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Taguchi ve RSM yöntemleri Kullanılarak MDF'nin Yüzey Pürüzlülüğünü Etkileyen İşleme Parametrelerinin Belirlenmesi

Ümmü KARAGÖZ İŞLEYEN*,

* Kastamonu University, Faculty of Forestry, Department of Forest Industrial Engineering, 37100, Kastamonu

Öz

Bu çalışmada, Taguchi ve yanıt yüzey metodu (RSM) kullanılarak, devir hızı, besleme oranı ve kesme derinliği gibi parametreler ile CNC freze makinasında işlenmiş MDF yüzeyleri üzerine işleme parametrelerinin etkisi incelenmiştir. Deney tasarımı için Taguchi L16 ortogonal dizisi kullanılmıştır. Yüzey pürüzlülüğünü etkileyen önemli parametreler Sinyal-gürültü oranı (S/N), 3D yüzey grafikleri, ortalamaların ana etki grafikleri ve ANOVA analizleri kullanılarak değerlendirilmiştir. İşleme parametrelerinin yüzey pürüzlülüğü üzerine etkilerinin matematiksel tahmin modelleri yanıt yüzey metodolojisi (RSM) kullanılarak geliştirilmiştir. Faktörlerin etkileşimlerinin yüzey pürüzlülüğü üzerinde bir etkisi olmamasına rağmen, faktörlerin (kesme derinliği, ilerleme oranı ve devir hızı) pürüzlülük üzerindeki ana etkilerinin istatistiksel olarak anlamlı olduğu görülmüştür. Yüzey pürüzlülük değerinin ilerleme oranı ve kesme derinliğinin artması ve devir hızının azalması ile arttığı belirlenmiştir. En iyi yüzey pürüzlülük değeri 2500 mm/dak. besleme oranı, 24000 rpm devir hızı ve 4 mm kesme derinliğinde elde edilmiştir.

Anahtar Kelimeler: MDF, yüzey pürüzlülüğü, yüzey işleme, Taguchi, yanıt yüzey metodu

Determination of Machining Parameters Affecting Surface Roughness of MDF Using the Taguchi and RSM Methods

Abstract

In this study, the influence of the machining parameters on surface roughness of MDF machined on a CNC router based on machining parameters such as feed rate, spindle speed and depth of cut) was investigated with Taguchi and Response surface method (RSM) method. Taguchi L16 orthogonal array was used for experiments design. The significant machining parameters effect on surface roughness were analyzed with the analysis of signal to noise ratios (S/N), ANOVA, main effect graphs of means and 3 D surface plots. Mathematical prediction models of the effects of processing parameters on surface roughness were developed using response surface methodology (RSM). It was observed that the main effects of factors (depth of cut, feed rate, spindle speed) on roughness were found to be statistically significant, although the interaction of factors has no effect on surface roughness. It was found that surface roughness value increased with increasing feed rate and depth of cut and decreasing spindle speed. The better surface roughness values were obtained at 2500 mm/min of feed rate, 24000 rpm of spindle speed and 4 mm of depth of cut.

Keywords: MDF, surface roughness, surface milling, Taguchi, response surface method.

***Sorumlu Yazar (Corresponding Author):**
Ümmü KARAGÖZ İŞLEYEN (Dr.);Kastamonu Üniversitesi, Orman Fakültesi, Orman Endüstri Mühendisliği Bölümü, 37100, Kastamonu-Türkiye. Tel: +90 (366) 280 1779, Fax: +90 (366) 215 2316, E-mail: ukaragoz@kastamonu.edu.tr
ORCID No: 0000-0001-6083-8524

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1. Giriş

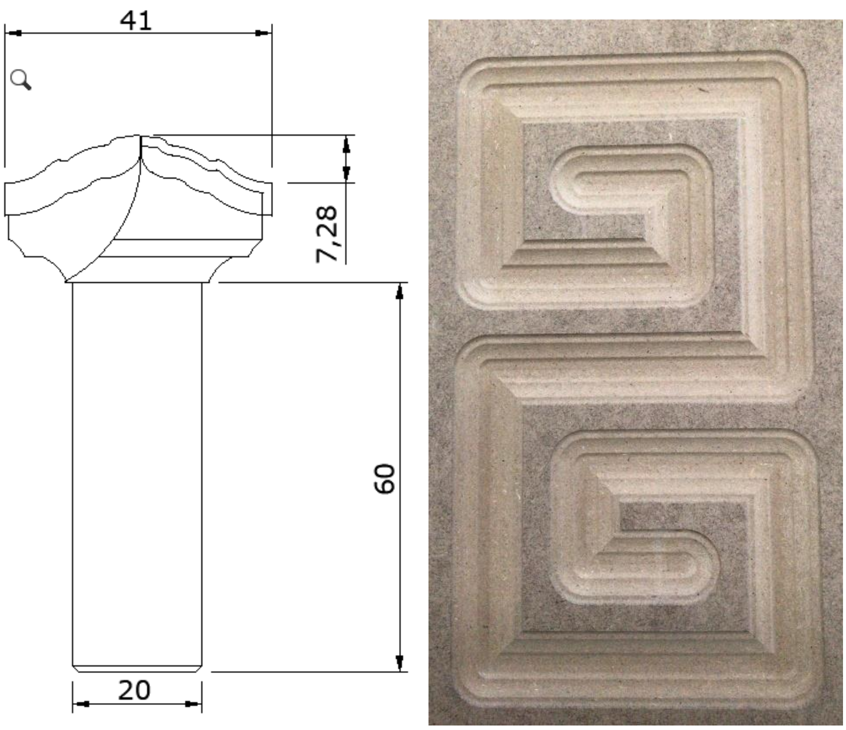
Surface roughness is an important parameter for determining the surface quality of machined wood material, which affects the cost of the final product in milling operation of furniture industry. The manufacturers, which focused on international competition, have invested in advanced technology machines such as CNC to save time and increasing quality and efficiency of product. Therefore, it is important to know the optimum machining conditions to obtain a minimum surface roughness. the surface roughness measurements were conducted using the contact (stylus type of profilometer) and non-contact (laser or ultrasonic systems) measurement methods (Funck et al. 1992; Hızıroğlu 1996). In recent years, atomic force microscopy (AFM) and scanning electron microscopy (SEM) methods have been used to evaluate the surface properties of machined materials (Haq and Srivastava 2016). Also, digital image correlation method is used controlling or assessing the surface roughness, physical and mechanical properties of wood (Bardak et al. 2017). The optimum surface quality depends on the material properties, tool properties and machining conditions and parameters. In many studies in which the effect of processing parameters on surface roughness of MDF and massive wood edge glued panels were investigated, it was stated that the roughness decreased with increasing spindle speed and decreasing feed rate and depth of cut (Magos 2008; Malkoçoğlu 2007; Zhong et al. 2013). At the same time, it was determined that surface quality decreased with increasing tool diameter (Sütçü and Karagöz 2013; Koc et al. 2017; Sofuoglu 2017). In addition, the optimization approaches such as genetic algorithm (GA), response surface method (RSM) and desirability function (DF) were used to estimate optimum machining parameters, which allow to minimum surface roughness value (Hazir and Ozcan, 2018). In this study, minimum surface roughness values were determined by using RSM-DF and RSM-DF-GA and were obtained with the highest spindle speed, lower feed rate, medium tool radius and the lowest depth of cut. Another optimization method used to model the surface roughness of wood in the processing process is artificial neural networks (ANN). The ANN model was used successfully for modeling surface roughness of wood without needing the more experimental study requiring much time and high experiment costs (Tiryaki et al 2014). Palanikuma and Valarmathi (2016) used Taguchi method to predict the influence of cutting parameters on thrust force in drilling of MDF panels. Hazir et al (2018) determined optimal of CNC machining parameters such as spindle speed, feed rate, depth of cut, tool radius, and cutting directions using design of experiment (DOE) and desirability function. In this study, Minimum surface roughness values were obtained spindle speed at 18000 rpm, feed rate at 2000mm/min, depth of cut at 2 mm and tool diameter at 8 mm for tangential cutting direction. Sofuoğlu (2015) studied to optimize machining parameters using the Taguchi design method on the surface quality of massive wooden edge glued panels (EGP) and determined that surface roughness increased with increasing feed rate and decreasing spindle speed. The optimum cutting condition for minimum surface roughness was examined as 16000 rpm spindle speed and 1000 mm /min feed rate. Gaitonde et al. (2008) determined the optimum processing conditions of MDF drilling using the Taguchi method to minimize delamination and reported that the delamination reduced with increasing cutting speed and decreasing feed rate.

For removal of additional cost and labor on surface machined with CNC, the processing efficiency and accuracy of the material is a very important criterion for the furniture industry. Therefore, in this study, the influence of machining parameters on MDF surfaces machined by CNC router using Taguchi and RSM. It was observed the influence of spindle speed, feed rate and depth of cut parameters through the MDF surface roughness. The average roughness (Ra) of surface parameters were measured with a stylus type measurement device. Experimental data were evaluated using the signal to noise ratio, main and interaction effect graphs of means and ANOVA.

2. Materials and Method

2.1. Machining parameters and surface roughness measurements

In this experimental study, MDF was selected as test material for CNC milling. The density values (752 kg/m^3) of the MDF panels were measured at 7% moisture content according to EN 323 (1993). A total of 16 experiments were performed with 20 mm diameter of profile tool on MDF panels (Fig. 1). Surface milling process was carried out on a BİESSE CNC machine. Surface roughness values were measured with Handysurf E-35 measurement equipment based on stylus technique. Roughness measurement was performed from 10 different points on each sample. The average roughness Ra are considered as roughness parameters with ISO 4287 (1977) standard. A stylus tip with a 5 μm diameter and 90^o contact angle with measuring force of 4 mN was used to measure the surface roughness parameter with measurement length of 4 mm and cut-off length of 0.8 mm. In this study, machining parameters such as spindle speed, feed rate and depth of cut were selected as independent variables. Each machining parameter levels were defined in Table 1.



a. b.

Fig. 1 a. Profile tool geometry b. machined surface of MDF

Table 1. Machining parameters and their levels

Symbol	Parameter	Unit	Level 1	Level 2	Level 3	Level 4
A	**Feed rate**	**mm/min**	2500	5000	7500	10000
B	**Spindle Speed**	**rpm**	18000	24000		
C	**Depth of Cut**	**mm**	4	6		

2.2. Experimental design

The use of experimental design allows to determine of influence of main and interaction of machining parameters on surface roughness. The Taguchi method, which is an experimental design method, is an effective method to reduce the cost and to determine the effects of the parameters on the result by a smaller number of trials. In this study, Taguchi optimization method is used as an experimental design method to concur the effect of spindle speed, feed rate and depth of cut processing parameters on surface roughness.

The experimental design for two milling parameters (depth of cut and spindle speed with two levels (2^2) and one parameter (feed rate) with four levels (4^1) are organized by the Taguchi's $L_{16}(4^1 \times 2^2)$ orthogonal array as shown in Table 2. Surface roughness values were determined by means of averaging of values obtained from ten different point on a sample surface.

The signal-to-noise (S/N) ratio as the quality characteristic of choice were used in Taguchi method. In this study, the smaller the better quality characteristics for Ra were selected to achieve minimum roughness. The S/N ratios were calculated using Eq. (1) for each of the 16 trials and is given below:

$$\text{SN ratio} = -10log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

where y is the response of the machining parameters and n is number of trial condition

2.3. 2.3. Response surface method

Response surface method (RSM) is a mathematical modeling method used for optimization of input parameters in surface milling system. This method is used to generate and analyze multifactorial models with quantitative data from the experimental design. The relationship between input parameters and their respective reactions in problems solved with RSM is generally expressed with the following second-degree polynomial equation in Eq. (2) as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} X_i X_j + \varepsilon \qquad (2)$$

Where; Y is the estimated response (Ra). $\beta 0$ is constant. β_i. β_{ii} and β_{ij} represent the coefficient of linear. quadratic and cross product terms respectively and n is the number of model parameters (i.e.. process parameters).

3. Result and Discussion

The average S/N ratio is calculated by using Taguchi method in Minitab R18 software for a confidence level of 95 % (e.g., significance level of 0.05) in order to obtain the optimal machining parameters of milling MDF panels. The smaller the better quality characteristics were considered in order to get minimal surface roughness with optimal machining parameters. The S/N ratio for every level of experiment is shown in Table 2. A high S / N value refers to the processing parameter that ensures the minimum surface quality. The according to the S / N ratio in Table 2, the optimum machining parameters for the minimum surface roughness were stated at feed rate of 2500 mm/min, spindle speed of 24000 rpm and depth of cut of 4 mm. The roughest surface was determined at feed rate of 10000 mm/min, spindle speed of 18000 rpm and depth of cut of 6 mm.

Table 2. Response Table for Signal to Noise Ratios

No	**A Feed rate (mm/min)**	**B Spindle speed (rpm)**	**C Depth of cut (mm)**	**Ra (µm)**	**S/N ratio**
1	2500	18000	4	10.36	-20.31
2	2500	18000	6	10.7	-20.59
3	2500	24000	4	9.25	-19.32
4	2500	24000	6	9.45	-19.51
5	5000	18000	4	10.87	-20.72
6	5000	18000	6	11.19	-20.98
7	5000	24000	4	9.53	-19.58
8	5000	24000	6	10.14	-20.12
9	7500	18000	4	11.18	-20.97
10	7500	18000	6	11.41	-21.15
11	7500	24000	4	9.96	-19.97
12	7500	24000	6	10.45	-20.38
13	10000	18000	4	11.26	-21.03
14	10000	18000	6	11.63	-21.31
15	10000	24000	4	10.09	-20.08
16	10000	24000	6	11.25	-21.02

Analysis of variance

Mean surface roughness values obtained from Taguchi's $L_{16}(4^1 \times 2^2)$ orthogonal array were used for RSM method. RSM based model observed main and interaction effect of machining parameters on surface roughness with regression models**.** In this study, RSM based full quadratic models for predicting surface roughness value (Ra) were developed under the influence of parameters as feed rate (A), spindle speed (B), depth of cut (C). The full quadratic regression model fitted for surface roughness was obtained and are represented by Eq. (3)

$$Ra = 16.59 - 0.000084\,A - 0.000357\,B - 0.465\,C - 0.000000\,A^2 + 0.000000\,A{*}B + 0.000028\,A{*}C + 0.000025\,B{*}C \qquad (3)$$

The Analyses of variance (ANOVA) for the adequacy of the adequacy of the response surface quadratic model was performed. It has been investigated that the process parameters have a significant effect on surface roughness with variance analysis. The analysis of variance for surface roughness is shown in Table 3. The model summary that R^2 and Adj-R^2 values were found as 97.83% and 95.92%. respectively. The main and interaction effects of machining parameters on surface roughness values were analyzed with variance analysis (ANOVA) at a 95% confidence level. There were significant effects of the spindle speed, feed rate and depth of cut parameters on the Ra value at a confidence level of 95%. There was no significant interaction between the model parameters.

Table 3. Analysis of Variance (ANNOVA) for Surface Roughness (Ra)

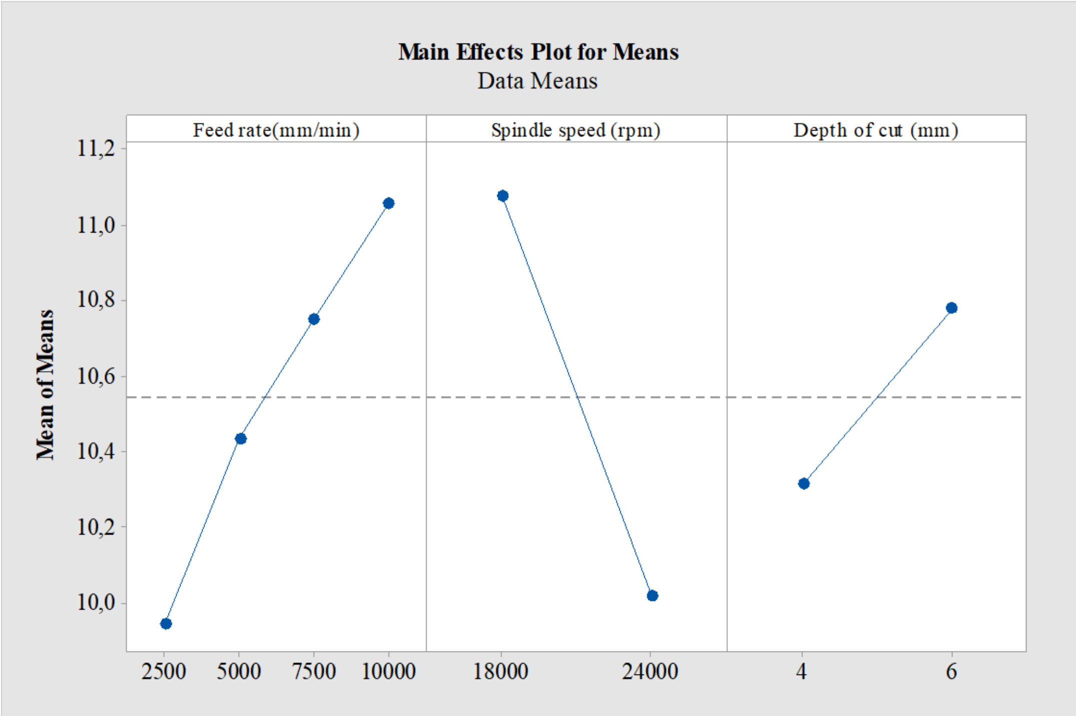
Source	**DF**	**SS**	**MS**	**F-Value**	**P-Value**
Model	7	8.359	1.194	51.43	0.000
Linear	3	8.053	2.684	115.61	0.000
feed rate	1	2.693	2.693	116.01	0.000*
spindle speed	1	4.494	4.494	193.56	0.000*
depth of cut	1	0.864	0.864	37.25	0.000*
Square	1	0.034	0.034	1.47	0.259
feed rate*feed rate	1	0.034	0.034	1.47	0.259
2-Way Interaction	3	0.272	0.090	3.91	0.055
feed rate*spindle speed	1	0.087	0.087	3.75	0.089
feed rate*depth of cut	1	0.095	0.095	4.10	0.077
spindle speed*depth of cut	1	0.090	0.090	3.88	0.085
Error	8	0.185	0.023		
Total	15	8.545			

Model summary

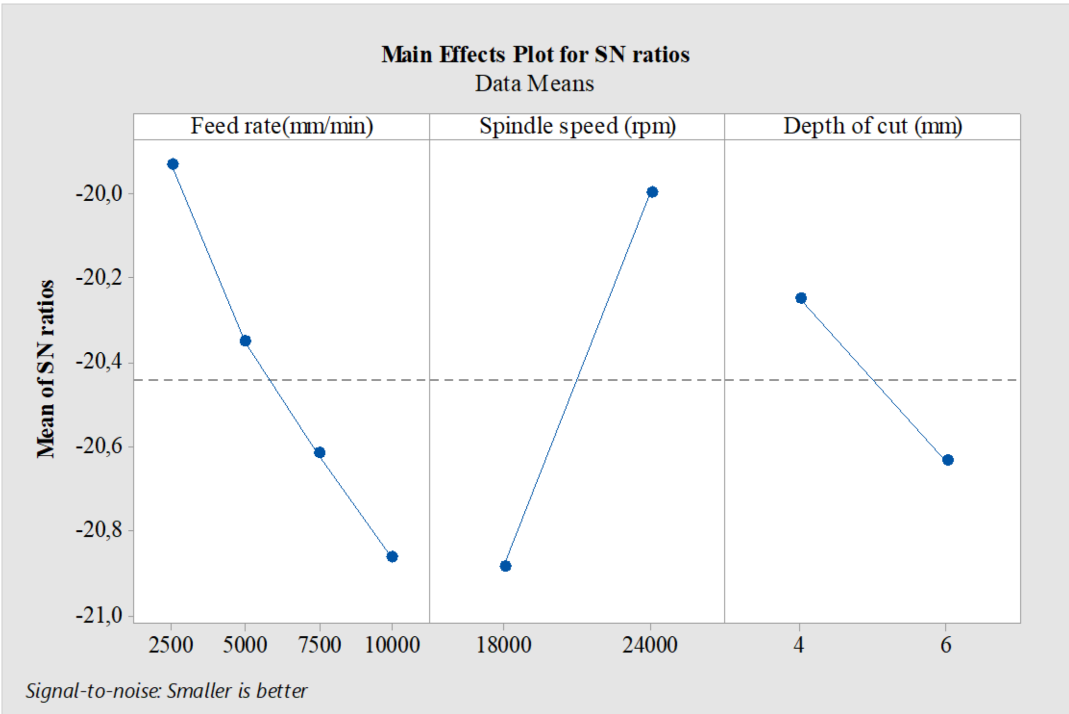
S=0.152379 R^2 = 97.83% R^2(adj) = 95.92 % R^2 (pred)=85.94 %

*:p<0.05

S/N ratio and means graphics of levels of parameters were used for the evaluation the optimal machining parameters for Ra. The main effect plot for S/N ratio and means according to surface roughness are shown in Fig. 2. According to Fig. 2a, the average Ra values for the levels of the machining parameters are 9.940 µm (level 1), 10.43 µm (level 2), 10.75 µm (level 3), 11.05 µm (level 4) of feed rate, 11.07 µm (level 1) and 10.015 µm (level 2) of spindle speed, 10.313 µm (level 1) and 10.77 µm (level 2) of depth of cut, respectively. The highest surface roughness value was obtained with feed rate of 10000 mm/min (Ra = 11.05 µm, level 4), while the lowest surface roughness value was obtained with feed rate of 2500 mm/min (Ra=9.94 µm). The optimal machining conditions for minimum surface roughness were determined according to S/N ratio. From the S/N ratio plots in Fig. 2b, the optimal machining parameters for surface roughness value (Ra) were determined as $A_1B_2C_1$ which are 2500 mm/min of feed rate (level 1). 24000 rpm of spindle speed (level 2) and 4 mm of depth of cut (level 1). The main effects of factors (depth of cut, feed rate, spindle speed) on surface roughness were obtained and the surface roughness value increased with increasing feed rate and depth of cut and decreasing spindle speed.



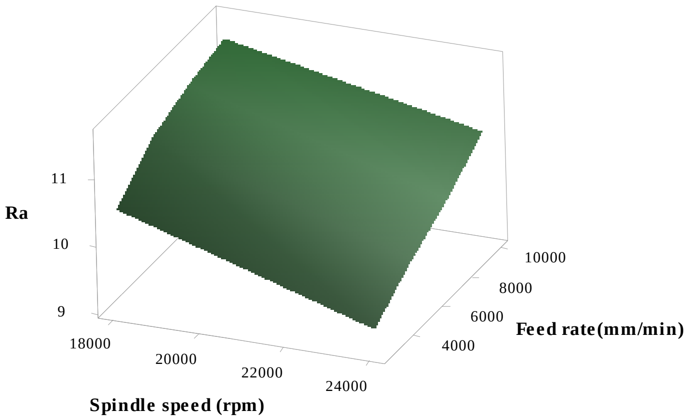
a.



b.

Fig. 2. Main effect plots, a. Mean for surface roughness (Ra) b. Mean S/N ratio for surface roughness (Ra).

The interaction effects of machining parameters on the surface roughness are presented in Fig. 3. The interaction effect of spindle speed-feed rate, depth of cut-feed rate and spindle speed-depth of cut influenced the surface roughness. However, the interaction of the machining parameters as well as depth of cut had no significant effect on surface roughness according to variance analysis.



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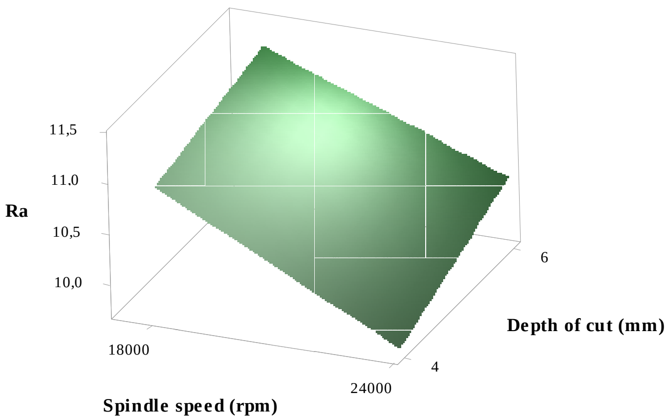

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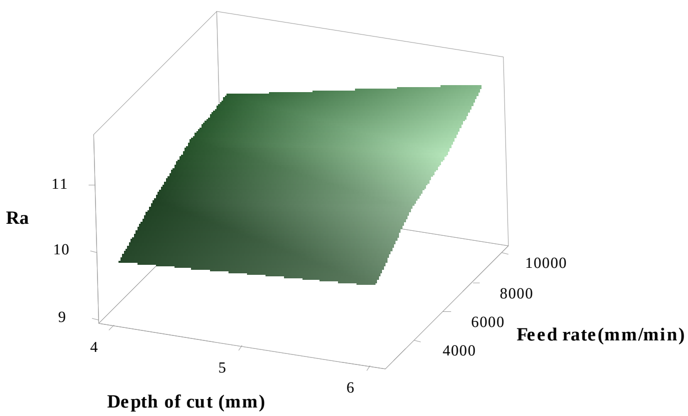

c.

Fig. 3. The interactions effect plot of machining parameters, a. spindle speed versus feed rate b. spindle speed versus depth of cut c. depth of cut versus feed rate

In this study, with developed mathematical models by using Taguchi method and RSM, the effects of the processing parameters on the surface roughness have been optimized. It has been determined that the main effect of the feed rate, spindle speed and depth of cut processing parameters on the surface roughness had a significant effect on the surface roughness by developed mathematical models. The interaction effect of machining parameters on surface roughness had no significant. The surface roughness decreased with increasing spindle speed. The smoother surface at spindle speed of 24000 rpm was obtained than the spindle speed of 18000 rpm. The surface roughness value decreased with reducing feed rate and the lowest surface roughness value was considered as feed rate of 2500 mm/min feed rate. There is a linearly relationship between depth and surface roughness value. The surface roughness value increases with increasing the depth of cut and the highest roughness value was also obtained.at 6 mm depth of cut. The depth of cut is an important factor affecting tool wear. Increasing the depth of cut allows high friction by increasing the contact area between the tool and the work piece (Debnath *et al*. 2016). Also, The vertical density value decreases from the surface layer towards the core layer of MDF (Gupta *et al*. 2006). As the increasing of depth of cut, the density decreases and the surface roughness value increases. A many studies have been carried out to determine the effect of machining parameters on surface roughness values. Previous studies indicated that the lowest surface roughness value was obtained with the increasing spindle speed, decreasing feed rate, and decreasing depth of cut (Sütçü 2013; Sütçü and Karagöz 2012; Sofuoglu 2015; Hazir and Özcan 2018).

4. Conclusions

In this study, the influence of various machining parameters on surface roughness was studied using Taguchi method and response surface methodology. In milling experiments, there different machining parameters (such as spindle speed, feed rate, depth of cut) were selected for grooving on MDF with CNC router. A total of 16 trial were produced and surface roughness was measured. Experimental data were analyzed with the analysis of ANOVA, signal to noise, interaction effect 3D surface plots, main effect graphs of means. Optimal machining parameters are determined by the Taguchi and RSM method. The conclusions obtained in this study are summarized as follows:

- According to analysis of variance (ANOVA) it was found that spindle speed, feed rate, depth of cut parameters had significant effect on surface roughness. The interaction effect of machining parameters had no significant effect on surface roughness.
- The S/N ratios and main effect graphs and the surface graphs showed the main and interactive effects of the processing parameters on surface roughness.
- In order to increase the surface quality for machining operations, increasing spindle speed and reducing feed rate and depth of cutting depth is a good solution.
- The better surface roughness values were obtained at as $A_1B_2C_1$. which are 2500 mm/min of feed rate (level 1). 24000 rpm of spindle speed (level 2) and 4 mm of depth of cut (level 1) of machining condition for surface roughness were determined.
- The proposed quadratic model was developed for the prediction of responses using RSM method. The R^2 and Adj-R^2 values were found as 97.83% and 95.92%. respectively which indicated the statistical adequacy of the model.

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