Influence Of Cutting Parameters On Surface Roughness And Surface Roughness Model When Milling XC42 Steel With A Face Milling Cutter

Le Hong Ky
Vinh Long University of Technology Education, 73 Nguyen Hue Street,
Vinh Long City, Vinh Long Province, Vietnam
lehongkydhspktvl@gmail.com & kylh@vlute.edu.vn

***Abstract*—This paper presents an empirical study to determine the influence of cutting parameters on surface roughness when milling a plane with a face milling cutter. The testing material used in this study was XC42 steel. Three parameters of the cutting mode were investigated in this study: the cutting velocity, the feed rate and the depth of cut. Fifteen tests were designed according to the Box – Behnken matrix, including three tests at the central point. An analysis of the test results has determined the influence of the parameters as well as the influence of the interaction between parameters on surface roughness. A rough surface model was proposed in this study as a quadratic polynomial. An assessment of the suitability of surface roughness model with test data was also conducted in this study.**

Keywords—milling a plane with a face milling cutter, XC42 steel, surface roughness model.

1. Introduction

Milling of a plane with a face milling cutter is a common machining method offering high productivity and being widely applied in mechanical processing. Surface roughness has a great influence on the shelf life of products and is often chosen as one of the criteria to evaluate the efficiency of milling processes [1- 4]. Studying the milling process to find solutions to optimize surface roughness of workpiece has been done by many authors. Among them, the authors often focus on the study of the effect of cutting mode parameters on surface roughness. From there, there is a basis for controlling the milling process. Pham Thi Hoa et al. [5] tested milling aluminum alloy A6061; Erol Kilickap et al. [6] tested milling Ti-6242S alloy; Okokpujie Imhade et al. [7] tested milling aluminum alloys; Tien Dung Hoang et al. [8], Huu-That Nguyen et al. [9], Nguyen Thanh Binh et al. [10] tested SKD11 steel milling; Muhammmad Yasir et al. [11] tested milling AISI 316L steel; Dražen Bajić et al. [3] tested milling 42CrMo4 steel; Pathak et al. [12] tested milling Al-1Fe-1V-1Si and Al-2Fe-1V-1Si alloys; Hasan Gökkaya et al. [13] tested milling AA2014 (T4) alloy; Luis Wilfredo Hernández-González et al. [14] tested milling AISI 304 steel; ect.

This paper presents the study on the influence of cutting velocity, feed rate and depth of cut on surface roughness when milling XC42 steel. A surface roughness model was proposed in this study. The accuracy evaluation of the roughness model was also conducted in this study.

2. Milling test

2.1. Testing material

The testing material used in this study was XC42 alloy steel. This steel is often used to make machine parts that work under heavy loads, such as parts in cars, construction machines and mining machines. The equivalent symbols for this steel according to some standards are presented in Table 1. The chemical composition of this steel is shown in Table 2. The test sample is a cube with a size of 50 (mm).

Table 1. XC42 steel equivalent of countries

France	USA	Japan	Germany		U.K	Italy
AFNOR	AISI	JIS	W.nr	DIN	BS	UNI
XC42	1045	S45C	1.12	CK45	080M46	C45

Table 2. Chemical composition of XC42 steel

C	Si	Mn	Cr	Ni	Mo	V	Ti	B	Cu
0.44	0.23	0.65	0.15	0.15	0.04	0.01	0.001	0.0004	0.21

2.2. Milling machine and milling cutter

The testing machine used in this study is a vertical milling machine with the symbol TF-OSS (Figure 1). The cutting tool used in this study was a face milling cutter with a cut piece, the cut piece is made of hard alloy.

2.3. Design of experiment

The Box-Behnken test matrix was applied to design the tests. Three input parameters include cutting velocity, feed rate and depth of cut. Test matrix was designed with 15 tests, including 3 test points at the center. Each input signal will have three values corresponding to three encrypted values (Table 3), the test matrix is shown in Table 4.

2.4. Measuring device

The SJ-201 roughness tester has been used to measure roughness of test samples. For each test sample, roughness has been measured at least three times. The roughness value for each test is the average of successive measurements, also included in Table 4.

3. Influence of parameters on surface roughness

The minitab statistical software was used to analyze the data in Table 4. The results are presented in Table 5, Figures 2 and 3.

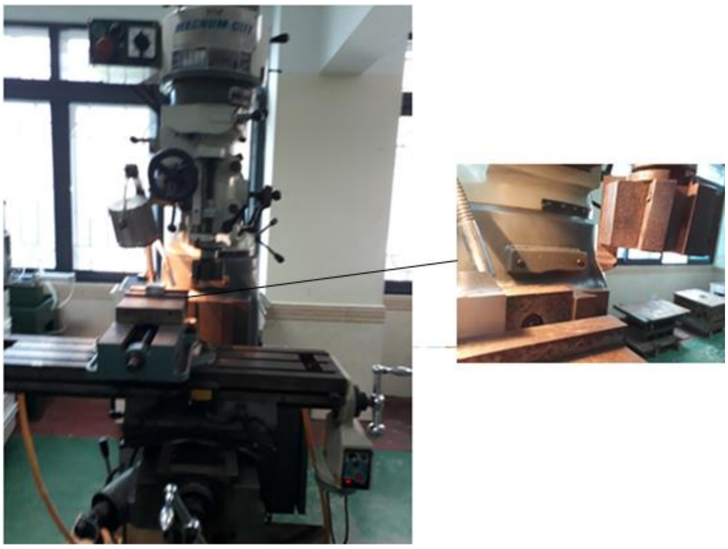

Fig 1. Milling machine

Table 3. Value at levels

Parameter	Symbol	Unit	Giá trị tại các mức		
			-1	0	1
Cutting velocity	v	m/min	80	140	200
Feed rate	f	mm/min	30	65	100
Depth of cut	t	t	0.2	0.35	0.50

Table 4. Experimental matrix and result

No.	Code value			Actual value			Surface roughness
	v	f	t	v (m/min)	f (mm/min)	t (mm)	Ra (µm)
1	0	-1	-1	140	30	0.2	1.12
2	1	-1	0	200	30	0.35	0.82
3	0	1	1	140	100	0.50	2.40
4	0	1	-1	140	100	0.2	2.50
5	-1	-1	0	80	30	0.35	1.48
6	-1	0	-1	80	65	0.2	2.28
7	1	1	0	200	100	0.35	1.90
8	0	0	0	140	65	0.35	1.52
9	1	0	1	200	65	0.50	1.08
10	1	0	-1	200	65	0.2	0.99
11	0	0	0	140	65	0.35	1.68
12	-1	1	0	80	100	0.35	2.88
13	0	-1	1	140	30	0.50	0.88
14	-1	0	1	80	65	0.50	2.35
15	0	0	0	140	65	0.35	1.46

Table 5. Analysis results

Response Surface Regression: Ra versus v, f, t

The analysis was done using coded units.

Estimated Regression Coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	1.55333	0.11105	13.988	0.000
v	-0.52500	0.06800	-7.720	0.001
f	0.67250	0.06800	9.890	0.000
t	-0.02250	0.06800	-0.331	0.754
v*v	0.08333	0.10010	0.833	0.443
f*f	0.13333	0.10010	1.332	0.240
t*t	0.03833	0.10010	0.383	0.717
v*f	-0.08000	0.09617	-0.832	0.443
v*t	0.00500	0.09617	0.052	0.961
f*t	0.03500	0.09617	0.364	0.731

S = 0.192337 PRESS = 2.6038
R-Sq = 96.98% R-Sq(pred) = 57.52% R-Sq(adj) = 91.55%

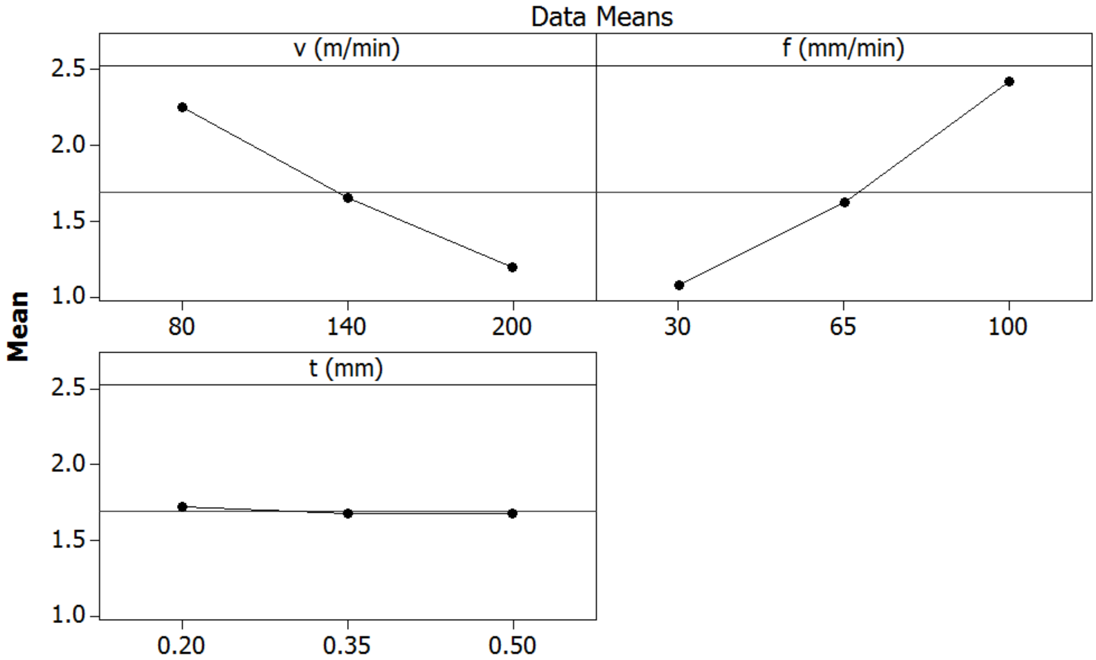

Fig 2. Main effects for surface roughness

The results in Table 5 shows:

- The feed rate is the parameter that has the greatest influence on the surface roughness, when the feed rate increases, the surface roughness increases. The cutting velocity also has a significant influence on the surface roughness, when the cutting speed increases, the surface roughness decreases. The depth of cut has a negligible influence on the surface roughness because the probability coefficient P with a value of 0.754 is much larger than the significant level (normally the significance level α selected is 0.05). The graph depicting the influence of the parameters on surface roughness presented in Figure 2 will illustrate more clearly for these statements.

- The meticulous review shows that the interaction between parameters influencing surface roughness will gradually decrease in the order: the interaction between the cutting velocity and the feed rate, the interaction between the feed rate and the depth of cut, interaction between the cutting velocity and the depth of cut. However, these interactions do not significantly influence surface roughness. Figure 3 clearly shows these statements.

4. Surface roughness model

From the data in Table 5, the roughness model represents each relationship between surface roughness and cutting velocity, feed rate and depth of cut expressed by the following regression equation. In this model, the cutting parameters are taken in encrypted form. This equation has a determination coefficient R^2 = 0.9698, very close to 1. This model is used to calculate roughness and compare it with roughness values tested in Table 4, the results are illustrated in Figure 4.

Figure 4 shows the roughness value when calculated by formula (1) is very close to the value of test result. The average value of deviation between the calculated results and the test results is only about 6.76%. The largest deviation between the predicted results and the test results is only about 20.4%. This confirms that model (1) is very consistent with test data. This model is the basis for determining the value of the cutting velocity, the feed rate and the depth of cut to ensure a certain value of surface roughness.

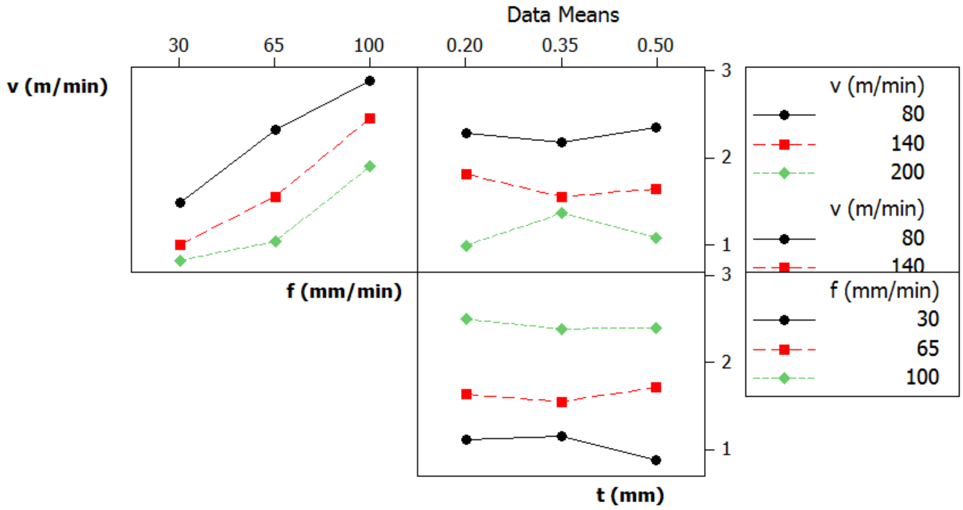

Fig 3. Interaction plot for surface roughness

$$Ra = 1.55333 - 0.525 \times v + 0.6725 \times f - 0.0225 \times t + 0.08333 \times v^2 + 0.13333 \times f^2 + 0.03833 \times t^2 - 0.08 \times v \times f + 0.005 \times v \times t + 0.035 \times f \times t \quad (1)$$

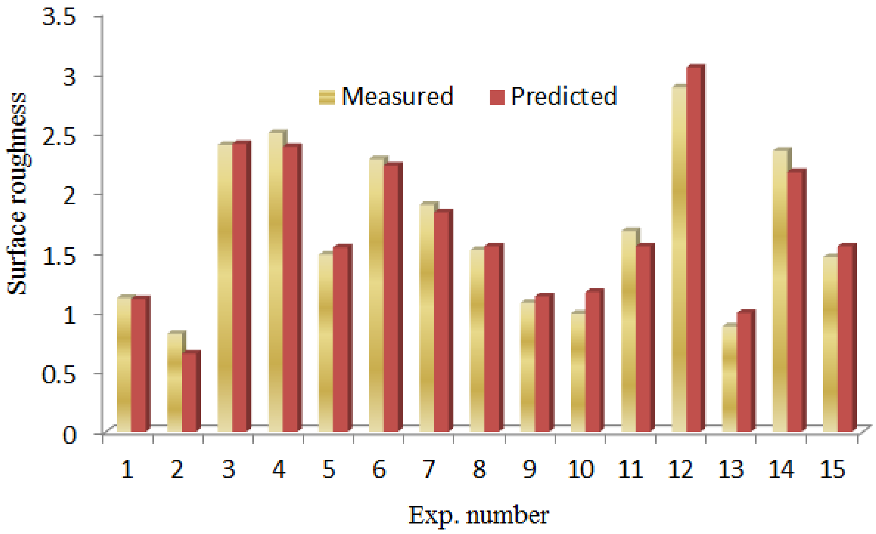

Fig 4. Value of surface roughness by Eq. (1) and in measurement

5. Conclusion

Some conclusions are drawn when milling XC42 steel by face milling cutter with hard alloy cut pieces as follows:

1) The feed rate is a parameter that greatly influences the surface roughness, when increasing the feed rate, the surface roughness increases. The cutting velocityalso has a significant influence on the surface roughness, when the cutting speed increases the surface roughness decreases. The depth of cut

and the interaction between the parameters have a negligible influence on the surface roughness.

2) A surface roughness model was proposed in this study. This model gives very high accuracy compared to the test results. This model allows prediction of surface roughness with each different value of cutting parameters. This model can also be used to determine the value of the cutting parameters to ensure surface roughness is reached at the desired value.

Acknowledgement

The work was supported by Vinh Long University of Technology Education (http://vlute.edu.vn/).

References

1. Eyup Bagci, Ercüment U. Yüncüoğlu (2017), *The Effects of Milling Strategies on Forces, Material Removal Rate, Tool Deflection, and Surface Errors for the Rough Machining of Complex Surfaces*, Strojniški vestnik - Journal of Mechanical Engineering Vol. 63, No. 11, pp. 643-656.
2. Mohammed T. Hayajneh, Montasser S. Tahat, Joachim Bluhm (2007), *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, No. 1, pp. 1-5.
3. Dražen Bajić, Luka Celent, Sonja Jozić (2012), *Modeling of the Influence of Cutting Parameters on the Surface Roughness*, Tool Wear and Cutting Force in Face Milling in Off-Line Process Control, Strojniški vestnik - Journal of Mechanical Engineering 58, Vol. 11, pp. 673-682.
4. Rui Wang, Bingxu Wang, Gary C. Barber, Jie Gu, J.David Schall (2019), *Models for Prediction of Surface Roughness in a Face Milling Process Using Triangular Inserts*, Lubricants, Vol. *7*, No. 9; doi:10.3390/lubricants7010009.
5. Pham Thi Hoa, Doan Thi Huong, Nguyen Quang Viet, Banh Tien Long, Nguyen Duc Toan (2016), *Study on effects of cutting parameters to the chip shrinkage coefficient and surface roughness when machining aluminum alloy A6061*, 5th national workshop of Science and technology, Ha Noi, Viet Nam
6. Erol Kilickap, Ahmet Yardimeden, Yahya Hı¸sman Çelik (2017), *Mathematical Modelling and Optimization of Cutting Force, Tool Wear and Surface Roughness by Using Artificial Neural Network and Response Surface Methodology in Milling of Ti-6242S*, Applied Sciences, Vol. *7*, No. 1064, doi:10.3390/app7101064
7. Okokpujie Imhade P., Okonkwo Ugochukwu C. (2013), *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, No. 5, pp. 2937-2943.
8. Tien Dung Hoang, Nhu-Tung Nguyen, Đuc Quy Tran, Van Thien Nguyen (2019), *Cutting Forces and Surface Roughness in Face-Milling of SKD61 Hard Steel*, Strojniški vestnik - Journal of Mechanical Engineering 65, Vol. 6, pp. 375-385.
9. Huu-That Nguyen and Quang-Cherng Hsu (2016), *Surface Roughness Analysis in the Hard Milling of JIS SKD61 Alloy Steel*, Applied Sciences, Vol. 6, No. 172, doi:10.3390/app6060172
10. Nguyen Thanh Binh, Nguyen Huy Ninh, Hoang Tien Dung (2015), *An investigation about the effect of cutting conditions to surfaces roughness when high-speed milling on the 5-axis machine UCP600*, Journal of science and technology, vol. 53, No.5 , pp. 671-678.
11. Muhammmad Yasir, Turnad Lenggo Ginta, Bambang Ariwahjoedi, Adam Umar Alkali, Mohd Danish (2016), *Effect of cutting spedd 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.
12. B. N. Pathak, K. L. Sahoo, and Madhawanand Mishra (2013), *Effect of Machining Parameters on Cutting Forces and Surface Roughness in Al-(1-2) Fe-1V-1Si Alloys*, Materials and Manufacturing Processes, No. 28, pp. 463–469.
13. Hasan Gökkaya (2010), *The Effects of Machining Parameters on Cutting Forces, Surface Roughness, Built-Up Edge (BUE) and Built-Up Layer (BUL) During Machining AA2014 (T4) Alloy*, Strojniški vestnik - Journal of Mechanical Engineering, Vol. 56, pp. 584-593.
14. Luis Wilfredo Hernández-González, Roberto Pérez-Rodríguez, Ana María Quesada-Estrada, Luminita Dumitrescu (2018), Effects of cutting parameters on surface roughness and hardness in milling of AISI 304 steel, DYNA, 85(205), pp. 57-63.