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ORIGINAL SCIENTIFIC PAPERS

REVIEW PAPER / Pregledn rad

Umit Ergin[1], Sait Dundar Sofuoglu[2]

Determination of Machining Characteristics of Heat-Treated Siberian Pine (*Pinus sibirica*)

Određivanje svojstava obradivosti toplinski modificiranog drva sibirskog bora (*Pinus sibirica*)

ORIGINAL SCIENTIFIC PAPER
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ABSTRACT • *The main objective of this study is to determine the effect of heat treatment on the machining properties of solid wood material and determine the optimum cutting parameters to obtain surfaces with minimum surface roughness. In line with this goal, Siberian pine (Pinus sibirica) wood species, widely used in the woodworking and furniture industry, was chosen as the experimental material. The heat-treated (at a temperature of 190 °C for 2 hours) and untreated samples were machined using two different cutters (carbide upcut milling cutter and carbide compression milling cutter) with 5 mm diameter at 1000, 1500 and 2000 mm/min feeds, 8000, 12000, 16000 rpm spindle speed, 50, 75 and 100 % stepover on the CNC machine. Surface roughness values (Ra and Rz) were measured to evaluate the obtained surfaces according to ISO 468 (2009), ISO 3274 (2005), and ISO 4287 (1997) using a contact profilometer. When the data was evaluated in general, the lowest roughness value for Ra occurred in upcut milling cutter, with 50% stepover, 12000 rpm, 1000 mm/min feed on untreated solid wood material. The highest roughness value for Ra occurred in a compression milling cutter, with 100 % stepover, 16000 rpm, 2000 mm/min feed on heat-treated solid wood material. It has been observed that the feed is the most critical parameter affecting the surface roughness.*

KEYWORDS: *heat treatment, machining parameter, roughness, Siberian pine, wood material*

SAŽETAK • *Glavni cilj ovog istraživanja bio je utvrditi utjecaj toplinske modifikacije na svojstva obradivosti cjelovitog drva te utvrditi optimalne parametre rezanja za postizanje obrađene površine minimalne hrapavosti. U skladu s tim ciljem, za istraživanje je odabrano drvo sibirskog bora (Pinus sibirica) koje ima široku primjenu u drvoprerađivačkoj industriji i proizvodnji namještaja. Toplinski modificirani (na temperaturi 190 °C tijekom dva sata) i nemodificirani uzorci obrađeni su na CNC stroju dvama različitim glodalima (usadnim glodalom s uzlaznom zavojnicom i usadnim glodalom s uzlazno-silaznom zavojnicom) promjera 5 mm s oštricama od tvrdog metala, te uz posmičnu brzinu od 1000, 1500 i 2000 mm/min, frekvenciju vrtnje vretena od 8000, 12 000 i 16 000 okr./min te s korakom glodanja od 50, 75 i 100 %. Hrapavost površine (Ra i Rz) izmjerena je kontaktnim profilome-*

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trom kako bi se površina ocijenila prema ISO 468 (2009), ISO 3274 (2005) i ISO 4287 (1997). Dobiveni rezultati pokazuju da je najmanja vrijednost hrapavosti Ra zabilježena za površinu nemodificiranih uzoraka obrađenih usadnim glodalom s uzlazno-silaznom zavojnicom, i to uz ove parametre obrade: korak glodanja 50 %, frekvenciju vrtnje vretena 12 000 okr./min i posmičnu brzinu 1000 mm/min. Najveća vrijednost hrapavosti Ra zabilježena je za modificirane uzorke obrađene usadnim glodalom s uzlazno-silaznom zavojnicom za ove parametre obrade: korak glodanja 100 %, frekvenciju vrtnje vretena 16 000 okr./min i posmičnu brzinu 2000 mm/min. Uočeno je da je posmična brzina najkritičniji parametar koji utječe na hrapavost obrađene površine.

KLJUČNE RIJEČI: *toplinska modifikacija, parametri obrade, hrapavost, drvo sibirskog bora, drvni materijal*

1 INTRODUCTION
1. UVOD

From the past to the present, different "Wood Modification Methods" have been developed due to all scientific studies and research done to eliminate some of the negativities of solid wood material. Wood modification is applied to change or improve the negative properties of wood material (Senol, 2018; Senol and Budakci, 2016).

Today, heat treatment is applied to wood material to improve its dimensional stability and increase its biological durability. This is a nature and environment friendly method.

The physical and mechanical properties of heat-treated wood materials change. This change can be positive or negative, occurring during production and post-production use. The effect of heat treatment needs to be determined for each tree species and condition. However, there are not enough studies in the literature on the subject.

Related to heat treated wood materials, there are studies in the literature on mechanical properties (Akman, 2008; Bal and Kilavuz, 2021; Doruk *et al.*, 2014; Esen and Ozcan, 2012; Icel and Beram, 2017; Korkut *et al.*, 2008; Mburu *et al.*, 2008; Percin and Ayan, 2012; Percin *et al.*, 2017; Percin and Altunok, 2019; Yildiz *et al.*, 2006), mass loss (Zaman *et al.,* 2000, Esteves *et al.,* 2007; Lunguleasa *et al.*, 2018) wettability (Hakkou *et al.*, 2005a; Kilincarslan and Simsek, 2020, Petrissans *et al.*, 2003), color changes (Atar *et al.*, 2019; Ayadi *et al.,* 2003; Ayata, 2020; Baysal *et al.*, 2018; Gurleyen *et al.*, 2018; Karamanoglu and Kaymakci, 2018; Pelit, 2017; Sahin Kol *et al.*, 2017; Yasar, 2009) hardness (Adela Salca and Hiziroglu, 2014; Efe and Bal, 2016; Gurleyen *et al.*, 2017; Karamanoglu and Kaymakci, 2018), biological durability to brown rot fungi (Duzkale Sozbir and Bektas, 2019), evaluations on microscopic images of heat treated wood (Icel and Simsek, 2017), surface roughness (Ayata *et al.*, 2018; Altun and Esmer, 2017; Çakicier, 2018; Korkut and Guller, 2008; Pelit *et al.*, 2021) dimensional stability (Sahin and Guler, 2018) bonding strength of some adhesives (Percin and Uzun, 2014; Ayata and Cakicier, 2018) surface densification (Ayrilmis *et al.*, 2019; Gong *et al.*, 2010), chemical changes (Hakkou *et al*, 2005b), evaluation of studies on heat treatment (Esteves and Pereira, 2009; Ulay *et al.*, 2014). Heat treatment changes the chemical composition of wood, leading to mass loss (Esteves and Pereira, 2009). Heat treatment reduces specific wood mechanical properties, but the dimensional stability and biological durability of wood increase through heat treatment. In addition, heat treatment results in favorable changes in the physical properties of the wood, such as reduced shrinkage and swelling, low equilibrium moisture content, enhanced weather resistance, a decorative dark color, and better decay resistance (Korkut *et al.*, 2008; Yildiz, 2002). However, there are few studies on the change in machining properties and optimum machining parameters of heat-treated wood materials. Budakci *et al.* (2011) examined the effects of different circular saws on the surface roughness of heat-treated wood. Heat treatment increased the surface roughness of the wood used (Budakci *et al.*, 2011). Heat treatment of Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), Uludag fir (*Abies bornmülleriana* Mattf.), and sessile oak (*Quercus petraea* L.) decreases the surface roughness value of the wood material and a significant difference in surface roughness cannot be detected between planing (Budakci *et al.*, 2013). Gunduz *et al.* (2008) reported that the surface roughness of modified Camiyani Black Pine wood (*Pinus nigra* Arn. subsp. *pallasiana* var. *pallasiana*) is lower. The surface roughness of heat-treated beech machined by milling was slightly higher than that of untreated wood (Ispas *et al.*, 2016). Hacibektasoglu *et al.* (2017) revealed that heat-treating beech (*Fagus sylvatica* L.) for 1 h and 2 h had a negligible effect on the processing roughness after planing, measured by *Rk*.

Industrial development and international competitiveness impose higher demands on wood industry. New technologies and cutting materials are the key to successful productivity in the manufacturing process (Dobrzynski *et al*, 2018). Before heat-treated wood materials are turned into the final product, they may need to be machined with classical machines and modern CNCs. After machining, solid wood is expected to be smooth (minimum surface roughness) and free of machining defects. In this context, machining parameters will be determined to obtain the lowest surface roughness.

Therefore, the scope of this study was as follows:

1. To choose optimum machining parameters (cutter type, stepover, spindle speed, and feed) for Siberian pine wood material,
2. To determine the effect of heat treatment on machining properties and to investigate optimum machining parameters to obtain the smoothest surface.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Siberian pine (*Pinus sibirica*), which is one of the coniferous tree species with a wide area of use and widely grown, was chosen as the experimental material in the study. The samples (heat-treated at a temperature of 190 °C for 2 hours and untreated) were all randomly selected from Atlas Tomruk, Simav, Kutahya Turkey. They were conditioned at temperatures of (20±2) °C and (65±5) °C, with a relative humidity to the moisture content (MC) of about 12 % (Nuve, ID500). The density of the Siberian pine tree species at 12 % humidity was determined as 0.623 g/cm^3 for untreated samples and 0.470 g/cm^3 for heat-treated samples (ISO 13061-1, 2014; ISO 13061-2, 2014). The experimental process flowchart of the study is given in Figure 1.

The experiments were carried out on a Diacam 3 axis CNC milling machine (Simav Vocational and Technical Anatolian High School¸ Simav, Kutahya, Turkey) with a maximum spindle speed of 24000 rpm. New and sharp cutters were used in each cutting test. Upcut milling cutter had cutting helixes and, when looking at the router bit with the tip pointing downwards, the cutting helixes were inclined to the right. When rotating clockwise, the router bit pushed the chips upwards ensuring an excellent finish on the bottom side of the workpiece. The ability of the positive cutting edge to move the chip towards the shank is called the 'pulling feature' and allows the router bit to make single passes. Carbide positive-negative milling cutter (pulling and pushing feature) with positive and negative cutting edges can achieve an optimal finish on both sides of the wood and wood-based materials. These cutters are used in CNC for contouring, sizing, and profiling hardwood and wood composites, laminated, and plastic materials. These cutters have two positive helixes at the bottom of the cutting edge and two negative ones at the top. The cutter 2+2 mouth positive and negative structure discharges chips from both the top and bottom of the material and gives smooth results for every surface cut (Figure 2). The ex-

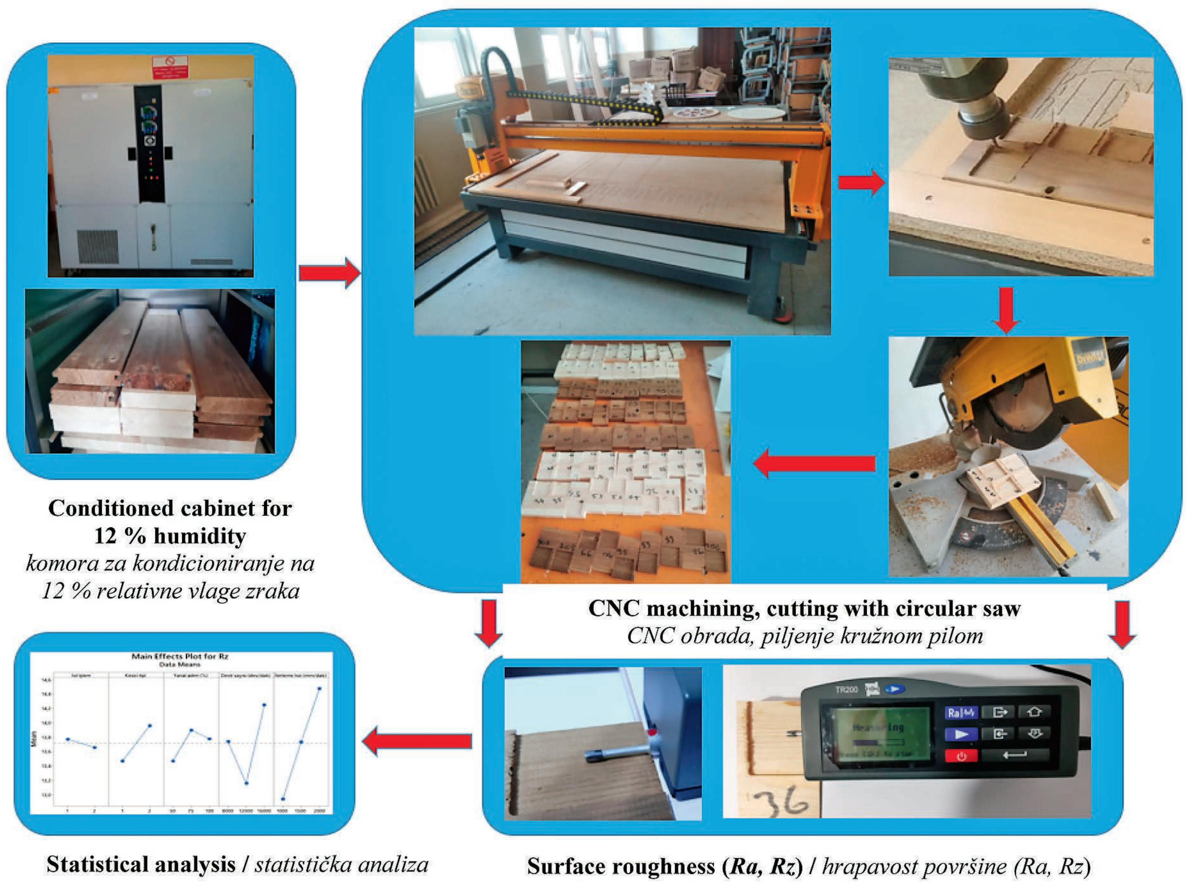

Figure 1 Experimental process flowchart
Slika 1. Dijagram tijeka eksperimenta

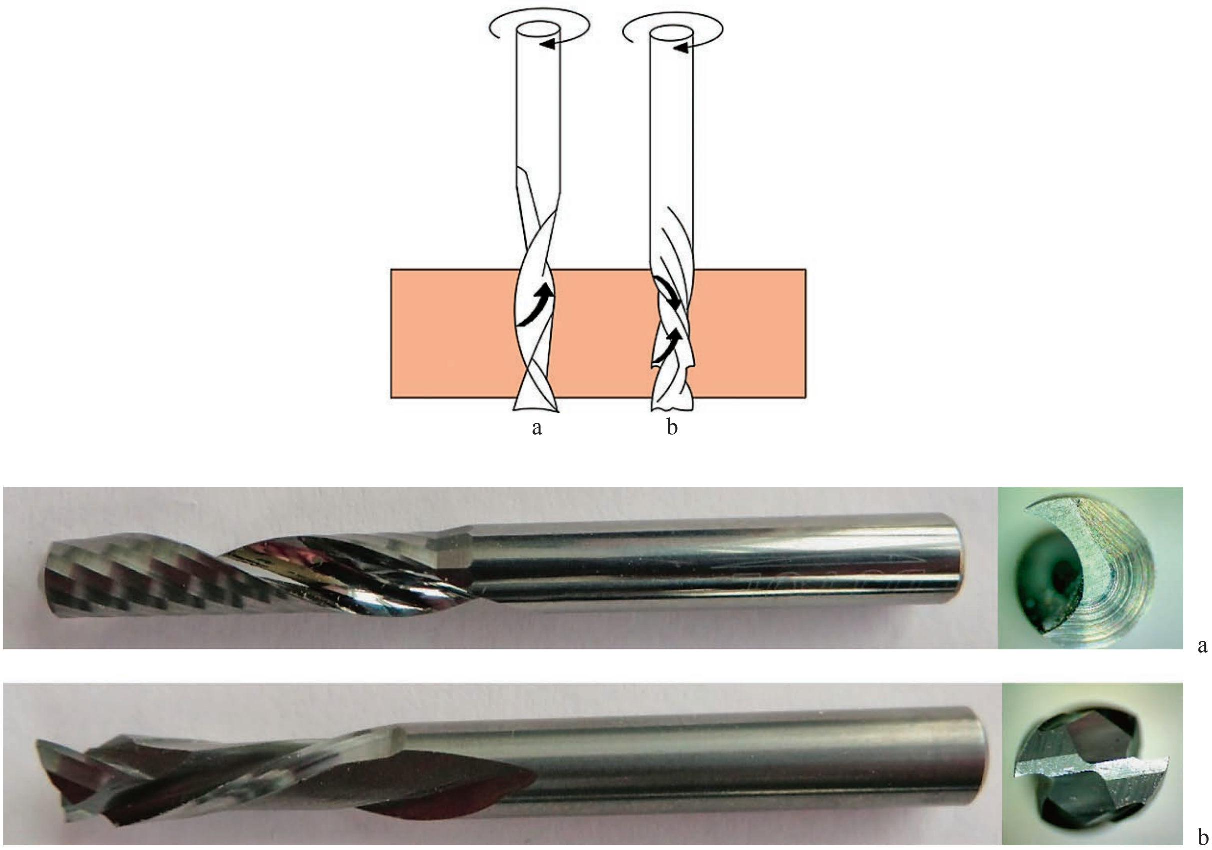

Figure 2 Cutter types: a) Carbide upcut milling cutter, discharges chips upwards b) Carbide compression (positive-negative) milling cutter, discharges chips from both the top and bottom
Slika 2. Vrste glodala: a) usadno glodalo s uzlaznom zavojnicom i oštricama od tvrdog metala; izbacuje strugotinu prema gore, b) usadno glodalo s uzlazno-silaznom zavojnicom i oštricama od tvrdog metala; izbacuje strugotinu i s gornje i s donje strane

periments were carried out with two router cutters (Toolstechnic, Tungsten carbide upcut milling cutter (helix angle: 19°) and Toolstechnic, tungsten carbide positive-negative (compression) milling cutter (helix angle:23°) with 5 mm in diameter) (Figure 3).

Stepover is a machining parameter that defines the distance between two neighboring passes over the workpiece. It is usually given as a percentage (ratio) of the tool diameter (Topal, 2009). The term stepover is illustrated in Figure 3. Various experiments were carried out in this study under stepover (50 %, 75 % and 100 of tool diameter).

A total of 108 pieces (54 treated + 54 untreated) of dimensions of 50 mm × 50 mm were grooved on wood materials by a CNC router (Figure 3). The surface roughness measurements were performed on a radial surface parallel to the grain at 3 separate lines on each specimen. The measuring parameters (average roughness (*Ra*) and ten point average roughness (*Rz*)) are described in ISO 468 (2009). The measurement of surface roughness was conducted according to the protocols in ISO 468 (2009), ISO 3274 (2005), and ISO 4287 (1997). The Surface Roughness Tester Time TR200 (Time Group Inc., China), surface roughness measurement equipment, was used for the determination of the surface roughness values via a contact stylus trace method. Gaussian filter type was used. The Robust Gaussian Regression Filter is useful for wood surfaces and can avoid the anatomical biasing effect (Gurau and Irkle, 2017). The sampling length was taken as

Table 1 Assignment of levels to factors (parameters used in face milling of Siberian pine)
Tablica 1. Dodjeljivanje razina *čim*benicima glodanja (parametri koji se koriste pri *čeonom* glodanju drva sibirskog bora)

Parameter / *Parametar*	**Coded levels** / *Oznake razine*		
	Level 1 / *Razina 1.*	Level 2 / *Razina 2.*	Level 3 / *Razina 3.*
Heat treatment / *toplinska modifikacija*	1 (untreated)	2 (heat- treatment)	
Cutter type / *vrsta glodala*	1 (upcut)	2 (compression, positive- negative)	
Stepover / *korak glodanja,* %	50	75	100
Spindle speed, rpm *frekvencija vrtnje vretena,* okr./min	8000	12000	16000
Feed, mm/min / *posmična brzina,* mm/min	1000	1500	2000

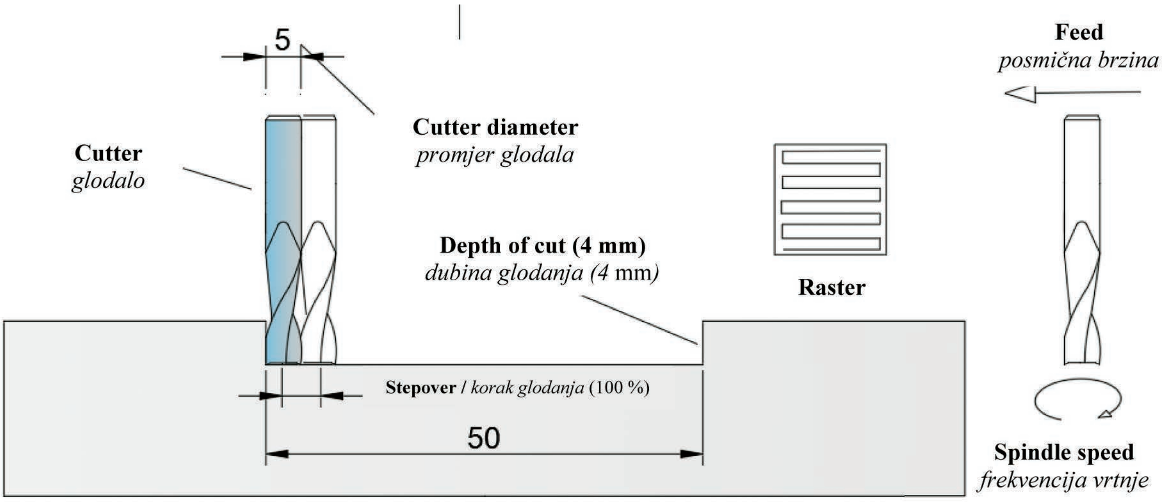

Figure 3 Parameters of CNC process
Slika 3. Parametri CNC obrade

0.8 mm. With increasing scanning length, the spatial resolution (along the scanned profile) was reduced, as well as the accuracy for determining the minute surface irregularities, such as wood anatomical components (Sandak *et al*., 2020). Surface roughness values were measured with an accuracy of ±0.01 µm. The stylus probe speed was chosen as 10 mm/ min, the diameter of the measurement needle was 5 µm, and the needle tip was 90°. Care was taken to provide adequate measurement conditions - temperature around 18-22 °C with no vibrations. The tool was calibrated prior to the measurement, and the calibration was checked at established intervals.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In the study, specimens were machined with CNC to determine the effect of heat treatment, cutter type, stepover, speed and feed on the roughness parameters (*Ra* and *Rz*). The roughness values measured on the machined surfaces are given in Table 2.

The lowest roughness value for *Ra* (*Ra* = 1.42 µm) was in the untreated specimens; it occurred in upcut milling cutter (cutter type 1), 100 % stepover, 16000 rpm and 1500 mm/min feed. The highest roughness value for *Ra* was in the untreated specimen (*Ra* =

Table 2 Surface roughness values obtained according to machining conditions
Tablica 2. Vrijednosti hrapavosti površine ovisno o uvjetima obrade

Number *Broj*	**Heat treatment** *Toplinska modifikacija*	**Cutter type** *Vrsta glodala*	**Stepover, %** *Korak glodanja, %*	**Spindle speed, rpm** *Brzina vretena, okr./min*	**Feed, mm/min** *Posmična brzina, mm/min*	***Ra*, µm**	***Rz*, µm**
1	1	1	50	8000	1000	2.36	11.20
2	1	1	50	8000	1500	2.75	13.63
3	1	1	50	8000	2000	1.99	9.95
4	1	1	50	12000	1000	2.54	13.19
5	1	1	50	12000	1500	2.81	14.09
6	1	1	50	12000	2000	1.54	9.70
7	1	1	50	16000	1000	2.84	14.48
8	1	1	50	16000	1500	2.31	11.42
9	1	1	50	16000	2000	2.74	12.81
10	1	1	75	8000	1000	1.99	10.87
11	1	1	75	8000	1500	2.19	11.73
12	1	1	75	8000	2000	2.63	13.24
13	1	1	75	12000	1000	2.14	11.04
14	1	1	75	12000	1500	2.37	12.19
15	1	1	75	12000	2000	3.00	14.98
16	1	1	75	16000	1000	3.15	15.45
17	1	1	75	16000	1500	2.10	10.03
18	1	1	75	16000	2000	3.81	20.67
19	1	1	100	8000	1000	3.48	17.21
20	1	1	100	8000	1500	2.53	12.63

Number *Broj*	**Heat treatment** *Toplinska modifikacija*	**Cutter type** *Vrsta glodala*	**Stepover, %** *Korak glodanja, %*	**Spindle speed, rpm** *Brzina vretena,* okr./min	**Feed, mm/min** *Posmična brzina,* mm/min	***Ra*, μm**	***Rz*, μm**
21	1	1	100	8000	2000	2.73	15.44
22	1	1	100	12000	1000	3.12	16.60
23	1	1	100	12000	1500	2.95	14.99
24	1	1	100	12000	2000	3.30	16.18
25	1	1	100	16000	1000	3.07	14.35
26	1	1	100	16000	1500	1.42	7.26
27	1	1	100	16000	2000	3.79	17.85
28	1	2	50	8000	1000	1.76	9.71
29	1	2	50	8000	1500	1.89	9.99
30	1	2	50	8000	2000	3.71	18.58
31	1	2	50	12000	1000	2.12	10.78
32	1	2	50	12000	1500	2.67	14.53
33	1	2	50	12000	2000	2.68	14.57
34	1	2	50	16000	1000	2.49	14.41
35	1	2	50	16000	1500	3.36	17.93
36	1	2	50	16000	2000	3.09	14.38
37	1	2	75	8000	1000	2.21	11.61
38	1	2	75	8000	1500	2.56	12.76
39	1	2	75	8000	2000	2.78	14.39
40	1	2	75	12000	1000	3.08	15.09
41	1	2	75	12000	1500	2.76	14.27
42	1	2	75	12000	2000	2.98	15.50
43	1	2	75	16000	1000	3.41	16.10
44	1	2	75	16000	1500	3.23	15.48
45	1	2	75	16000	2000	3.15	16.56
46	1	2	100	8000	1000	2.43	11.90
47	1	2	100	8000	1500	2.55	12.57
48	1	2	100	8000	2000	3.35	17.36
49	1	2	100	12000	1000	2.61	13.50
50	1	2	100	12000	1500	3.17	15.36
51	1	2	100	12000	2000	2.73	13.26
52	1	2	100	16000	1000	2.53	12.99
53	1	2	100	16000	1500	2.92	14.79
54	1	2	100	16000	2000	2.16	12.33
55	2	1	50	8000	1000	1.80	9.91
56	2	1	50	8000	1500	3.24	15.42
57	2	1	50	8000	2000	3.71	16.63
58	2	1	50	12000	1000	2.77	12.57
59	2	1	50	12000	1500	3.33	15.19
60	2	1	50	12000	2000	3.12	14.91
61	2	1	50	16000	1000	2.28	11.74
62	2	1	50	16000	1500	3.29	16.21
63	2	1	50	16000	2000	3.27	15.66
64	2	1	75	8000	1000	3.10	15.89
65	2	1	75	8000	1500	2.15	10.04
66	2	1	75	8000	2000	2.88	12.77
67	2	1	75	12000	1000	3.00	13.42
68	2	1	75	12000	1500	2.84	1374
69	2	1	75	12000	2000	1.89	9.58
70	2	1	75	16000	1000	2.39	13.08
71	2	1	75	16000	1500	2.87	14.84
72	2	1	75	16000	2000	2.81	14.86
73	2	1	100	8000	1000	2.49	13.81
74	2	1	100	8000	1500	2.75	14.33
75	2	1	100	8000	2000	2.47	11.98

Number *Broj*	**Heat treatment** *Toplinska modifikacija*	**Cutter type** *Vrsta glodala*	**Stepover, %** *Korak glodanja, %*	**Spindle speed, rpm** *Brzina vretena, okr./min*	**Feed, mm/min** *Posmična brzina, mm/min*	***Ra*, µm**	***Rz*, µm**
76	2	1	100	12000	1000	1.98	1023
77	2	1	100	12000	1500	2.12	10.20
78	2	1	100	12000	2000	2.02	8.95
79	2	1	100	16000	1000	2.69	13.61
80	2	1	100	16000	1500	3.53	16.33
81	2	1	100	16000	2000	3.42	18.34
82	2	2	50	8000	1000	2.27	13.44
83	2	2	50	8000	1500	2.99	15.34
84	2	2	50	8000	2000	3.33	17.19
85	2	2	50	12000	1000	2.17	10.85
86	2	2	50	12000	1500	3.08	14.77
87	2	2	50	12000	2000	2.65	12.57
88	2	2	50	16000	1000	2.49	12.19
89	2	2	50	16000	1500	2.66	13.40
90	2	2	50	16000	2000	2.41	11.67
91	2	2	75	8000	1000	3.02	14.73
92	2	2	75	8000	1500	2.69	14.51
93	2	2	75	8000	2000	3.02	16.99
94	2	2	75	12000	1000	2.48	12.91
95	2	2	75	12000	1500	2.93	14.64
96	2	2	75	12000	2000	2.71	13.22
97	2	2	75	16000	1000	2.34	12.48
98	2	2	75	16000	1500	3.48	15.20
99	2	2	75	16000	2000	3.10	15.58
100	2	2	100	8000	1000	2.50	12.26
101	2	2	100	8000	1500	3.45	19.15
102	2	2	100	8000	2000	3.49	15.48
103	2	2	100	12000	1000	1.98	9.33
104	2	2	100	12000	1500	2.29	12.07
105	2	2	100	12000	2000	3.07	14.81
106	2	2	100	16000	1000	2.73	12.88
107	2	2	100	16000	1500	2.82	13.49
108	2	2	100	16000	2000	2.63	12.29

3,81 µm) in upcut milling cutter, 75 % stepover, 16000 rpm spindle speed and 2000 mm/min feed. The lowest roughness value for *Rz* (*Rz* = 7.26 µm) occurred in the untreated samples, cutter type 1, 100 % stepover, 16000 rpm spindle speed and 1500 mm/min feed. Upcut milling cutters push the chips upwards and thus ensure an excellent finish on the bottom side of the wood and wood- based materials. The highest roughness value for *Rz* (*Rz* = 20.67 µm) occurred in the untreated samples, cutter type 1, 75 % stepover, 16000 rpm spindle speed and 2000 mm/min feed (Table 2).

The lowest and highest *Ra* and *Rz* values occurred at 16000 rpm. Statistical analyses were performed by using MINITAB software for a confidence level of 95 % (e.g., significance level of 0.05). The obtained data were subjected to normality test.

As seen in Figure 4, the average *Ra* and *Rz* values obtained in average roughness measurements show normal distribution at 95% confidence level, since the *P* value is higher than 0.05 (*P* = 0.923 for *Ra*; *P* = 0.680 for *Rz*).

3.1 Surface roughness for *Ra*
3.1. Hrapavost površine za parametar *Ra*

Table 3 presents the results of analysis of variance for *Ra*.

According to the results of variance analysis for *Ra* at 95 % confidence level, it was seen that heat treatment (0.05 < *P* = 0.564), cutter type (0.05 < *P* = 0.520), stepover (0.05 < *P* = 0.751) and spindle speed (0.05 < *P* = 0.168) did not make a statistically significant difference, while feed (0.05 > *P* = 0.015) made a statistically significant difference (Table 3).

Figure 5 shows the interaction of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Ra* in the main effect plot.

Higher *Ra* values occurred on the machined surfaces of heat-treated wood materials. Heat treatment

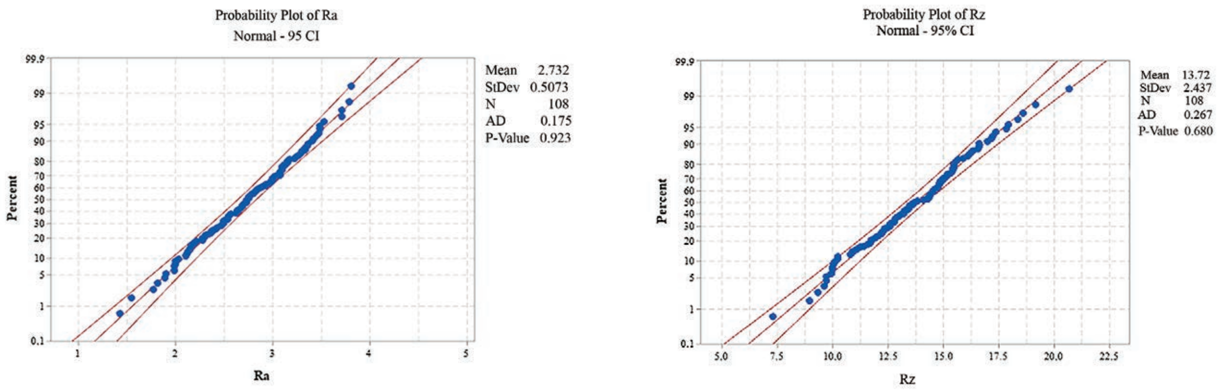

Figure 4 Normality graphs for *Ra* and *Rz*
Slika 4. Normalizirani grafovi za *Ra* i *Rz*

Table 3 Results of variance analysis (ANOVA) for *Ra*
Tablica 3. Rezultati analize varijance (ANOVA) za parametar *Ra*

Source / *Izvor*	***DF***	**Adj *SS***	**Adj *MS***	***F* Value**	***P* Value**
Heat treatment / *toplinska modifikacija*	1	0.0817	0.08173	0.33	0.564
Cutter type / *vrsta glodala*	1	0.1017	0.10171	0.42	0.520
Stepover / *korak glodanja,* %	2	0.1402	0.07009	0.29	0.751
Spindle speed, rpm / *brzina vretena,* okr./min	2	0.8872	0.44362	1.82	0.168
Feed, mm/min / *posmična brzina,* mm/min	2	2.1399	1.06995	4.38	0.015
Error / *pogreška*	99	24.1854	0.24430		
Total / *ukupno*	107	27.5361			

caused the development of surface roughness (Budakci *et al*., 2011; Pelit, 2014). Heating wood causes a decrease in the volume and mass of the wood via increased stringiness, water loss from the structure of the wood because of the loss of hydroxyl groups, material losses in the cell wall, and the breakup of hemicelluloses (Budakci *et al*., 2011, Korkut and Kocaefe 2009).

With the increase in the compression ratio (from 0 % to 40 %), roughness values decreased.

Smoother surfaces (lower *Ra* values) were obtained with cutter 1. *Ra* values increased when the stepover was increased from 50 % to 75 %, and there was not much change in *Ra* values when it was increased from 75 % to 100 %. The lowest *Ra* values were observed at 50 % stepover rate. *Ra* values decrease when the spindle speed is increased from 8000 rpm to 12000 rpm. When the spindle speed was increased from 12000 rpm to 16000 rpm, a remarkable increase in *Ra*

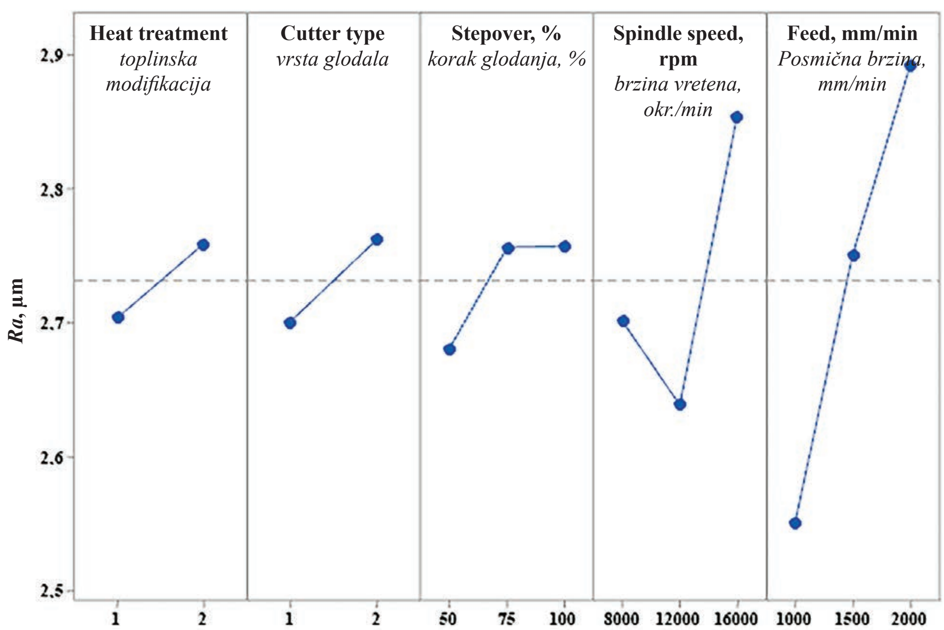

Figure 5 Main effects plot of *Ra* in terms of heat treatment, cutter type, stepover, spindle speed and feed
Slika 5. Prikaz glavnih utjecaja na parametar *Ra* u smislu toplinske obrade, vrste glodala, koraka glodanja, brzine vretena i posmične brzine

values occurred. The *Ra* values increased linearly as the feed increased from 1000 mm/min to 2000 mm/min. When evaluated in general, the lowest mean *Ra* value according to main effect plot occurred in the untreated specimens, cutter type 1, 50 % stepover, 12000 rpm spindle speed and 1000 mm/min feed.

According to the literature, smoother surfaces are obtained at low feeds in wood and wood-based material experiments. Generally, as the feed increases, the roughness values increase (Bal, 2018; Ilter *et al.*, 2002; Davim vd., 2009; Sutcu and Karagoz, 2012; Karagoz, 2010; Isleyen and Karamanoglu, 2019; Hazir *et al.*, 2018; Pinkowski *et al.*, 2018; Aykac and Sofuoglu, 2021; Bal and Akcakaya, 2018; Pelit *et al.*, 2021, Sofuoglu *et al.*, 2022). The results obtained in terms of feed are similar to those found in the literature.

The increased spindle speed in the rotating cutters decreases the roughness values resulting in smoother surfaces (Aghakhani *et al.*, 2014; Aykac and Sofuoglu, 2021; Davim *et al.*, 2009; Hazir *et al.*, 2018; Isleyen ve Karamanoglu, 2019; Karagoz, 2010; Kaya *et al.*, 2017; Koc *et al.*, 2017; Patel and Patni, 2014; Rawangwong *et al.*, 2011; Sofuoglu, 2015; Sutcu and Karagoz, 2012; Sutcu and Karagoz, 2013). The larger the number of cutter marks per unit distance on the solid wood surface, the better the surfaces can be. (Malkocoglu and Ozdemir, 2006; Sofuoglu and Kurtoglu, 2014; Sofuoglu, 2008). Vibration may occur in the machine, although it varies depending on the CNC and wood type, if the spindle speed exceeds a specific value, and this may cause an increase in roughness. In addition, burning may occur on the wood surface of the material. It is assumed that the increase in *Ra* values when the speed is increased from 12000 rpm to 16000 rpm is due to vibration.

Figure 6 presents graphically the interactions of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Ra*.

When the interaction graph is examined regarding heat treatment and cutter type, cutter 1 gives a lower *Ra* value than cutter 2 in the unheated specimens. In the heat-treated specimens, *Ra* values close to each other were obtained in both cutters. A smoother surface on the ground is obtained by evacuating the chips upwards of the Upcut milling cutter. The effect of the cutters was minimized with the changes in the chemical composition of wood, leading to mass loss of texture in the heat-treated wood material.

The *Ra* value increases linearly as the stepover increases in untreated specimens. The *Ra* value decreases inversely proportional to the increase in the stepover in heat-treated specimens.

In the machining of untreated specimens, the *Ra* value increases proportionally as the speed is increased from 8000 rpm to 16000 rpm. In the machining of heat-treated specimens, the *Ra* value decreases when the speed is increased from 8000 rpm to 12000 rpm, and the *Ra* value increases when the speed is increased from 12000 rpm to 16000 rpm.

3.1 Surface roughness for *Rz*
3.1. Hrapavost površine za parametar *Rz*

Table 4 presents the results of analysis of variance for *Rz*.

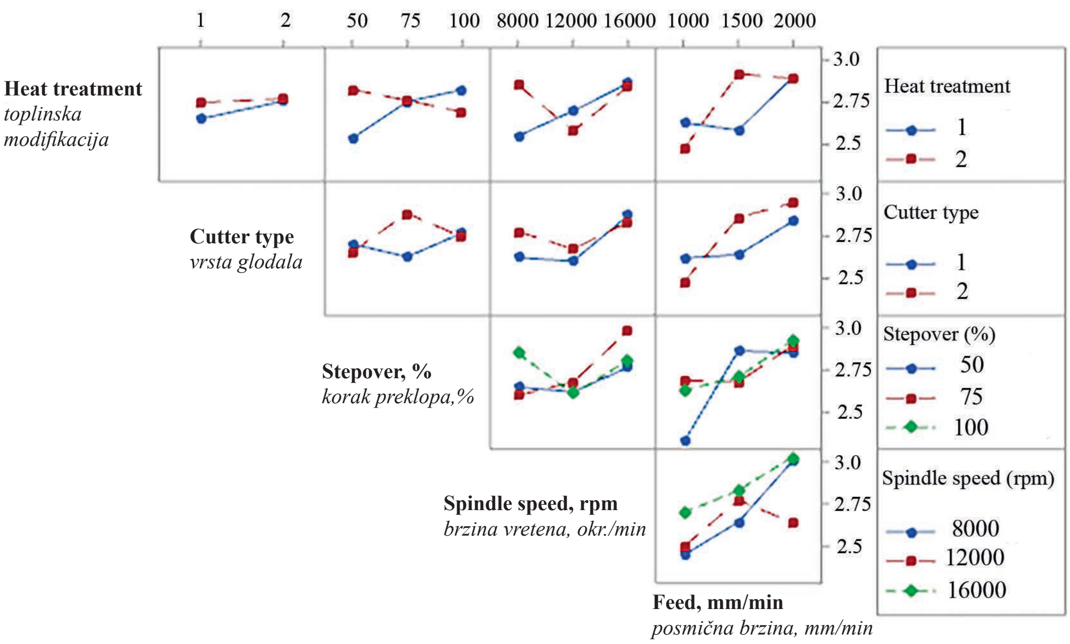

Figure 6 Interactions of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Ra*
Slika 6. Interakcije toplinske modifikacije, vrste glodala, koraka glodanja, brzine vretena i posmične brzine s parametrom *Ra*

Table 4 Results of variance analysis (ANOVA) for *Rz*
Tablica 4. Rezultati analize varijance (ANOVA) za parametar *Rz*

Source / *Izvor*	***DF***	**Adj *SS***	**Adj *MS***	***F* Value**	***P* Value**
Heat treatment / *toplinska modifikacija*	1	0.361	0.3608	0.06	0.801
Cutter type / *vrsta glodala*	1	6.606	6.6064	1.17	0.283
Stepover / *korak preklopa,* %	2	3.524	1.7622	0.31	0.733
Spindle speed, rpm / *brzina vretena,* okr./min	2	21.557	10.7784	1.90	0.155
Feed, mm/min / *posmična brzina,* mm/min	2	42.703	21.3516	3.77	0.026
Error / *pogreška*	99	560.680	5.6634		
Total / *ukupno*	107	635.432			

According to the results of variance analysis for *Rz* at 95 % confidence level, it was seen that heat treatment ($0.05 < P = 0.801$), cutter type ($0.05 < P = 0.283$), stepover ($0.05 < P = 0.733$) and spindle speed ($0.05 < P = 0.155$) did not make a statistically significant difference, while feed ($0.05 > P = 0.026$) made a statistically significant difference (Table 4).

Figure 7 shows the interaction of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Rz* in the main effect plot.

Lower *Rz* values were obtained in the heat-treated samples and the machining with cutter 1. *Rz* values increased when the stepover was increased from 50 % to 75 % and decreased when it was increased from 75 % to 100 %. In terms of *Rz* values, a decrease occurred when the number of revolutions was increased from 8000 rpm to 12000 rpm, and an increase occurred when it was increased from 12000 rpm to 16000 rpm. *Rz* values increase proportionally as the feed is increased from 1000 mm/min to 2000 mm/min. According to the main effect graph, the lowest *Rz* value on average occurred in the heat-treated samples, cutter type 1, 50 % stepover, 12000 rpm spindle speed, and 1000 mm/min feed when evaluated in general.

Figure 8 presents graphically the interactions of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Rz*.

The heat treated and untreated samples gave similar surface roughness values in both cutter types. However, cutter 1 gave lower *Rz* values in both types of samples. While the lowest *Rz* value was obtained at a 50 % stepover rate in unheated samples, it was obtained at a 100 % stepover rate in the heat-treated samples. When the stepover increased from 50 % to 100 %, the *Rz* value of the untreated samples increased, and of the heat-treated samples decreased. The *Rz* value increases linearly when the number of revolutions is increased from 8000 rpm to 16000 rpm in untreated samples. In heat-treated samples, the *Rz* value decreases when the speed increases from 8000 rpm to 12000 rpm

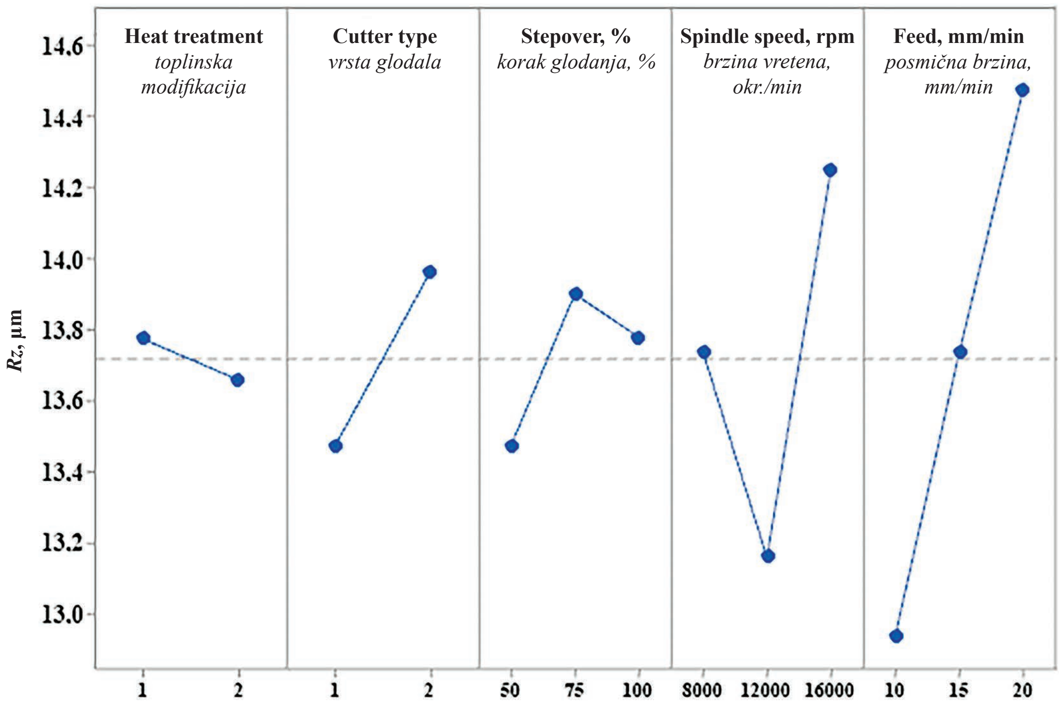

Figure 7 Main effects plot of *Rz* in terms of heat treatment, cutter type, stepover, spindle speed and feed
Slika 7. Prikaz glavnih utjecaja na parametar *Rz* u smislu toplinske obrade, vrste glodala, koraka glodanja, brzine vretena i posmične brzine

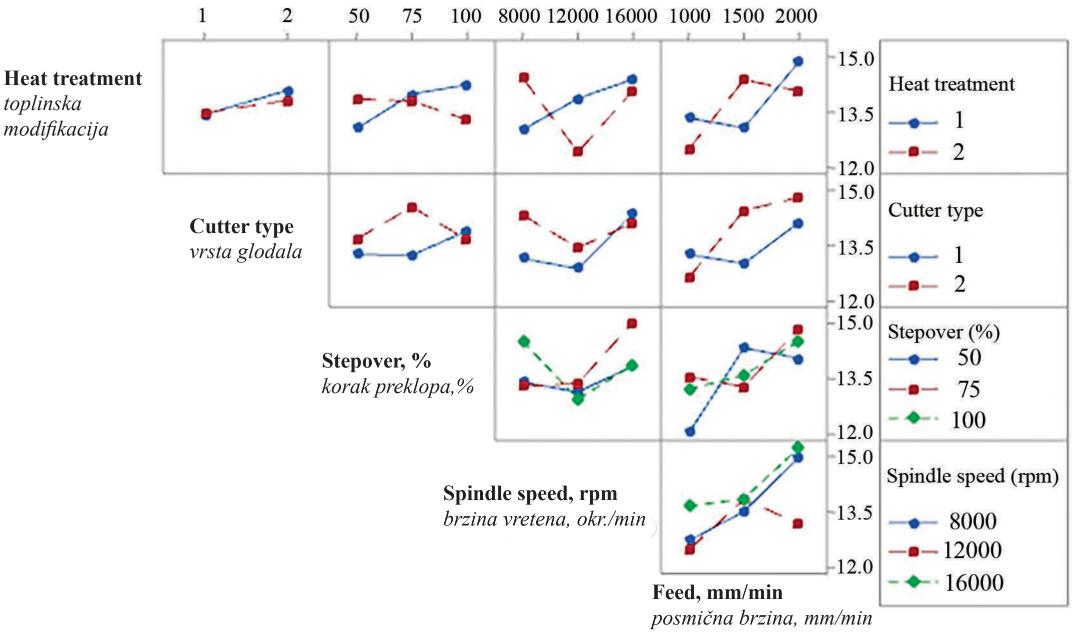

Figure 8 Interactions of heat treatment, cutter type, stepover, spindle speed and feed in terms of *Rz*
Slika 8. Interakcije toplinske modifikacije, vrste glodala, koraka glodanja, brzine vretena i posmične brzine s parametrom *Rz*

and increases when the speed is increased from 12000 rpm to 16000 rpm. In general, the surface roughness increases as the feed increases in heat-treated and untreated samples. Low feed speeds (1000 mm/min) and low percentages of stepover (50 %) are recommended for a smoother surface.

4 CONCLUSIONS
4. ZAKLJUČAK

The summary of the general evaluation of roughness values obtained is given below.

In untreated wood materials, it is recommended to use low feed, upcut milling cutters due to the remachining of the same surface at low depth: low lateral step rate, low-speed parameters.

Lower Ra and Rz values were obtained on the surfaces processed with an upcut milling cutter. Upcut milling cutters push the chips upwards and thus ensure an excellent finish on the bottom side of the wood and wood-based material.

For low surface roughness values, a low stepover rate is preferred for untreated materials, and a high stepover rate is preferred for heat-treated materials.

It has been observed that the feed is the most critical parameter affecting the surface roughness.

As the feed increases, the surface roughness values increase.

Surface roughness increases as the number of revolutions increases in untreated samples.

In heat-treated samples, as the number of revolutions increases in the 8000-12000 rpm range, the surface roughness decreases, and its positive effect disappears (probably caused by vibration in the CNC due to high speed) after 12000 revolutions.

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5 REFERENCES
5. LITERATURA

1. Aykac, E.; Sofuoglu, S. D., 2021: Investigation of the effect of machining parameters on surface quality in Bamboo. Tehnički vjesnik, 28 (2): 684-688. https://doi.org/10.17559/TV-20200102202928
2. Adela Salca, E. A.; Hiziroglu, S., 2014: Evaluation of hardness and surface quality of different wood species as function of heat treatment. Materials and Design, 62: 416-423. https://doi.org/10.1016/j.matdes.2014.05.029
3. Aghakhani, M.; Khazaeian, A.; Madhoushi, M., 2013: Different CNC machining condition of paulownia wood by CNC; Influence on the Abbott roughness parameters. Iranian Journal of Wood and Paper Science Research, 8 (2): 291-312.
4. Akman, M., 2018: A mechanische properties of heat treated Anatolian black pine and investigation of soil properties in growing area. Master's Thesis, Kutahya Dumlupinar University, Graduate School of Natural and Applied Sciences, Kutahya (in Turkey).
5. Altun, S.; Esmer, M., 2017: The effect of heat treatment on the surface roughness and varnish adhesion of wood. Journal of Polytechnic, 20 (1): 231-239.
6. Atar, M.; Yalinkilic, A. C.; Keskin, H., 2019: Impact of heat treatment on the exchange of color in varnished wood materials. Journal of Polytechnic, 22 (2): 407-413. https://doi.org/10.2339/politeknik.404008

7. Ayadi, N.; Lejeune, F.; Charrier, F; Charrier, B.; Merlin, A., 2003: Color stability of heat-treated wood during artificial weathering. Holz als Roh- und Werkstoff, 61: 221-226. https://doi.org/10.1007/s00107-003-0389-2
8. Ayata, U., 2020: Determination of some technological properties in Ayous wood and its color and glossiness properties after heat-treatment. Furniture and Wooden Material Research Journal, 3 (1): 22-33. https://doi.org/10.33725/mamad.724596
9. Ayata, U.; Cakicier, N., 2018: Impact of accelerated UV aging on the surface adhesion strength of water-based varnish applied and heat-treated (ThermoWood) some wood species. Journal of Polytechnic, 21 (3): 611-619. https://doi.org/10.2339/politeknik.389600
10. Ayata, U.; Gurleyen, T.; Gurleyen, L.; Cakicier, N., 2018: Determination of surface roughness parameters of heat-treated and untreated scotch pine, oak and beech woods. Furniture and Wooden Material Research Journal, 1 (1): 46-50. https://doi.org/10.33725/mamad.433945
11. Ayrilmis, N.; Kariz, M.; Kwon, J. H.; Kitek Kuzman, M., 2019: Surface roughness and wettability of surface densified heat-treated norway spruce (*Picea abies* L. Karst.). Drvna industrija, 70 (4): 377-382. https://doi.org/10.5552/drvind.2019.1852
12. Bal, B. C., 2018: The effects of some tool paths adjustments of CNC machines on surface roughness and processing time of fiberboards. Furniture and Wooden Material Research Journal, 1 (1): 21-30. https://doi.org/10.33725/mamad.427588
13. Bal, B. C.; Akcakaya, E., 2018: The effects of step over, feed rate and finish depth on the surface roughness of fiberboard processed with CNC machine. Furniture and Wooden Material Research Journal, 1 (2): 86-93. https://doi.org/10.33725/mamad.481278
14. Bal, B. C.; Kilavuz, M., 2021: Investigation of the effect of heat treatment in vacuum atmosphere on the mechanical properties of poplar wood. Kahramanmaras Sutcu Imam University Journal of Engineering Sciences, 24 (3): 146-153. https://doi.org/10.17780/ksujes.886540
15. Baysal, E.; Kart, S.; Altay, C.; Toker, H.; Turkoglu, T.; Cibo, C., 2018: Determination of color stability of heated and varnished wood after weathering. Mesleki Bilimler Dergisi (MBD), 7 (2): 142-152.
16. Budakci, M.; Ilce, A. C.; Korkut, D. S.; Gurleyen, T., 2011: Evaluating the surface roughness of heat-treated wood cut with different circular saws. BioResources, 6 (4), 4247-4258.
17. Budakci, M.; Ilce, A. C.; Gurleyen, T.; Utar, M., 2013: Determination of the surface ughness of heat-treated wood materials planed by the cutters of a horizontal milling machine. BioResource, 8 (3): 3189-3199. https://doi.org/10.15376/biores.8.3.3189-3199
18. Çakicier, N., 2018: Determination of surface roughness against the effect of accelerated UV aging on water based varnish applied and heat treated wood materials according to Thermowood method. GUSTIJ, 8 (1): 122-134. https://doi.org/10.17714/gumusfenbil.314186
19. Davim, J. P.; Clemente, V. C.; Silva, S., 2009: Surface roughness aspects in milling MDF (medium density fibreboard). International Journal of Advanced Manufacturing Technology, 40 (1-2): 49-55. https://doi.org/10.1007/s00170-007-1318-z
20. Dobrzynski, M.; Orlowski, K. A.; Biskup, M., 2019: Comparison of surface quality and tool-life of glulam window elements after planing. Drvna industrija, 70 (1), 7-18. https://doi.org/10.5552/drvind.2019.1741
21. Doruk, S.; Altınok, M.; Percin, O., 2014: The effects of heat treatment on some physical and mechanical properties of wood material. Suleyman Demirel University Journal of Natural and Applied Sciences, 14 (3): 262-270.
22. Duzkale Sozbir, G.; Bektas, I., 2019: Investigation of biological durability of heat treated and densified poplar wood against brown rot fungi. Turkish Journal of Forestry, 20: 421-426. https://doi.org/10.18182/tjf.636671
23. Efe, F. T.; Bal, B. C., 2016: Yüksek sıcaklıkta ısıl işlem görmüş kızılçam (*Pinus brutia* Ten.) odununun sertlik değerlerinde meydana gelen değişmeler (in Turkish). In: Proceedings of 1st International Conference on Engineering Technology and Applied Sciences Afyon Kocatepe University, Turkey 21-22 April 2016, pp. 79-86.
24. Ergin, U., 2021: Effect of heat treatment on surface quality in wood machining. Master's Thesis, Kutahya Dumlupinar University, Institute of Graduate Education, Turkey.
25. Esen, R.; Ozcan, C., 2012: The effects of heat treatment on shear strength of oak (*Quercus petraea* L.) wood. Turkish Journal of Forestry, 13 (2): 150-154.
26. Esteves, B.; Marques, A. V.; Domingos, I.; Pereira, H., 2007: Influence of steam heating on the properties of pine (*Pinus pinaster*) and eucalypt (*Eucalyptus globulus*) wood. Wood Science and Technology, 41 (3): 193-207. https://doi.org/10.1007/s00226-006-0099-0
27. Esteves, B.; Pereira, H., 2009: Wood modification by heat treatment: A review. BioResources, 4 (1): 370-404.
28. Gong, M.; Lamason, C.; Li, L., 2010: Interactive effect of surface densification and post-heat-treatment on aspen wood. Journal of Materials Processing Technology, 210 (2): 293-296. https://doi.org/10.1016/j.jmatprotec.2009.09.013
29. Gurau, L.; Irle, M., 2017: Surface roughness evaluation methods for wood products: A review. Current Forestry Reports, 3: 119-131. https://doi.org/10.1007/s40725-017-0053-4
30. Gurleyen, T.; Guler, C.; Unsal, O., 2017: Effect of heat treatment (Thermowood) on janka hardness resistance applied to some wood types. Journal of Advanced Technology Sciences, 6 (3): 876-888.
31. Gurleyen, T.; Ayata, U.; Gurleyen, L.; Esteves, B., 2018: Determination of glossiness and color values on ash, beech, red-bud maple, and red pine wood species heat-treated (Thermowood method). El-Cezeri, 5 (2): 566-575. https://doi.org/10.31202/ecjse.372941
32. Gunduz, G.; Korkut, S.; Korkut, D. S., 2008: The effects of heat treatment on physical and technological properties and surface roughness of Camiyanı black pine (*Pinus nigra* Arn. subsp. pallasiana var. pallasiana) wood. Bioresource Technology, 99: 2275-2280. https://doi.org/10.1016/j.biortech.2007.05.015.
33. Hacibektasoglu, M.; Campean, M.; Ispas, M.; Gurau, L., 2017: Influence of heat treatment duration on the machinability of beech wood (*Fagus sylvatica* L.) by planning. BioResource, 12 (2): 2780-2791. https://doi:10.15376/biores.12.2.2780-2791
34. Hakkou, M.; Pétrissans, M.; El Bakali, I.; Gerardin, P.; Zoulalian, A., 2005a: Wettability changes and mass loss during heat treatment of wood. Holzforschung, 59: 35-37. https://doi.org/10.1515/HF.2005.006
35. Hakkou, M.; Pétrissans, M.; Zoulalian, A.; Gérardin, P., 2005b: Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polymer Degradation and Stability, 89 (1): 1-5. https://doi.org/10.1016/j.polymdegradstab.2004.10.017

36. Hazir, E.; Erdinler, E. S.; Koc, K. H., 2018: Optimization of CNC cutting parameters using design of experiment (DOE) and desirability function. Journal of Forestry Research, 29 (5): 1423-1434. https://doi.org/10.1007/s11676-017-0555-8
37. Icel, B.; Simsek, Y. 2017: Evaluations on microscopic images of heat treated spruce and ash wood. Süleyman Demirel University Journal of Natural and Applied Sciences, 21 (2), 414-420. https://doi.org/10.19113/sdufbed.17217
38. Icel, B.; Beram, A., 2017: Effects of industrial heat treatment on some physical and mechanical properties of iroko wood. Drvna industrija, 68 (3): 229-239. https://doi.org/10.5552/drind.2017.1720
39. Ispas, M.; Gurau, L.; Campean, M.; Hacibektasoglu, M.; Racasan, S., 2016: Milling of heat-treated beech wood (*Fagus sylvatica* L.) and analysis of surface quality. BioResource, 11 (4): 9095-9111. https://doi: 10.15376/biores.11.4.9095-9111
40. ***ISO 468, 1982: Surface roughness – Parameters, their values and general rules for specifying requirements, International Organization for Standardization, Geneva, Switzerland.
41. ***ISO 13061-1, 2014: Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 1: Determination of moisture content for physical and mechanical tests, International Organization for Standardization, Geneva, Switzerland.
42. ***ISO 13061-2, 2014: Physical and mechanical properties of wood – Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests, International Organization for Standardization, Geneva, Switzerland.
43. ***ISO 3274, 2005: Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments, International Organization for Standardization, Geneva, Switzerland.
44. ***ISO 4287, 1997: Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters, International Organization for Standardization, Geneva, Switzerland.
45. Ilter, E.; Camliyurt, C.; Balkiz, O. D., 2002: Researches on the determination of the surface roughness values of Bornmullerian fir (*Abies bornmülleriana* Mattf.). Central Anatolia Forestry Research Institute, No. 181.
46. Isleyen, U. K.; Karamanoglu, M., 2019: The Influence of Machining Parameters on Surface Roughness of MDF in Milling Operation. BioResources, 14 (2): 3266-3277. https://doi.org/10.15376/biores.14.2.3266-3277
47. Karamanoglu, M.; Kaymakci, A., 2018: Effect of hygrothermal aging on color and hardness properties of heat treated chestnut wood. Furniture and Wooden Material Research Journal, 1 (1), 31-37. https://doi.org/10.33725/mamad.429726
48. Kaya, M.; Imirzi, H. O.; Sogutlu, C., 2017: Effect of cutter types, spindle speed and feed rate on the surface quality in CNC milling. In: Proceedings of the XXVIIIth International Conference: Research for Furniture Industry, 21-22 September 2017, Poznan, Poland.
49. Kilincarslan, S.; Simsek, Y., 2020: The effect of heat treatment application on wettability properties of wood materials. Journal of Engineering Sciences and Design, 8 (2), 460-466. https://doi.org/10.21923/jesd.570067
50. Karagoz, U., 2010: Investigation of machining parameters on the surface quality in CNC routing wood and wood-based materials. Master's Thesis, Suleyman Demirel University, Graduate School of Natural and Applied Sciences, Isparta, Turkey.
51. Koc, K. H.; Erdinler, E. S.; Hazir, E.; Ozturk, E., 2017: Effect of CNC application parameters on wooden surface quality. Measurement, 107: 12-18. https://doi.org/10.1016/j.measurement.2017.05.001
52. Korkut, D. S.; Guller, B., 2008: The effects of heat treatment on physical properties and surface roughness of red-bud maple (Acer trautvetteri Medw.) wood. Bioresource Technology, 99 (8): 2846-2851. https://doi.org/10.1016/j.biortech.2007.06.043
53. Korkut, S., Akgul, M.; Dundar, T., 2008: The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood. Bioresource Technology, 99 (6): 1861-1868. https://doi.org/10.1016/j.biortech.2007.03.038
54. Korkut, S., Kocaefe, D., 2009: Effect of heat treatment on wood properties. Duzce University Journal of Forestry, 5 (2), 11-34.
55. Korkut, S.; Alma, M. H.; Elyildirim, Y. K., 2009: The effects of heat treatment on physical and technological properties and surface roughness of European Hophornbeam (*Ostrya carpinifolia* Scop.) wood. African Journal of Biotechnology, 8 (20).
56. Kvietková, M.; Gašparík, M.; Gaff, M., 2015: Effect of thermal treatment on surface quality of beech wood after plane milling. BioResources, 10 (3), 4226-4238.
57. Lunguleasa, A.; Ayrilmis, N.; Spirchez, C.; Ozdemir, F., 2018: Investigation of the effects of heat treatment applied to beech plywood. Drvna industrija, 69 (4): 349-355. https://doi.org/10.5552/drind.2018.1768
58. Malkocoglu, A.; Ozdemir, T., 2006: The machining properties of some hardwoods and softwoods naturally grown in Eastern Black Sea Region of Turkey. Journal of Materials Processing Technology, 173 (3): 315-320. https://doi.org/10.1016/j.jmatprotec.2005.09.031
59. Mburu, F.; Dumarcay, S.; Bocquet, J. F.; Petrissans, M.; Gérardin, P., 2008: Effect of chemical modifications caused by heat treatment on mechanical properties of Grevillea robusta wood. Polymer Degradation and Stability, 93 (2): 401-405. https://doi.org/10.1016/j.polymdegradstab.2007.11.017
60. Patel, D. H.; Patni, V. N., 2014: An investigation effect of machining parameters on CNC router. International Journal of Engineering Development and Research, 2: 1583-1587.
61. Pelit, H., 2014: The effects of densification and heat treatment to finishing process with some technological properties of eastern beech and scots pine. PhD Thesis, Gazi University, Ankara, Turkey.
62. Pelit, H., 2017: The effect of different wood varnishes on surface color properties of heat treated wood materials. Journal of the Faculty of Forestry Istanbul University, 67 (2): 262-274. https://doi.org/10.17099/jffiu.300010
63. Pelit, H.; Korkmaz, M.; Budakci, M., 2021: Surface roughness of thermally treated wood cut with different parameters in CNC router machine. BioResources, 16 (3): 5133-5147. https://doi.org/10.15376/biores.16.3.5133-5147
64. Percin, O.; Ayan, S., 2012: Determination of screw withdrawal strength in heat treated wood material. Journal of Advanced Technology Sciences, 1 (1): 57-68.
65. Percin, O.; Uzun, O., 2014: Determination of bonding strength in heat treated some wood materials. Turkish Journal of Forestry, 15 (1): 72-76.
66. Percin, O.; Altunok, M., 2019: The effects of heat treatment, wood species and adhesive types on screw with-

drawal strength of laminated veneer lumbers. Kastamonu University Journal of Forestry Faculty, 19 (2): 152-163. https://doi.org/10.17475/kastorman.625819
67. Percin, O., Sadiye Yasar, S.; Altunok, M.; Uzun, O., 2017: Determination of screw withdrawal resistance of some heat-treated wood species. Drvna industrija, 68 (1): 61-68. https://doi.org/10.5552/drind.2017.1630
68. Pétrissans, M.; Gérardin, P.; Bakali, I. El.; Serraj, M., 2003: Wettability of Heat-Treated Wood. Holzforschung 57 (3): 301-307. https://doi.org/10.1515/HF.2003.045
69. Pinkowski, G.; Szymański, W.; Krauss, A.; Stefanowski, S., 2018: Effect of sharpness angle and feeding speed on the surface roughness during milling of various wood species. BioResources, 13 (3): 6952-6962. https://doi.org/10.15376/biores.13.3.6952-6962
70. Rawangwong, S.; Chatthong, J.; Rodjananugoon, J.; Boonchouytan, W., 2011: A study of proper conditions in face milling palmyra palm wood by computer numerical controlled milling machine. Silpakorn University Science and Technology Journal, 5 (2): 33-39. https://doi.org/10.14456/sustj.2011.7
71. Sahin, H. I.; Guler, C., 2018: Effect of heat treatment on the dimensional stability of ash (*Fraxinus angustifolia* Vahl.) wood/Disbudak (*Fraxinus angustifolia* Vahl.) odununun boyutsal stabilizasyonu uzerine isil islemin etkisi. Forestist, 68 (1): 42-52. https://doi.org/10.5152/forestist.2018.00
72. Sahin Kol, H.; Aysal Keskin, S.; Gunduz Vaydogan, K., 2017: Some surface characteristic of artifically weathered heat-treated wood. Journal of Advanced Technology Sciences, 6 (3): 831-838.
73. Sandak, J.; Orlowski, K. A.; Sandak, A.; Chuchala, D.; Taube, P., 2020: On-line measurement of wood surface smoothness. Drvna industrija, 71 (2): 193-200. https://doi.org/10.5552/drvind.2020.1970
74. Senol, S., 2018: Determination of physical, mechanical and technological properties of some wood materials treated with thermo-vibro-mechanical (TVM) process. PhD Thesis, Duzce University, Graduate School of Natural and Applied Sciences, Duzce, Turkey.
75. Senol, S.; Budakci, M., 2016: Mechanical wood modification methods. Mugla Journal of Science and Technology, 2 (2): 53-59. https://doi.org/10.22531/muglajsci.283619
76. Sofuoglu, S. D.; Kurtoglu, A., 2014: Some machining properties of 4 wood species grown in Turkey. Turkish Journal of Agriculture and Forestry, 38 (3): 420-427. https://doi.org/10.3906/tar-1304-124
77. Sofuoglu, S. D., 2008: Effects of wood machining properties of some native species on surface quality. PhD Thesis, Istanbul University, Institute of Graduate Studies In Sciences, Istanbul, Turkey.
78. Sofuoglu, S. D.; Tosun, M.; Atılgan, A., 2022: Determination of the machining characteristics of Uludağ fir (Abies nordmanniana Mattf.) densified by compressing, Wood Material Science & Engineering. https://doi.org/10.1080/17480272.2022.2080586
79. Sutcu, A.; Karagoz, U., 2012: Effect of machining parameters on surface quality after face milling of MDF. Wood Research, 57 (2): 231-240.
80. Topal, E. S., 2009: The role of stepover ratio in prediction of surface roughness in flat and milling, International Journal of Mechanical Sciences, 51 (11-12): 782-789. https://doi.org/10.1016/j.ijmecsci.2009.09.003.
81. Ulay, G.; Korkut, S.; Cakicier, N., 2014: Evaluation of the studies on the effect of heat treatment on wooden material in Turkey. Duzce University Journal of Forestry, 10 (1): 37-47.
82. Yasar, S., 2009: A study on color change in Brutian pine (*Pinus brutia* Ten.)) extractives exposed to heat treatment. Turkish Journal of Forestry, 10 (1): 95-100.
83. Yildiz, S., 2002: Physical, mechanical, technological and chemical properties of beech and spruce wood treated by heating. Ph. D. Thesis, Karadeniz Technical University, Trabzon, Turkey.
84. Yildiz, S.; Gezer, E. D.; Yildiz, U. C., 2006: Mechanical and chemical behavior of spruce wood modified by heat. Building and environment, 41 (12): 1762-1766. https://doi.org/10.1016/j.buildenv.2005.07.017
85. Zaman, A.; Alén, R.; Kotilainen, R. 2000: Thermal behavior of scots pine (*Pinus Sylvestris*) and silver birch (*Betula Pendula*) at 200-230. Wood and Fiber Science, 32 (2): 138-143.

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