

Influence of Cutting Parameters on Surface Roughness during Milling AISI 1045 Steel

D.D. Trung^{a,*}

^aFaculty of Mechanical Engineering, Hanoi University of Industry, Hanoi city, Vietnam.

Keywords:

Surface roughness model
Milling operation
Johnson transformation
AISI 1045 steel
Hard alloy BK8

* Corresponding author:

Do Duc Trung 
E-mail: doductrung@hau.edu.vn

Received: 25 September 2020

Revised: 24 October 2020

Accepted: 16 November 2020

ABSTRACT

The current study presents the influences of cutting parameters (cutting speed, feed rate, and depth of cut) on the surface roughness during milling. The used materials are AISI 1045 steel. The cutting tool is a face milling, made of hard alloy (BK8). The experimental plan of this study is carried out by using Box-Behnken technique. The analysis of experimental results found out the influence of the input parameters as well as their interaction on the surface roughness. In addition, the study proposed two models of surface roughness prediction, one of which is developed according to Response surface method (RSM) and the other is built on the basis of Johnson transformation. Research results showed that the Johnson-based is better than the model using RSM.

© 2020 Published by Faculty of Engineering

1. INTRODUCTION

Milling operation has been widely used to machine mechanical parts. This is attributed to its high productivity and high precise. Generally, the machinability of this operation is estimated by some factors such as machining quality, cutting forces, material removal rate, and tool wear. Regarding the quantification of the machining quality, the average surface roughness criterion has been widely used to characterize damage resulting from machining process. It has been known that surface roughness crucially affects the mechanical properties and working ability during services. Cutting speed, feed speed, depth of cut, radius of cutting edge, machined materials, cutting tools, coolant parameters, and machining vibrations have strong influences on the surface roughness.

Among the previously mentioned factors, cutting parameters (cutting speed, feed speed, and depth of cut) are generally adopted to be the input parameters for controlling the machining operation. The results presented in the study of [1] show that almost 94 % research work in literature dealing with surface roughness study have selected cutting parameters as input parameters in experimental studies. Furthermore, in order to ensure that the surface roughness meets requirements, it is probably more convenient and quicker for the operator to adjust value of the cutting parameters than to change the other such as tool type, cooling lubricants, etc. In fact, the cutting parameters are typically chosen according to the experiences of the operators or to the tabular data. Nevertheless, this can lead to the fact that the required surface roughness is not satisfied as expectation due to the unpredictable issue

happening during machining, or the tabular data is not regularly updated. When using some modern software (such as NX) to program the machining process, the programmer can set up the required roughness as an input parameter. The workpiece type and cutting tool geometry should also be used. The cutting parameters is automatically selected to obtain the surface roughness requirements. However, for the calculation to be done in this way, the program developers need to rely on the experiment results to find out a relationship between surface roughness and cutting variables in specific cases when building the software. In order to reduce the effect of selecting cutting parameters based on experiences or lookup tables and contribute to the software building process, many studies were conducted to develop surface roughness models as well as determine the influence of the machining parameters on the surface roughness. Hoa et al. [2] performed milling process of Aluminium alloy A6061 by face mill cutter using the hard alloy cut piece (APMT1604PDTR TC300). Their results reveal that surface roughness reduces when cutting speed increase and/or feed rate and depth of cut decrease. Hasan.G [3] conducted the milling process of alloy steel AA2014 (T4) and documented that feed rate has the strongest influence on the surface roughness which is orderly impacted by cutting speed and depth of cut. These conclusions are consistent with those presented in [3-8]. On the contrary, Hernandez.G et al. [9] said that cutting speed has the strongest influence on the surface roughness than other when carrying out the milling process of AISI 304 steel. However, the authors [10] showed that cutting speed, feed rate, and depth of cut have no influences on the Rz instead of Ra (average surface roughness) for both case of milled materials, i.e. Al-1Fe-1V-1Si and Al-2Fe-1V-1Si. Regarding the effect of the interaction between cutting parameters, the authors of [4] and [6] found the similar result. In this situation, the interaction between feed rate and depth of cut has the largest influence on the surface roughness. Nevertheless, Okokpuije. I et al. [11] found that the interaction between cutting speed and feed speed has the strongest impact on the surface roughness when milling aluminum alloy 6061 by using minimum quantify lubrication process.

Based on the previously analyzed studies, it is known that for a given cutting condition and cut materials, the influencing degree of cutting parameters on the surface roughness is also

different. In addition, the authors used the RSM to build the models. These show the relationship between the surface roughness and the cutting parameters. BK8 hard alloy (including 92 % WC and 8 % Co) is a material with high abrasion resistance and high temperature resistance up to 1000 °C. The BK8 cutting tools are used to process a wide variety of materials. AISI 1045 steel is commonly used to machine details in the manufacturing industry such as levers, spindles, gears, flanges, bolts. Many researches on milling this steel were carried out. There is no research published on the use of BK8 cutting tools to process the AISI 1045 steel. Milling using a face milling cutter on a vertical milling machine is more productive than a cylindrical milling cutter on a horizontal milling machine. Thus, the face are more commonly used than the cylindrical in machining planes. This is because there are many teeth of the face milling cutter are involved in the machining process, while only one tooth (of the straight-tooth milling cutter) or a few teeth (of the helical milling cutter) is involved simultaneously during the operation. In this paper, the effects of cutting speed, feed rate and depth of cut on the surface roughness using cutting tool BK8 for milling AISI1045 steel on vertical milling machine was studied. A model to predict surface roughness will be proposed based on the Response surface methods in which the Johnson transformation is also applied to improve the accuracy of proposed model. Moreover, the validation of proposed model will be conducted when compared with experiments.

2. MILLING PROCESS

2.1 Material preparation

Samples for testing are made of AISI 1045 steels which are widely used in mechanical machining. Before testing, the rough cutting to sample preparation was milled to get the dimension of 50x50x50 mm. The chemical composition of used materials is listed in Table 1. Table 2 shows the designations of AISI in several standards.

2.2 Experimental set up and measurement

Milling tests are conducted by using vertical milling machine (TF-OSS, Taiwan origin) (c.f. Fig. 1). Cutting tools are the face mill cutter using the hard alloy cut piece (BK8). The tool nose radius is 0.6 mm, is fitted to 80 mm-diameter tool holder.



Fig. 1. Vertical milling machine for tests.

Each specimen was measured at least three times. The surface roughness of each trial is the average of the successive measurements. The trials were carried out under milling conditions without cooling lubricants (dry machining).

2.3 Design of Experiment

A plan of experiment is prepared according to Box-Behnken design. The values of the cutting parameters selected within the permissible range were used in several studies when milling AISI 1045 steel [12-13] and depended on the technological capabilities of the testing machine, as shown in Table 3. The matrix of Box-Behnken experimental design is shown in Table 4.

Surface roughness is measured by using roughness tester SJ301 (MITUTOYO – Japan).

Table 1. Chemical component and mechanical properties of AISI 1045 steels.

Composition (%)										Properties			
C	Si	Mn	Cr	Ni	Mo	V	Ti	B	Cu	modulus of elasticity (GPa)	Poisson's ratio	Shear module (Gpa)	Density (kg/m ³)
0.45	0.22	0.68	0.18	0.13	0.02	0.01	0,001	0.0005	0.20	210	0.3	80	7800

Table 2. Designation of AISI 1045 steel in several standards.

Country	USA	China	Germany	Italy	Japan
Standard	AISI	BS	DIN	UNI	JIS
Symbols	1045	060A4	CK45	C45	S45C

Table 3. Input parameters with different levels.

Parameter	Unit	code	Values at different levels		
			-1	0	1
Cutting speed	m/min	v	140	200	260
Feed rate	mm/tooth	f	0.1	0.2	0.3
Depth of cut	mm	t	0.28	0.4	0.52

Table 4. Plan matrix of testing and results.

Trial no.	code			Real values			Surface roughness Ra, μm
	v	f	t	v, m/min	f, mm/tooth	t, mm	
1	0	0	0	200	0.2	0.4	0.88
2	-1	0	1	140	0.2	0.52	1.02
3	1	0	-1	260	0.2	0.28	0.67
4	0	0	0	200	0.2	0.4	0.86
5	1	1	0	260	0.3	0.4	1.22
6	-1	0	-1	140	0.2	0.28	0.82
7	0	1	-1	200	0.3	0.28	1.88
8	1	-1	0	260	0.1	0.4	0.72
9	-1	1	0	140	0.3	0.4	1.19
10	0	0	0	200	0.2	0.4	0.87
11	0	0	0	200	0.2	0.4	0.82
12	-1	-1	0	140	0.1	0.4	0.83
13	0	-1	1	200	0.1	0.52	0.72
14	1	0	1	260	0.2	0.52	0.62
15	0	-1	-1	200	0.1	0.28	0.69
16	0	0	0	200	0.2	0.4	0.82
17	0	0	0	200	0.2	0.4	0.93
18	0	1	1	200	0.3	0.52	2.02

3. RESULTS AND DISCUSSION

3.1 Developing prediction model of surface roughness using Response surface method

Roughness criteria have been widely used in industry and research community. It can be representative by several parameters such as arithmetical mean deviation of the assessed profile (R_a), maximum height of profile (R_z), maximum profile peak height (R_p), maximum profile valley depth (R_v), total height of profile (R_t), root mean square deviation of the assessed profile (R_q), mean width of the profile element (R_{sm}) [14]. Among the mentioned parameters, R_a is most widely adopted to quantitatively estimate machining quality [16-20]. It will be used to characterize machining quality in this study. Three measurements of R_a will be averaged to get the representative values as arranged in Table 4.

Analysis of Variance (ANOVA) is conducted to investigate the influencing degree of input parameters on the response, R_a . Moreover, the interactions between input parameters are also considered and can be seen in Figs. 2 and 3.

When the significant level of 0.05 is selected, the parameter has a considerable impact on the output if its p-value is less than 0.05. That means the smaller P-value of the parameter, the more it affects the output. In this case, the results in Table 5 revealed that the feed rate has a great influence on surface roughness, while cutting speed, depth of cut and their interaction have the negligible impact. Similar conclusions are drawn from Figs. 2 and 3. This result is consistent with those given by [3-8].

A regression model is proposed to predict R_a . This model is based on experimental results listed in Table 5, presented in (1). It has a determination coefficient (R^2) of 0.8571. This coefficient shows that experimental data is 85.71 % suitable compared to the predicted data when using (1). Moreover, the P-value of the Lack-of-Fit is 0.000 (Table 5), showing that (1) does not match the data in the Table 4 Hence, the transformation of these data is performed in this study in order to build an accurate model for predicting surface roughness, compared to experimental data.

$$R_a = 0.86333 - 0.07875 * v + 0.41875 * f + 0.04 * t - 0.20197 * v^2 + 0.33583 * f^2 + 0.12833 * t^2 + 0.035 * v * f - 0.0625 * v * t - 0.0275 * f * t \quad (1)$$

Table 5. ANOVA for R_a .

Source	Sum of square	Degree of freedom	F-value	P-value	
Regression	2.20969	9	5.33	0,014	Significant
Linear	1.46523	3	10.61	0,004	Significant
v	0.04961	1	1.08	0,330	Not significant
f	1.40281	1	30.47	0,001	Significant
t	0.01280	1	0.28	0,612	Not significant
Square	0.72092	3	5.22	0,027	Significant
v^2	0.11772	1	4.15	0,076	Not significant
f^2	0.53133	1	10.69	0,011	Significant
t^2	0.07187	1	1.56	0,247	Not significant
Interaction	0.02355	3	0.17	0,913	Not significant
v * f	0.00490	1	0.11	0,753	Not significant
v * t	0.01563	1	0.34	0,576	Not significant
f * t	0.00302	1	0.07	0,804	Not significant
Residual Error	0.36831	8			
Lack-of-Fit	0.35978	3	70.27	0,000	Significant
Pure Error	0.00853	5			
Total	2.57800	17			
Mean		0.9767		R^2	0.8571
Standard deviation		0.3894		Adjusted R^2	0.6964
PRESS		5.76869		Predicted R^2	0.00

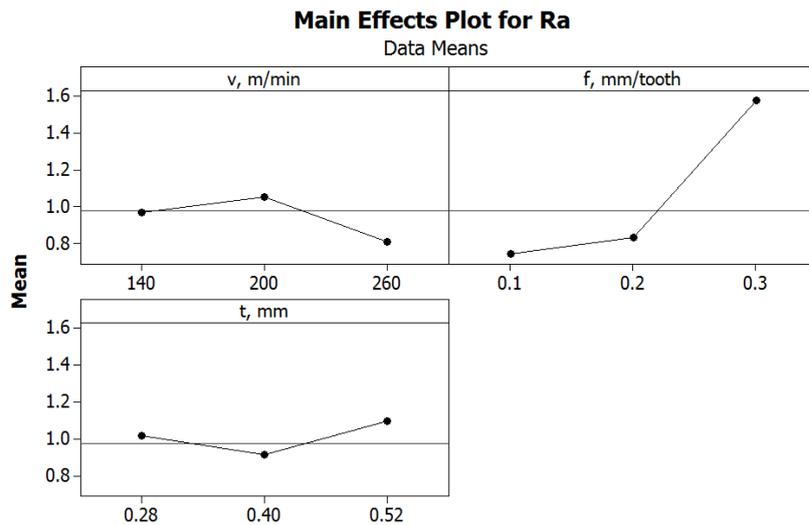


Fig. 2. Influence of cutting parameters on Ra.

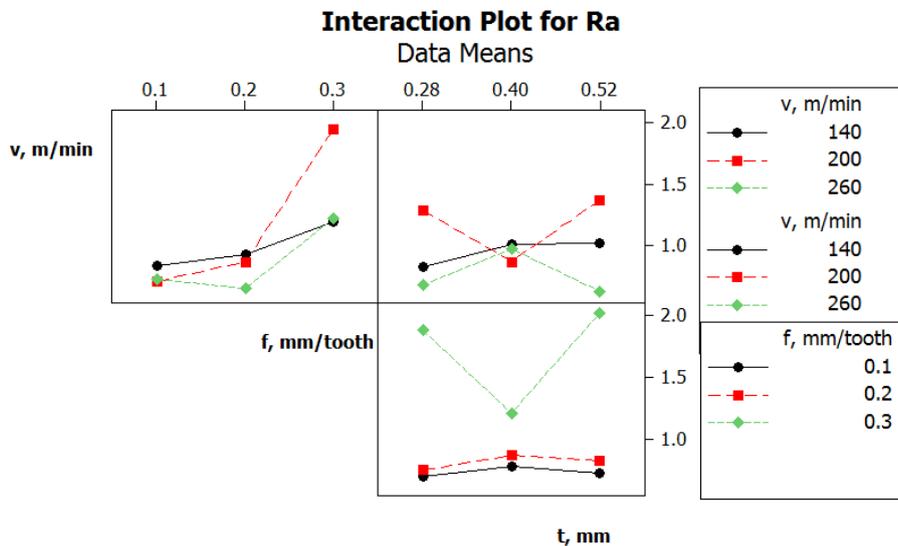


Fig. 3. Interaction effects of cutting parameters on Ra.

3.2 Proposing the model to predict surface roughness using Johnson transformation

Johnson transformation is used to convert a given data so that to follow normal distribution [15]. In order to check whether the values of surface roughness follow normal distribution or not, the data given in Table 4 are analyzed, and graphically expressed in Fig. 4.

The graphical results in Fig. 4 show that the experimental data are not along the limit line or reference lines. On other hand, P-value is small (<0.005). This means that the data do not follow normal distribution. In order to improve the accuracy of proposed model, Johnson transformation can be used. The transformation processes are carried out and presented in Fig. 5. The improved model to predict surface

roughness is representative in shape of hyperbolic as in equation (2). The determination coefficient are approximate of 0.8686 which is larger than that of (1). It means that the data after the Johnson transformation match 86.86 % the predicted data using formula (2). This shows the potential of using (2) for predicting surface roughness to be more accurate than (1).

The distribution of data after transforming is showed in the low left corner of Fig. 5. It is observed that the data are inside the reference lines, and the P-value of 0.594 are larger than significant level of 0.05. This means that the adjusted data follow normal distribution.

$$\begin{aligned}
 R_a = & 0.65928 + 0.076954 * \text{Sinh}(1.688403 \\
 & -0.60526 * v + 1.12039 * f + 0.072586 * t \\
 & - 0.49213 * v^2 + 0.697348 * f^2 - 0.35146 * t^2 \\
 & + 0.216904 * v * f - 0.34902 * v * t - 0.0566 * f * t)
 \end{aligned}
 \tag{2}$$

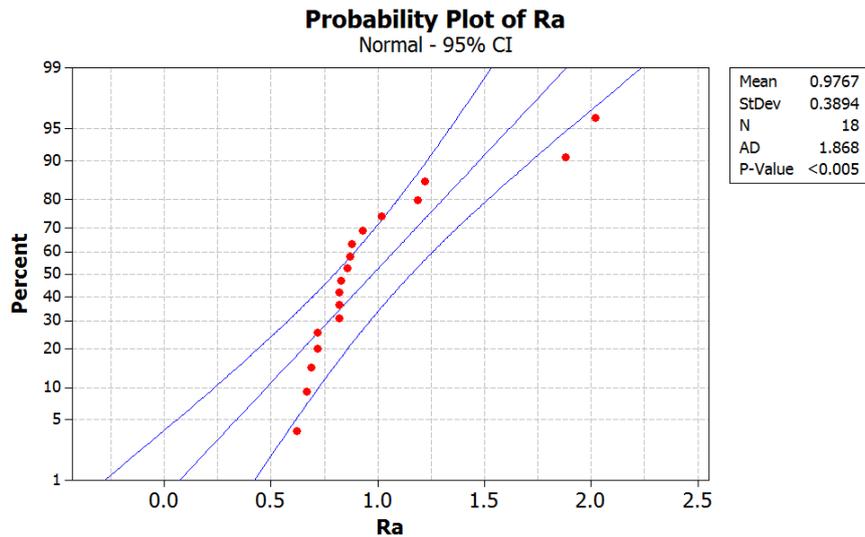


Fig. 4. Probability plot of Ra.

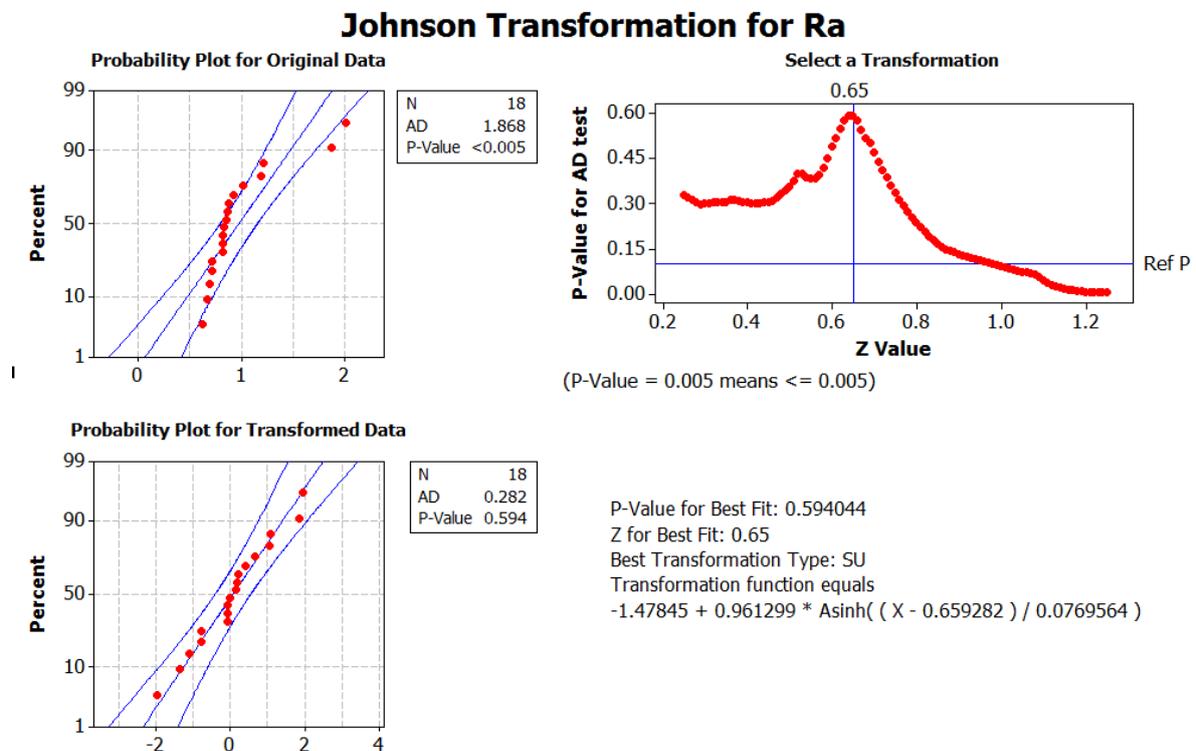


Fig. 5. Johnson plot for power transformation.

3.3 Analysis of model errors

A comparison between prediction given by proposed models and experiment is carried out and presented in Table 6 where model (1) is not used and model (2) is used Johnson transformation.

In order to investigate the accuracy of two proposed models, the mean absolute errors – MAE and mean square error – MSE given by prediction will be compared with experiments in term of determination coefficient and listed in Table 7.

$$\%MAE = \left(\frac{1}{n} \sum_i^n \left| \frac{e_i - p_i}{e_i} \right| \right) * 100\% \quad (3)$$

$$\%MSE = \left(\frac{1}{n} \sum_i^n |e_i - p_i|^2 \right) * 100\% \quad (4)$$

Where: e is denoted for experimental data, p is representative for predicted data, n is the number of tests.

Table 6. Comparison between prediction and experiments.

Order	Experimental surface Roughness Ra (μm)	Predicted surface roughness Ra (μm)		% Absolute error	
		Without transformation	With transformation	Without transformation	With transformation
1	0.88	0.8633	0.8604	1.90	2.23
2	1.02	0.9709	0.9035	4.81	11.42
3	0.67	0.7334	0.7008	9.46	4.60
4	0.86	0.8633	0.8604	0.38	0.04
5	1.22	1.3722	1.1880	12.48	2.62
6	0.82	0.7659	0.7532	6.60	8.15
7	1.88	1.7337	1.5456	7.78	17.79
8	0.72	0.4647	0.6555	35.46	8.96
9	1.19	1.4597	1.8137	22.66	52.41
10	0.87	0.8633	0.8604	0.77	1.11
11	0.82	0.8633	0.8604	5.28	4.92
12	0.83	0.6922	0.8412	16.60	1.35
13	0.72	0.9762	0.7549	35.58	4.85
14	0.62	0.6884	0.6565	11.03	5.88
15	0.69	0.8412	0.7261	21.91	5.23
16	0.82	0.8633	0.8604	5.28	4.92
17	0.93	0.8633	0.8604	7.17	7.49
18	2.02	1.7587	1.5745	12.94	22.05

Table 7. Comparison between two proposed models for surface roughness.

Model	% Mean absolute error	% Mean square error	R ²
Without using Johnson transformation	12.11	2.54	0.8571
Using Johnson transformation	9.22	2.25	0.8686

It is seen that the model using and without using Johnson transformation exhibit the errors compared with experiments are 9.22 % and 12.11 % respectively. Regarding the mean square error, the corresponding values are in order 2.54 % and 2.25 %. Based on the above analysis, it can be concluded that the surface roughness model using Johnson transformation can predict more exactly than that not using Johnson transformation does.

4. CONCLUSIONS

The research carried out the experiment of milling AISI 1045 steel using hard-alloy BK8 cutting tool. The influence of cutting parameters on surface roughness is found out. The Johnson transformation is applied for improving surface roughness model. The study revealed that:

- Among three cutting parameters including cutting speed, feed rate and depth of cut, only the feed rate has a significant effect on surface

roughness. Their interaction does not considerably affect surface roughness

- The surface roughness model using the Johnson transformation predicted better than the non-Johnson-based model. After the transformation, Mean absolute error and Mean square error are reduced from 12.11 % to 9.22 and 2.54 to 2.25, respectively.

In order to propose the model which can be applied for various milling process of AISI 1045 steel other parameters like tool geometries, coolant, tool materials should be included into the model. This is an open issue which can be continuously studied in the future.

REFERENCES

- [1] N.H. Son, *Comprehensive Study of Surface Roughness of Workpiece When Surface Milling Using a Face Milling Cutter*, International Journal of Science and Engineering Investigations, vol. 9, iss. 97, pp. 54-59, 2020.
- [2] P.T. Hoa, D.T. Huong, N.Q. Viet, B.T. Long, N.D. Toan, *Study on effects of cutting parameters to the chip shrinkage coefficient and surface roughness when machining aluminum alloy A6061*, in 5th national workshop of Science and technology, 13 - October, 2016, Hanoi university of science and technology, Ha Noi, Viet Nam, pp. 29-35.
- [3] M.T. Hayajneh, M.S. Tahat, J. Bluhm, *A Study of the Effects of Machining Parameters on the Surface*

Roughness in the End-Milling Process, Jordan Journal of Mechanical and Industrial Engineering, vol. 1, iss. 1, pp. 1-5, 2007.

- [4] H. Gökkaya, *The Effects of Machining Parameters on Cutting Forces, Surface Roughness, Built-Up Edge (BUE) and Built-Up Layer (BUL) During Machining AA2014 (T4) Alloy*, Strojniškovestnik - Journal of Mechanical Engineering, vol. 56, iss.9, pp. 584-593, 2010.
- [5] M. Yasir, T.L. Ginta, B. Ariwahjoedi, A.U. Alkali, M. Danish, *Effect of cutting speed and feed rate on surface roughness of AISI 316LSS using end-milling*, ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 4, pp. 2496-2500, 2016.
- [6] N.H. Son, *Effect of Cutting Parameters on Cutting Force and Surface Roughness of Workpiece When Milling 40Cr Steel Using PVD-Coated Cutter*, International Journal of Science and Engineering Investigations, vol. 9, iss. 96, pp. 13-18, 2020.
- [7] D. Bajić, L. Celent, S. Jozić, *Modeling of the Influence of Cutting Parameters on the Surface Roughness, Tool Wear and Cutting Force in Face Milling in Off-Line Process Control*, Strojniškovestnik - Journal of Mechanical Engineering, vol. 58, iss. 11, pp. 673-682, 2012, doi: [10.5545/sv-jme.2012.456](https://doi.org/10.5545/sv-jme.2012.456)
- [8] H.T. Dung, N.-T. Nguyen, T.D. Quy, N.V. Thien, *Cutting Forces and Surface Roughness in Face-Milling of SKD61 Hard Steel*, Strojniškovestnik - Journal of Mechanical Engineering, vol. 65, iss. 6, pp. 375-385, 2019, doi: [10.5545/sv-jme.2019.6057](https://doi.org/10.5545/sv-jme.2019.6057)
- [9] H. González, L. Wilfredo, R. Pérez-Rodríguez, A.M. Quesada-Estrada, L. Dumitrescu, *Effects of cutting parameters on surface roughness and hardness in milling of AISI 304 steel*, DYNA, vol. 85, iss. 205, pp. 57-63, 2018, doi: [10.15446/dyna.v85n205.64798](https://doi.org/10.15446/dyna.v85n205.64798)
- [10] B.N. Pathak, K.L. Sahoo, M. Mishra, *Effect of Machining Parameters on Cutting Forces and Surface Roughness in Al-(1-2) Fe-1V-1Si Alloys*, Materials and Manufacturing Processes, vol. 28, iss. 4, pp. 463-469, 2013, doi: [10.1080/10426914.2013.763952](https://doi.org/10.1080/10426914.2013.763952)
- [11] P.O. Imhade, C.O. Ugochukwu, *Effects of Cutting Parameters on Surface Roughness during End Milling of Aluminium under Minimum Quantity Lubrication (MQL)*, International Journal of Science and Research, vol. 4, iss. 5, pp. 2937-2943, 2013.
- [12] M. Jacas-Cabrera, T. Rodríguez-Moliner, J.L. Lopes-Da Silveira, *Influencia de la velocidad de corte y la velocidad de avance en la integridad superficial del acero AISI 1045*, Ingeniería Mecánica, vol. 18, iss. 3, pp. 203-210, 2015.
- [13] M.T. Demirci, İ. Asiltürk, E. Canli, *Surface roughness optimization of milling process of AISI 1045 steel with Taguchi technique*, Journal of Selçuk University Natural and Applied Science, vol. 2, no. 4, pp. 10-20, 2013.
- [14] Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters, available at: www.iso.org/standard/10132.html, accessed: 12.10.2020.
- [15] N. Van Du, N. Dang Binh, *Design of experiment techniques*, Science and technics publishing House, Ha Noi, Viet Nam, 2011.