, R_{max} and R_z) for all of the panel types decreased with increasing values of spindle rotational frequency. In the literature, the reasons for changes in spindle rotational frequency were determined by some researchers (Pelit *et al.*, 2021; Deus *et al*., 2015; Valarmathi *et al.*, 2013). Pelit *et al.* (2021) stated that the contact between the cutting edge of the tool and the cut surface increased with the increase of spindle rotation frequency, and hence the surface roughness values of wood materials decreased. Deus *et al.* (2015) explained that each cutting tooth removes less material at high spindle rotational frequency where the feed rate is constant, and thus less rough material surfaces can be obtained. Moreover, Valarmathi *et al.* (2013) stated that, with the increase of spindle rotational frequency, the processed material heats up and its surface softens and becomes smoother. As a result of these effects, surface roughness decreases. Similar results have been obtained in many studies on the effects of spindle rotation frequency on wood and chipboard surface roughness. Similar results were obtained in many studies regarding the effects of spindle rotation frequency on the surface roughness of wood and fiberboard (Sofuoglu, 2017; Hazir and Koc, 2019; Deus *et al.,* 2015; Prakash *et al.,* 2011; Sedlecký *et al.,* 2018; Sutcu and Karagoz, 2012). In this study, the spindle rotational frequency at 18.000 rpm provided the smallest surface roughness values for all wood-based panel types.

Similarly, the surface roughness parameters decreased statistically with increasing feed rate for the plywood and particleboard panels. In the MDF panels, although the effect of feed rate on R_{max} and R_z roughness values was not statistically significant, it was ob-

Table 1 ANOVA test results for R_a, R_{max} and R_z values of wood-based panel types
Tablica 1. Rezultati ANOVA testiranja vrijednosti R_a, R_{max} i R_z za ploče na bazi drva

Panel types *Vrsta ploče*	**Source of variance** *Izvor odstupanja*	R_a		R_{max}		R_z	
		F	Sig.	*F*	Sig.	*F*	Sig.
Plywood *furnirska ploča*	A: Tool diameter / *promjer alata*, mm	93.477	0.000	129.753	0.000	44.463	0.000
	B: Spindle rotational frequency *frekvencija rotacije vretena*, mm^{-1}	45.903	0.000	40.764	0.000	28.501	0.000
	C: Feed rate / *posmična brzina*, m/min	12.219	0.000	11.716	0.000	8.034	0.001
	A*B	1.265	0.289	0.194	0.824	2.393	0.099
	A*C	0.872	0.423	0.898	0.412	4.236	0.018
	B*C	1.208	0.315	0.910	0.463	1.684	0.163
	A*B*C	0.349	0.844	0.418	0.795	0.987	0.420
Particleboard *ploča iverica*	A: Tool diameter / *promjer alata*, mm	13.671	0.000	0.219	0.641	1.359	0.248
	B: Spindle rotational frequency *frekvencija rotacije vretena*, mm^{-1}	119.143	0.000	568.722	0.000	240.809	0.000
	C: Feed rate / *posmična brzina*, m/min	15.890	0.000	91.551	0.000	39.536	0.000
	A*B	10.280	0.000	14.792	0.000	11.220	0.000
	A*C	0.593	0.555	1.454	0.240	5.013	0.009
	B*C	1.088	0.369	31.039	0.000	9.655	0.000
	A*B*C	3.697	0.009	6.081	0.000	2.974	0.025
MDF	A: Tool diameter / *promjer alata*, mm	67.827	0.000	113.898	0.000	66.810	0.000
	B: Spindle rotational frequency *frekvencija rotacije vretena*, mm^{-1}	19.846	0.000	19.887	0.000	23.156	0.000
	C: Feed rate / *posmična brzina*, m/min	2.922	0.060	2.914	0.061	1.807	0.171
	A*B	0.760	0.471	2.017	0.140	0.337	0.715
	A*C	0.305	0.738	0.142	0.868	0.187	0.830
	B*C	0.676	0.611	0.345	0.847	0.311	0.869
	A*B*C	0.156	0.960	2.175	0.080	0.144	0.965

Table 2 Results of Student-Newman-Keuls test at 95 % confidence level for CNC processing parameters
Tablica 2. Rezultati Student-Newman-Keulsova testa za razinu pouzdanosti od 95 % za parametre CNC obrade

Panel types *Vrsta ploče*	**Factors** / *Čimbenici*	R_a		R_{max}		R_z	
		LS Mean	**HG***	**LS Mean**	**HG**	**LS Mean**	**HG**
Plywood *furnirska ploča*	Tool diameter / *promjer alata,* mm						
	2	8.15	a	81.04	a	72.04	a
	5	10.26	b	97.45	b	80.79	b
	Spindle rotational frequency *frekvencija vrtnje vretena,* min^{-1}						
	10.000	10.50	c	96.92	c	82.49	c
	14.000	9.18	b	89.81	b	76.41	b
	18.000	7.94	a	81.01	a	70.35	a
	Feed rate / *posmična brzina,* m/min						
	5	9.71	b	92.03	b	78.82	b
	7	9.44	b	91.39	b	77.67	b
	9	8.46	a	84.33	a	72.75	a
Particleboard *ploča iverica*	Tool diameter / *promjer alata,* mm						
	2	12.65	a	126.73	a	95.72	a
	5	13.93	b	127.20	a	97.04	a
	Spindle rotational frequency *frekvencija vrtnje vretena,* min^{-1}						
	10.000	16.98	c	148.08	c	113.13	c
	14.000	12.24	b	126.37	b	92.53	b
	18.000	10.65	a	106.46	a	83.48	a
	Feed rate / *posmična brzina,* m/min						
	5	14.53	c	136.57	b	102.67	c
	7	13.21	b	122.97	a	96.11	b
	9	12.13	a	121.37	a	90.36	a
MDF	Tool diameter / *promjer alata,* mm						
	2	9.10	a	69.05	a	59.91	a
	5	11.02	b	83.42	b	69.28	b
	Spindle rotational frequency *frekvencija vrtnje vretena,* min^{-1}						
	10.000	11.02	c	81.63	c	69.72	c
	14.000	9.93	b	75.83	b	63.82	b
	18.000	9.23	a	71.25	a	60.25	a
	Feed rate / *posmična brzina,* m/min						
	5	10.42	b	77.60	a	66.08	a
	7	10.03	ab	77.16	a	64.22	a
	9	9.73	a	73.95	a	63.49	a

*Homogeneity Groups: different letters denote a statistically significant difference. / *Homogene grupe: različita slova označavaju statistički značajnu razliku.*

served that Ra roughness values of the whole group decreased with increasing feed rate except for the samples processed with 2 mm diameter cutting tool at 10.000 rpm spindle rotational frequency. Davim *et al.* (2015) suggested that the last low feed rate values reduce the stress on the tool, contribute to the prevention of grooves on the surface of the wood and increase the processing efficiency. In the literature, there are many studies showing different relationships between the feed rate and the surface roughness values of wood materials. Some researchers found that the surface roughness of processed materials decreased with increasing feed rate (Gawronski, 2013; Davim *et al.,* 2009; Sutcu and Karagoz, 2012), while others found that the surface roughness of processed materials increased with increasing feed rate (Koc *et al.,* 2017; Isleyen and Karamanoglu, 2019; Deus *et al.,* 2015). Sutcu (2013) stated that the effect of feed rate on surface roughness is statistically insignificant. In this study, the same results were obtained for the R_{max} and R_z values of the MDF panels (Table 2). The differences between the results in literature are thought to be due to the selected feed rate values and the differences between them. Generally, 9 m/min feed rate presented the smallest surface rough-

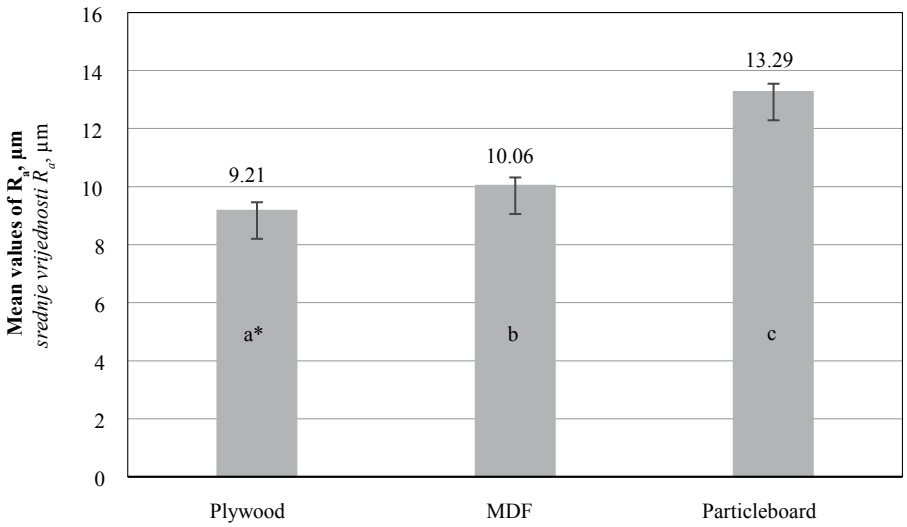

Figure 5 Comparison of wood-based panel types processed with CNC machine (*Different letters denote a statistically significant difference)
Slika 5. Usporedba vrijednosti hrapavosti ploča na bazi drva obrađenih CNC strojem (*različita slova označavaju statistički značajnu razliku)

ness for the wood-based panels in this study. Similarly, the use of high feed rates in wood milling has been strongly recommended by Očkajová *et al.* (2020).

Even though the most influencing CNC processing parameters on the surface roughness are spindle rotational frequency and feed rate, tool geometry and tool diameter also have influence on the processing of composites (Prakash *et al.,* 2011). As can be seen from Table 2 and Figure 4, the surface roughness values increased as the cutting tool diameter increased for the plywood and MDF panel groups. The same results were obtained from the R_a values of particleboard panel groups. However, there was no statistically significant effect of tool diameter on the R_{max} and R_z values of the particleboard panels. İsleyen and Karamanoğlu (2019) stated that the friction area between the tool and the material increased with the increase of the tool diameter, and hence the surface roughness values of the materials increased. Many researchers determined that cutting tool diameter was an effective factor in all the wood machining processes and the smallest roughness values were obtained from lower tool diameter values (Isleyen and Karamanoglu, 2019; Prakash *et al.,* 2011). In this study, it was determined that the plywood and MDF samples processed with 2 mm diameter cutting tool had the lowest surface roughness values.

The average roughness values (R_a) of the panel types processed with CNC machine were statistically analysed according to the panel types. The comparison results of the panel types are shown in Figure 5.

As can be seen from Figure 5, the plywood processed with CNC machine has the smoothest surfaces of all other panel types. The highest surface roughness values were measured at the particleboard samples processed with CNC machine. Since the chips have a rough surface compared to the peeling veneers and fibers, the surface roughness values of the particleboards are also expected to be high. However, Zhong *et al.* (2013) determined surface roughness values of plywood, particleboard, MDF and solid wood manufactured from different wood species in Singapore. According to the results of that study, the R_a values of MDF panel were found to be the highest among the wood-based panels. Moreover, some researchers compared the surface roughness values of particleboard and MDF panels and found that MDF panels had smoother surfaces than particleboard (Hiziroglu *et al.,* 2004; Ulker, 2018). The various factors such as wood species, humidity, wood processing, measurement methods can cause the differences in the results obtained from the studies.

4 CONCLUSIONS
4. ZAKLJUČAK

This study was aimed to determine the effects of process parameters on the surface roughness values after CNC machine processing of plywood, particleboard and MDF panels, which are frequently used in the furniture industry. The findings obtained from this study are given below.

The CNC processing parameters such as tool diameter, spindle rotational frequency and feed rate are very important factors in terms of surface roughness values (R_a, R_{max} and R_z) of plywood and particleboard as well as MDF panels.

The surface roughness values of the plywood and MDF panels processed with 2 mm diameter cutting

tool were found to be higher than those processed with 5 mm diameter cutting tool. Although similar results were found for R_a values of particleboard groups, no statistical difference was found in other surface roughness parameter values (R_{max} and R_z) depending on the increase in tool diameter values.

The higher spindle rotational frequency values caused the smoothest surface on all of panel groups. Therefore, the selected spindle rotational frequency of 18.000 rpm was the best for the surface quality of these boards.

The surface roughness values of the plywood and particleboard panel groups decreased with increasing feed rate values. The smoothest surfaces for these panels were obtained at the feed rate of 9 m/min. Although similar results were found for R_a values of MDF panel groups, no statistical difference was found in other surface roughness parameter values (R_{max} and R_z) depending on the increase in feed rate values.

When comparing the R_a values measured on the panel samples after processing with CNC machine, the plywood groups presented the smoothest surfaces. The highest R_a values were obtained for the particleboard samples.

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