Kastamonu Uni., Orman Fakültesi Dergisi, 2022, 22(3): 264-272 Research Article
Kastamonu Univ., Journal of Forestry Faculty
Doi:10.17475/kastorman.1215347

Effects of Cutter Parameters on Surface Roughness of Fiberboard and Energy Consumption of CNC Machine

Bekir Cihad BAL[1*], Fatih MENGELOĞLU[2], Elif AKÇAKAYA[3], Zeynep GÜNDEŞ[3]

[1]Kahramanmaraş Sütçü İmam University, Vocational School of Technical Sciences, Kahramanmaraş, TÜRKİYE
[2]Kahramanmaraş Sütçü İmam University, Faculty of Forestry, Kahramanmaraş, TÜRKİYE
[3]Kahramanmaraş Sütçü İmam University, Graduate School of Natural and Applied Sciences, Kahramanmaraş, TÜRKİYE
*Corresponding Author: bcbal@hotmail.com

Received Date: 11.04.2022 Accepted Date: 05.08.2022

Abstract

Aim of study: The aim of this study was to determine the effects of cutter parameters on the energy consumption of CNC machine, and surface roughness of medium density fiberboard (MDF).

Material and methods: Experiments were conducted using a three-axis CNC router. The energy consumption and surface roughness values were measured using a wattmeter (TT-Technic PM 001) and roughness tester (Mitutoyo SJ 210), respectively. The values of the *Ra, Rq,* and *Rz* roughness parameters, and energy consumption were determined.

Main results: The surface roughness increased with increases in the step over and feed rate, whereas the energy consumption decreased. In addition, the energy consumption increased when a high spindle speed was used. When the spindle speed is increased from 8000 rpm to 16000 rpm, the energy consumption increases by 154%. When the stepover is increased from 20% to 60%, energy consumption is reduced by 63%. When the feed rate is increased from 3 m/min to 7 m/min, the energy consumption is reduced by 60%.

Highlights: The energy consumption increased as the step over and feed rate decreased. The energy consumption increased as the spindle speed increased. The surface roughness increased with the step over and feed rate

Keywords: CNC Machine, MDF, Roughness, Production, Energy Consumption

Takım Yolu Ayarlarının Lif Levhanın Yüzey Pürüzlülüğü ve CNC Makinesinin Enerji Tüketimi Üzerine Etkileri

Öz

Çalışmanın amacı: Bu çalışmanın amacı, takım yolu ayarlamalarının CNC makinesinin enerji tüketimi ve orta yoğunlukta lif levhanın (MDF) yüzey pürüzlülüğü üzerindeki etkilerini belirlemektir.

Materyal ve yöntem: Deneyler, üç eksenli bir CNC makinesi kullanılarak gerçekleştirilmiştir. Enerji tüketimi ve yüzey pürüzlülük değerleri sırasıyla bir wattmetre (TT-Technic PM 001) ve pürüzlülük test cihazı (Mitutoyo SJ 210) kullanılarak ölçülmüştür. *Ra, Rq* ve *Rz* pürüzlülük parametreleri ve enerji tüketim değerleri belirlenmiştir.

Temel Bulgular: Elde edilen verilere göre, bıçak adımı ve ilerleme hızının artmasıyla yüzey pürüzlülüğü artarken, enerji tüketimi azalmıştır. Ayrıca, yüksek bıçak motoru hızı kullanıldığında enerji tüketimi artmıştır. Bıçak motoru hızı 8000 rpm'den 16000 rpm'e çıkarıldığında, enerji tüketimi %154 artmıştır. Bıçak adımı %20'den %60'a çıkarıldığında, enerji tüketimi %63 azalmıştır. Besleme hızı 3 m/dk'dan 7 m/dk'ya çıkarıldığında, enerji tüketimi %60 azalmıştır.

Araştırma Vurguları: Bıçak adımı ve ilerleme hızı azaldıkça enerji tüketimi artmıştır. Bıçak motoru hızı arttıkça enerji tüketimi artmıştır. Yüzey pürüzlülüğü, bıçak adımı ve ilerleme hızı ile artmıştır.

Anahtar Kelimeler: CNC Makinesi, MDF, Pürüzlülük, Üretim, Enerji Tüketimi

Citation (Atıf): Bal, B. C., Mengeloglu, F., Akcakaya, E., & Gundes, Z. (2022). Effects of Cutter Parameters on Surface Roughness of Fiberboard and Energy Consumption of CNC Machine. *Kastamonu University Journal of Forestry Faculty*, 22 (3), 264-272.

Introduction

Furniture manufacturing is a continuously changing sector, and is trying to adapt to the fashion of the day. From the past to the present, some important alterations have occurred in the raw materials and semi-finished products used in the furniture industry. In the past, plenty of solid wood materials were used in the manufacture of furniture. Over the years, particle board and medium density fiberboard (MDF) began to be used extensively. Today, melamine faced particle board and melamine faced fiberboard are being used extensively. In addition, single surface faced fiber board is used. These boards are used to make cabinet doors and other decorative items. Different patterns are drawn by CNC machines on the uncoated surfaces of single surface faced fiberboards. The processed surface is later coated with a PVC film, and these boards are used for furniture parts. CNC machines are utilized in modern factories when the surfaces of these boards are processed.

On the CNC machines, many different machining parameters have to be adjusted before the boards are processed. The surface roughness of the MDF boards varies based on these adjustments. Many researchers have studied the effects of these adjustments on the surface roughness of solid wood and fiberboard. Benardos and Vosniakos (2003), and Karagöz (2011) revealed general criteria on this issue. In these studies, it was shown that the parameters affecting the roughness were those related to the cutting, cutting tool, and machining. Ohuchi (2001) investigated the effects of the machining accuracy on the surface roughness of MDF, particleboard, and plywood. In a study using a different method, Lin et al. (2006) investigated the machinability of MDF using a digital camera, and it was determined that the board density had a major influence on the machinability characteristics of the boards. Sütçü and Karagöz (2012), Koç et al. (2017) and Bal and Akçakaya (2018) investigated the machining parameters related to the surface roughness of MDF routed by a CNC machine. Bal (2018) studied the influence of some machining parameters on the surface roughness and processing time of CNC machine. Recently, Bal and Gündeş (2020), investigated the effects of the moisture content and density of MDF formed using CNC machine on the surface roughness. In addition, Bal and Dumanoğlu (2019) studied the effects of the spindle speed and feed rate on the processing time and energy consumption of a CNC machine, and the surface roughness of a cabinet door using vectorial forming method.

Previous studies have shown that the surface roughness of medium density fiberboard was decreased by the use of a higher spindle motor speed, lower step over, and lower fade rate adjustment. However, the effect of cutter parameters on the energy consumption was not intensively studied. On the other hand, there were not enough data to take into account the effects of the cutter parameters on the energy consumption of a CNC machine while processing MDF boards.

The main purpose of present study was to investigate the effects of the machining parameters of a CNC machine on its energy consumption and the surface roughness of MDF boards. For this purpose, test samples were processed using different spindle speed and feed rate, and it was tried to determine how the energy consumption and surface roughness changed.

Material and Method

Test Samples

The MDF panels used in this study were single-side melamine-coated MDF boards for commercial use. They were obtained by purchasing. The dimensions of the MDF panels were 1.8 cm × 210 cm × 280 cm (thickness × width × length). The density of the MDF panels was 762 kg/m^3, and the moisture content was 8.2%. Test samples were cut from the panels with the dimensions of 1.8 cm × 10 cm × 10 cm (thickness × width × length).

CNC Machine

A CNC machine was used to complete the processing of the samples. The CNC machine has a four servo-motor, and was specially manufactured by the US Mekatronik company for laboratory use (Fig. 1-A). The CNC machine had 2.2 kW of spindle power. The dust generated by the CNC machine was removed from the

environment using a vacuum cleaner. The CNC machine was controlled using a Mach 3 program. The G-code files to control the CNC machine were created using the ArtCAM software program. The machining parameters showed in Table 1.

Table 1. Tool path adjustment of CNC machine

Machining parameters	Level 1	Level 2	Level 2
Spindle speed	8000 rpm	12000 rpm	16000 rpm
Step over	20%	40%	60%
Feed rate	3 m/min	5 m/min	7 m/min
Depth of cut	6 mm	-	-
Processing strategy	raster	-	-

The Cutters

Two flute end mills produced from high-speed steel (HSS) were used in the processing for the test specimens. The cutter is shown in Fig 1-B. One cutter was used for each feed rate group. A total of nine cutters were used.

Figure 1. CNC machine (A), cutter (B), and wattmeter (C)

Energy Consumption

The energy consumption was measured using a wattmeter (TT-Technic PM 001) installed between the CNC machine and electrical outlet as can be seen in Figure 1-C and Figure 2.

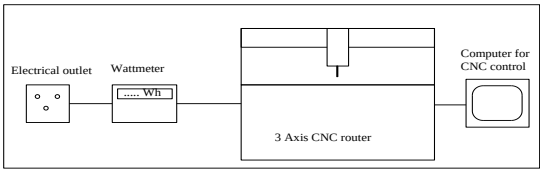

Figure 2. Schematic view of CNC router and wattmeter (Bal and Dumanoğlu 2019)

The Measurement of the Surface Roughness

A 5 cm × 6 cm rectangular area in the middle of test samples was processed using the CNC machine. Surface roughness was measured in this section five times as can be seen in Fig 3. The surface roughness was measured using a surface tester (Mitutoyo SJ-210). The surface roughness settings and features were as follows: cut-off λc: 2.5 mm, stylus angle: 60°, drive unit speed: 0.75 mm/s, x-axis measurement range: 12.5 mm, and z-axis: 360 μm. *Ra, Rq* and *Rz* roughness parameters were determined according to TS 971 (TS 1988).

Figure 3. The measurement of the surface roughness with roughness tester

Results and Discussions

Surface Roughness

Test results related to the surface roughness parameters and energy consumption are given in Table 2. The lowest Ra, Rq, and Rz values were measured at a 20% step over, 3 m/min feed rate, and 16000 rpm spindle speed. The highest Ra and Rq values were measured at a 60% step over, 5 m/min feed rate, and 16000 rpm spindle speed. Conversely, the lowest energy consumption was measured at a spindle speed of 8000 rpm, step over values of 40 and 60%, and feed rates of 5 and 7 m/min. It can be seen that the surface roughness increases and the energy consumption decreases as the step over increases. The differences among the groups were statistically significant (P<0.001) (Table 3 and Table 4). In previous studies, many researchers determined similar results related to the relationship between the step over and surface roughness. For example, Sütçü and Karagöz (2012) determined that the surface roughness (Ra) of MDF test samples measured at a 50% step over was greater than that with a 15% step over. In addition, Sütçü and Karagöz (2013) determined that the surface roughness of wooden panels processed with a CNC machine increased with the step over.

Table 2. Surface roughness (Ra, Rq, Rz) and energy consumption test results

Step over (%)	Feed rate (m/min)	Spindle speed (rpm)											
		8.000				12.000				16.000			
		Ra	Rq	Rz	EC	Ra	Rq	Rz	EC	Ra	Rq	Rz	EC
			µm		Wh		µm		Wh		µm		Wh
20	3	11.5*	14.4	76.8	4.9	11.4	14.3	76.4	6.0	**11.1**	**13.9**	**71.8**	7.0
		0.9**	1.2	5.4	0.3	1.0	1.3	7.4	0.0	0.7	1.0	5.9	0.0
	5	12.2	15.3	81.0	3.4	12.5	15.8	82.9	4.0	11.8	14.9	78.4	5.0
		0.6	0.8	4.4	0.5	0.5	0.5	3.1	0.0	0.8	0.9	4.6	0.0
	7	12.5	15.6	81.5	3.0	12.9	16.3	86.0	3.0	12.1	15.2	81.6	4.0
		0.7	0.8	4.4	0.2	1.1	1.4	5.9	0.0	0.5	0.5	3.5	0.0
40	3	12.9	16.4	87.7	3.0	13.6	17.3	92.0	4.0	13.5	17.2	90.0	5.0
		1.0	1.4	7.2	0.2	0.6	0.9	7.2	0.0	1.0	1.3	10.0	0.0
	5	12.8	16.3	88.4	1.9	13.6	17.3	91.4	3.0	13.5	17.2	93.6	4.0
		0.6	0.9	5.3	0.3	0.9	1.2	6.1	0.0	0.8	1.0	5.5	0.0
	7	13.5	17.1	90.6	1.9	13.4	16.9	87.5	2.9	13.6	17.2	90.7	3.0
		0.8	1.0	6.6	0.3	0.8	1.0	4.8	0.3	0.9	1.2	4.2	0.0
60	3	13.8	17.5	90.8	2.9	14.1	17.8	93.4	4.0	14.1	18.0	96.9	4.0
		1.1	1.4	5.5	0.3	0.7	0.9	3.6	0.0	0.8	0.9	2.8	0.0
	5	13.1	16.7	89.5	1.9	14.2	18.0	95.3	3.0	**14.3**	**18.1**	95.6	3.0
		0.7	0.9	4.8	0.3	0.8	1.1	4.8	0.0	0.9	1.2	6.9	0.0
	7	13.8	17.3	90.1	1.9	13.9	17.5	90.8	2.0	13.9	20.6	92.9	3.0
		0.6	0.9	5.2	0.3	0.9	1.2	6.9	0.0	0.7	9.6	4.4	0.0

*Mean values, **Standard deviations, Wh: watt-hours, EC: energy consumption

Table 3 lists the F and Sig. values of three-way ANOVA test results. It can be seen that the effects of the spindle speed on Ra and Rz were significant, with P<0.01 and P<0.05, respectively. The effects of the step over on Ra, Rq, and Rz were significant, with P<0.001, P<0.001, and P<0.001, respectively. The effect of the feed rate on Ra and Rz were significant (P < 0.01), and that on Rq and Rz was also significant (P<0.05).

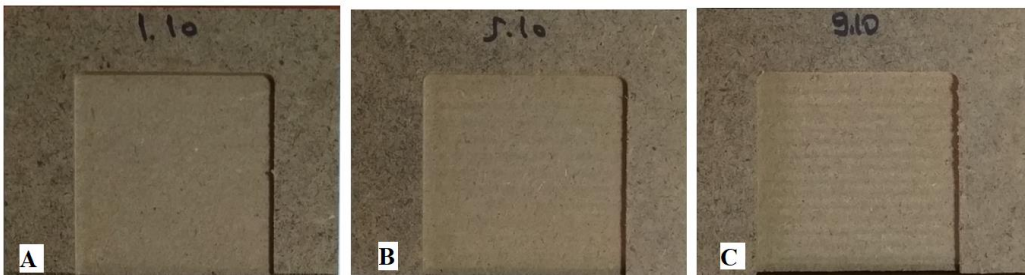

Figure 4. Test samples of step over groups (A:20%, B:40% and C:60%)

In addition, according to the F value, it can be said that the effects of these factors were step over > feed rate > spindle speed. The most important cutter parameter affecting surface roughness was the step over with a ratio of 46.5%, followed by the feed rate with a ratio of 1.9%, and the spindle speed with a ratio of 1.8%, according to the ANOVA results given. It is evident that the surface roughness of the MDF was strongly influenced by the step over. Related to this issue, some test samples were given in Fig 4. The differences among surfaces can be seen visually in Fig 4-A, 4-B, and 4-C. In Fig 4-C, the trace of the cutter is more pronounced than that of Fig 4-B. In Fig 4-A, the trace of the cutter cannot be visible to the naked eye.

Energy Consumption

The effects of the spindle speed, step over, and feed rate on the energy consumption were significant (P<0.001). The effect of the feed rate on the energy consumption was greater than those of the step over and spindle speed. This situation can be explained as follows: the longer the processing time, the higher the energy consumption. According to the ANOVA results given in Table 3, the most important cutter parameter affecting energy consumption was the feed rate with a ratio of 35.9%, followed by the step over with a ratio of 30.8%, and the spindle speed with a ratio of 23.1%.

Table 3. ANOVA results related to Ra, Rq, Rz, and energy consumption (F and Sig. values)

Source	Ra				Rq				Rz				Energy consumption			
	SS	F	Sig.	PCR	SS	F	Sig.	PCR	SS	F	Sig.	PCR	SS	F	Sig.	PCR
Spindle Speed (SS)	7	5.3	0.006	1.8	20	2.2	0.112	1.2	225	3.6	0.030	1.2	98	1189	0.000	23.1
Step Over (SO)	175	135	0.000	46.5	384	42.6	0.000	23.5	8801	138.6	0.000	46.7	131	1586	0.000	30.8
Feed Rate (FR)	7	5.5	0.005	1.9	28	3.2	0.045	1.7	253	4.0	0.020	1.3	153	1832.9	0.000	35.9
SS*SO	7	2.7	0.032	1.9	43	2.4	0.051	2.6	551	4.3	0.002	2.9	6	35.7	0.000	1.3
SS*FR	3	1.3	0.291	0.9	13	0.7	0.594	0.8	72	0.6	0.686	0.4	5	29.7	0.000	1.2
SO*FR	16	6.0	0.000	4.2	22	1.2	0.300	1.4	923	7.3	0.000	4.9	17	106.1	0.000	4.0
SS*SO*FR	4	0.7	0.665	1.0	29	0.8	0.589	1.8	294	1.2	0.326	1.6	7	19.0	0.000	1.6
Error	158			41.9	1092			67.0	7715			41.0	9			2.1
Total	377			100	1631			100	18836			100	427			100

SS: Sum of square, **PCR**: percentage contribution ratio

Table 4 lists the effects of the step over on the surface roughness and energy consumption. According to the data in Table 4, Ra, Rq, and Rz increase with the step over; conversely, the energy consumption decreases. All of the groups are different from each other.

Table 4. Tukey HSD test results for step over (SO)

Ra			Rq			Rz			Energy consumption		
SO	N	Subset	SO	N	Subset	SO	N	Subset	SO	N	Subset
%	Number	µm	%	Number	µm	%	Number	µm	%	Number	Wh
20	90	12.0 A	20	90	15.1 A	20	90	79.6 A	60	93	2.84 A
40	90	13.4 B	40	90	16.9 B	40	90	90.1 B	40	87	3.20 B
60	90	13.9 C	60	90	17.9 C	60	90	92.8 C	20	90	4.47 C

The test results for the energy consumption are given in Table 2. As can be seen in this table, there is an inverse correlation between the SR and energy consumption. The energy consumption decreased as the step over and feed rate increased, as can be seen in Tables 4 and 5. Conversely, the energy consumption increased with the spindle speed (Table 6). The differences among groups are statistically significant according to the three-way ANOVA test results given in Table 3, and a Tukey HSD multiple comparison test showed that all of the groups were different from each other (Tables 4, 5, and 6). In a similar study, Aguilera *et al*. (2000) investigated the relationships between the SR, cutting power, and chip thickness, and the results showed that the SR and cutting power increased with the chip thickness.

The *Ra, Rq* and *Rz* values differ among the step over groups as the feed rate increases as can be seen in Table 2. The increasing or decreasing relationship between the feed rate and surface roughness cannot be easily seen in all of the step over groups. However, according to the Tukey HSD test results, the surface roughness increases with the feed rate, as can be seen in Table 5. In previous studies, some researchers determined that the surface roughness increased with the feed rate (Davim et al., 2009; Sütçü & Karagöz, 2012; Sedlecký, 2018). Deus et al., (2015) determined that the surface roughness differences among feed rate groups were significant at different spindle speeds. However, there was no increasing or decreasing relationship between the feed rate and surface roughness. Table 5 shows that effects of the feed rate on the surface roughness parameters (*Ra, Rq,* and *Rz*) and energy consumption. The feed rate groups of Ra, Rq, and Rz were different according to Tukey HSD multiple comparison test. However, the results were very close to each other. Increasing the feed rate causes an increase in surface roughness not only in MDF material, but also in metal materials. This has been found in previous studies (Bayraktar and Kara, 2020; Özbek et al., 2021; Akgün and Kara, 2021).

Table 5: Tukey HSD test results for feed rate (FR)

Ra			Rq			Rz			Energy consumption		
FR	N	Subset	FR	N	Subset	FR	N	Subset	FR	N	Subset
m/ min	Number	µm	m/ min	Number	µm	m/ min	Number	µm	m/ min	Number	Wh
3	90	12.9 A	3	90	16.3 A	3	90	86.2 A	7	90	2.73 A
5	90	13.1 AB	5	90	16.6 AB	7	90	87.9 AB	5	90	3.24 B
7	90	13.3 B	7	90	17.1 B	5	90	88.4 B	3	90	4.52 C

Another important result was related to the effect of the spindle speed on the surface roughness, as listed in Table 2. In previous studies, generally, the surface roughness decreased as the spindle speed increased (Davim et al., 2009; Sütçü & Karagöz, 2012; Deus et al., 2015; Sofuoğlu, 2017; Sedlecký, 2018). However, according to data obtained from this study, there was no similar relationship between the spindle speed and surface roughness. Similar results were obtained by Supadarattanawong and Rodkwan (2006), and Aras and Sofuoğlu (2021). In the present study, the obtained data related to the effects of the step over and feed rate on the surface roughness were expected. However, the obtained data related to the effect of the spindle speed on the surface roughness were unexpected. There is no increasing or decreasing relationship between the spindle speed and surface roughness as can be seen in Table 2. It is thought that this may have several causes. First, the cutter used in the experiments was made of high-speed steel (HSS). One cutter was used for each feed rate group. A total of nine cutters were used. This was a very important issue influencing the surface roughness. Second, vibration on the spindle motor that occurred at a high spindle speed may have caused the roughness to change. Third, the surface of the MDF test samples became warmer and had a darker color after the machine processed the MDF surface

using a greater spindle speed and lower feed rate. This warming caused changes in the surface properties. Benardos and Vosniakos (2003) noted that the surface roughness is affected by many factors such as the machining parameters (step over, feed rate, depth of cut, tool angle, and cutting speed cooling fluid), work piece properties (work piece hardness and length), cutting phoneme (friction, vibration, and chip formation), and cutting tool properties (tool material, tool shape, and nose radius). In addition, Ohuchi (2001) reported that during idling at a spindle speed of 20000 rpm, the vibration was great because of the resonance of the spindle head of the CNC router. As a result, many factors affected the SR. The previous studies contained limited investigations of MDF processing using a CNC machine. In addition, it is well known that when materials are processed with machines using a greater cutting speed and lower feed rate, the surface of the material quickly becomes warmer. Heating of a cutting tool of CNC machine causes thermal deformations of the machined surfaces (Bobyr, 2020). In previous studies, some studies were conducted related to thermal deformations of the metals processed using CNC machine (Bobyr, 2020).

Table 6 lists the Tukey HSD test results on the effects of the spindle speed on the surface roughness and energy consumption. The energy consumption values at different spindle speeds were statistically different. The relationship between the energy consumption and spindle speed was linear. However, the relationship between the roughness and spindle speed was not linear. The results were close to each other.

Table 6: Tukey HSD test results for spindle speed (SS)

Ra			Rq			Rz			Energy consumption		
SS	N	Subset	SS	N	Subset	SS	N	Subset	SS	N	Subset
rpm	Number	µm	rpm	Number	µm	rpm	Number	µm	rpm	Number	µm
8000	90	12.9 A	8000	90	16.3 A	8000	90	86.26 A	8000	90	2.74 A
12000	90	13.1 AB	12000	90	16.8 A	12000	90	87.9 AB	12000	90	3.54 B
16000	90	13.3 B	16000	90	16.9 A	16000	90	88.4 B	16000	90	4.22 C

Conclusions

In this study, the effects of some cutter parameters on the SR and energy consumption were investigated. According to the obtained data, the following conclusions could be reached:

- The SR increased with the step over and feed rate. The differences between groups were significant.
- Complex results related to the relationship between the surface roughness and spindle speed were obtained. The lowest surface roughness was obtained at a spindle speed of 8000 rpm, unlike previous studies. The reason for this was thought to be the metal properties of the cutter, vibration of the spindle, and warming of the MDF surfaces
- The energy consumption increased as the step over and feed rate decreased, and as the spindle speed increased.
- The CNC router used in this study was not designed for industrial use. However, the results obtained were comparable to those obtained with an industrial CNC machine.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed

Author Contributions

Conceptualization: B.C.B; Investigation: B.C.B., E.A., Z.G.; Material and Methodology: B.C.B., F.M., E.A.; Supervision: B.C.B.; Writing-Original Draft: B.C.B., F.M.; Writing-review & Editing: B.C.B., F.M.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

Funding

The data presented in this study was financially supported by TÜBİTAK, Project Number: 215 O 899. We thank TÜBİTAK for this support.

References

Aguilera, A., Meausoone, P.J. & Martin, P. (2000). Wood material influence in routing operations: the MDF case. *Eur. J. Wood Prod*, 58(4),278-283. https://doi.org/10.1007/s001070050425

Akgün, M. & Kara, F. (2021). Analysis and optimization of cutting tool coating effects on surface roughness and cutting forces on turning of AA 6061 alloy. *Advances in Materials Science and Engineering*, https://doi.org/10.1155/2021/6498261

Aras, O. & Sofuoğlu, S.D. (2021). Anadolu kestanesi (Castenia sativa Mill.) ağaç türünün CNC ile işlenmesinde yüzey pürüzlülüğünün işleme parametreleri ile ilişkisi. *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi*, 4(2), 114-125. https://doi.org/10.33725/mamad.992157

Bal, B.C. (2018). CNC makinelerinin bazı ayarlarının parça işleme süresi ve lif levhanın yüzey pürüzlülüğü üzerine etkileri. *Mobilya ve Ahşap Malzeme Araştırmaları Dergisi,*1(1), 21-30. https://doi.org/10.33725/mamad.427588

Bal, B.C. & Akçakaya, 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

Bal, B.C. & Gündeş, Z. (2020). Surface roughness of medium-density fiberboard processed with CNC machine. *Measurement, 153,*107421. https://doi.org/10.1016/j.measurement.2019.107421.

Bal, B.C. & Dumanoğlu, F. (2019), Surface roughness and processing time of a medium density fiberboard cabinet door processed via CNC Router, and the Energy Consumption of the CNC Router, *BioResources,* 14(4), 9500-9508. https://doi.org/10.15376/biores.14.4.9500-9508

Bayraktar, F. & Kara, F. (2020). Investigation of the effect on surface roughness of cryogenic process applied to cutting tool. *International Journal of Analytical, Experimental and Finite Element Analysis,* 7(2), 19-27.

Benardos, P.G. & Vosniakos, G.C. (2003). Predicting surface roughness in machining: a review. *International journal of machine tools and manufacture*, 43(8), 833-844. https://doi.org/10.1016/S0890-6955(03)00059-2

Bobyr, M.V., Yakushev, A. S. & Dorodnykh, A. A. (2020). Fuzzy devices for cooling the cutting tool of the CNC machine implemented on FPGA. *Measurement*, 152, 107378. https://doi.org/10.1016/j.measurement.2019.107378

Davim, J.P., Clemente, V.C., & Silva, S. (2009). Surface roughness aspects in milling MDF (medium density fibreboard). *Int J Adv Manuf Technol*, 40(1-2),49-55. https://doi.org/10.1007/s00170-007-1318-z

De Deus, P.R., de Sampaio Alves, M.C. & Vieira, F.H.A. (2015). The quality of MDF workpieces machined in CNC milling machine in cutting speeds, feed rate, and depth of cut. *Meccanica*, 50(12), 2899-2906. https://doi.org/10.1007/s11012-015-0187-z.

Karagöz, Ü. (2011). CNC ile işlemede ahşap malzemenin yüzey kalitesini etkileyen faktörler, *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, 11(1), 18-26.

Koc, K.H., Erdinler, E.S., Hazir, E. & Öztürk, E. (2017). Effect of CNC application parameters on wooden surface quality. *Measurement*, 07, 12-18.

Lin, R.J., van Houts, J. & Bhattacharyya, D. (2006). Machinability investigation of medium-density fibreboard. *Holzforschung*, 60(1), 71-77. https://doi.org/10.1515/HF.2006.013

Ohuchi, T. (2001). Milling of wood and wood-based materials with a computerized numerically controlled router I: on the machining accuracy for grooving. *Mokuzai Gakkaishi*, 47(2001), 212-217.

Özbek, N.A., Özbek, O. & Kara, F. (2021). Statistical analysis of the effect of the cutting tool coating type on sustainable machining parameters. *Journal of Materials Engineering and Performance*, 30(10), 7783-7795.

Sedlecký, M., Kvietková, M.S. & Kminiak, R. (2018). Medium-density fiberboard (MDF) and Edge-Glued Panels (EGP) after edge milling-surface roughness after machining with different parameters, *BioResources*, 13(1), 2005-2021. DOI:10.15376/biores. 13.1.2005-2021.

Sofuoglu, S.D. (2017). Determination of optimal machining parameters of massive wooden edge glued panels which is made of Scots pine (Pinus sylvestris L.) using Taguchi design

method. *European Journal of Wood and Wood Products, 75*(1), 33-42.

Supadarattanawong, S. & Rodkwan, S. (2006). An investigation of the optimal cutting conditions in Parawood (*Heavea Brasiliensis*) machining process on a CNC wood router. *Kasetsart Journal (Natural Science)*, 40(5), 311-319.

Sütçü, A. & Karagöz, Ü. (2012). Effect of machining parameters on surface quality after face milling of MDF. *Wood Research*, 57(2), 231-240.

Sütçü, A. & Karagöz, Ü. (2013). The influence of process parameters on the surface roughness in aesthetic machining of wooden edge-glued panels (EGPs). *BioResources*, *8*(4), 5435-5448.

TS 971, (1988). Surface roughness-parameters, their values and general rules for specifying requirements, Ankara, Turkey.