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Experiment Determines The Influence Of Cutting Mode Parameters On Surface Roughness When Milling S45C Steel

Do Thi Kim Lien[1], Phung Tran Dinh[2], Pham Thi Thu Hang[3], Can Trung Đinh[4], Le Ngoc Ha[5]
[1,2,3,4,5] Faculty of Mechanical and Construction Viet Hung University of Industry, Vietnam.
Email: kimlien.viu@gmail.com

***Abstract*—In this article, experimental research is presented to determine the influence of cutting parameters on surface roughness when milling S45C steel. Three cutting parameters were mentioned in this study including cutting speed, feed rate, and depth of cut. Surface roughness was selected as an indicator to evaluate the milling process in this study. The experimental process was performed on a vertical milling machine. The Box-Behnken experimental matrix was used to design the experiments with 18 experiments. Analyzing the experimental results has determined the influence of input parameters and their interaction on surface roughness. The cutting parameters optimization problem was also implemented in this study. Solving the problem has found the optimal value of the input parameters to ensure the surface roughness has the smallest value. The optimization results have been verified by the experimental process. Finally, the development direction for further research has also been mentioned in this article.**

Keywords—milling, S45C steel, surface roughness, cutting parameters, optimization

1. Introduction

Milling is a popular machining method, has high productivity, and is widely used in mechanical processing. Milling methods can be used to machine many different types of surfaces, with many different types of materials. Surface roughness has a great influence on the longevity of products, and it is often chosen as one of the criteria to evaluate the effectiveness of milling processes in particular and cutting processes in general [1-4]. Researching the milling process to find solutions to reduce surface roughness when milling has been done by many authors. Among them, the authors often focus on research on the influence of cutting parameters on surface roughness when milling. This is also easily explained because controlling the cutting parameters will be easier to do by the machine operator than adjusting other parameters. The results of those studies are the basis for selecting cutting parameters under each specific condition.

Experiments on the milling process of AISI 304 steel have been carried out in document No. [5], the results of this study have come to the following conclusion: both cutting speed and feed rate parameters greatly affect the surface roughness. In which the influence of cutting speed on surface roughness is greater than the influence of feed rate.

In document number [13], the milling of two types of alloys, Al-1Fe-1V-1Si and Al-2Fe-1V-1Si, was studied, and comments were made: All three parameters of cutting parameters (cutting speed, feed rate, and depth of cut) have almost negligible influence on surface roughness when milling 1Fe-1V-1Si alloy; When milling Al-2Fe-1V-1Si alloy, cutting parameters have a large influence on the Rz criterion. But for the Ra criterion, the cutting parameters have a negligible influence.

In document number [6], when milling AISI 316L SS steel using a milling cutter with inserts covered with a WC layer, it was shown that Both feed rate and cutting speed parameters have significantly affects surface roughness. In particular, the influence of the feed rate on surface roughness is greater than the influence of cutting speed; The rule of influence of feed rate and depth of cut on surface roughness is quite complex. Increasing the value of these two parameters sometimes increases, and sometimes decreases the value of surface roughness.

The research content was presented in document number [2] and concluded that the feed rate has the greatest influence on surface roughness, followed by the influence of cutting speed, and depth of cut has a smaller influence on surface roughness than the influence of feed rate and cutting speed; The interaction between feed rate and cutting depth has the strongest influence on surface roughness, followed by the influence of the interaction between cutting speed and feed depth, the interaction between cutting speed and cutting depth. Depth of cut has a negligible effect on surface roughness.

In study number [7], when studying milling of Ti-6242S alloy, the conclusion was reached: All three cutting parameters have a significant influence on surface roughness; If the increasing the value of feed rate and depth of cut, the surface roughness will increase. On the contrary, the surface roughness will decrease if the value of the cutting speed is increased.

In research number [8], milling of 6061 aluminum alloy was tested under conditions of minimum cooling lubrication (MQL) with high-speed steel knives and commented: The interaction between cutting speed and quantity of cutter has a great influence on surface roughness; Speed has a greater influence on surface roughness than the influence of feed rate.

Research results presented in document No. [9] have shown that: When milling SKD61 steel, all three parameters of the cutting parameters include cutting speed, feed rate, depth of cut, and material hardness. Machining has a significant influence on surface roughness.

In document number [3], milling experiments on 42CrMo4 steel were conducted using TiN-coated cutting tools. The conclusions of this study were shown as follows: Cutting speed has little effect on surface roughness; Regarding the feed rate, when machining with a fixed depth of cut, the influence of the feed rate on surface roughness is greater than when machining with a variable depth of cut.

In document No [10], it was shown that: When experimenting with milling AA2014 (T4) alloy, the feed rate has a significant effect on surface roughness, while the cutting speed has a negligible effect on surface roughness; Increasing the value of the feed rate will increase surface roughness. Meanwhile, the rule of influence of cutting speed on surface roughness is quite complicated. Increasing the value of cutting speed sometimes increases, and sometimes reduces the value of surface roughness.

From several general studies as above, it can be seen that although there have been many published studies investigating the influence of cutting parameters on surface roughness when milling. However, in each specific machining condition, the level and influence rules of cutting parameters on surface roughness are different. From there, it shows that for applying research results in production, it is necessary to conduct experimental research with each specific machining condition in terms of machining materials and cutting tool materials. In this article, research will be conducted to determine the influence of cutting parameters on surface roughness when milling S45C steel.

2. Milling process experiment

2.1. Experimental system

The experimental sample used is S45C steel (JIS – Japan standard). In Table 1, the equivalent symbols of this steel type according to several standards are presented. In Table 2, the chemical composition of steel is presented. The length, width, and height dimensions of the test sample are 80mm, 40mm, and 30mm, respectively.

Table 1. Equivalent symbol of S45C steel according to some countries

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

Table 2. Chemical composition of S45C steel

Composition (%)									
C	Si	Mn	Cr	Ni	Mo	V	Ti	B	Cu
0.43	0.22	0.66	0.18	0.12	0.04	0.02	0,001	0.008	0.2

The experimental machine used in this study is a vertical milling machine with the symbol JL-VH320B. Roughness meter SJ201 (Mytutoyo – Japan) was used during the experiment. At each experimental sample, measurements will be conducted at least three times. The surface roughness value at each experiment is the average value of consecutive measurements. During the measurement process, the machine's standard length is set to 0.8mm, and the measuring head diameter is set to 0.005mm

2.2. Experimental design

The Box-Behnken experimental matrix was used to design the experiments in this study. The input parameters of each experiment are cutting parameters, including cutting speed, feed rate, and cutting depth. Each parameter will have three value levels. The values of the parameters at the levels are chosen according to practical experience as shown in table 3. The experimental matrix includes 18 experiments presented in Table 4

Table 3. Cutting parameters

Parameter	Unit	code	Values at different levels		
			-1	0	1
Cutting speed	m/min	v	168	240	312
Feed rate	mm/tooth	f	0.12	0.24	0.36
Depth of cut	mm	a_p	0.336	0.48	0.624

Table 4. Experimental matrix

No.	Code value			Actual values			Surface roughness
	v	f	a_p	v (m/min)	f (mm/tooth)	a_p (mm)	Ra (µm)
1	0	0	0	240	0.24	0.48	0.775
2	0	1	1	240	0.36	0.624	1.683
3	1	0	-1	312	0.24	0.336	0.558
4	0	0	0	240	0.24	0.48	0.717
5	1	1	0	312	0.36	0.48	1.017
6	0	-1	-1	240	0.12	0.336	0.575
7	0	0	0	240	0.24	0.48	0.683
8	1	-1	0	312	0.12	0.48	0.600
9	0	0	0	240	0.24	0.48	0.725
10	0	-1	1	240	0.12	0.624	0.600
11	1	0	1	312	0.24	0.624	0.517
12	-1	1	0	168	0.36	0.48	0.992
13	0	0	0	240	0.24	0.48	0.683
14	-1	-1	0	168	0.12	0.48	0.692
15	-1	0	-1	168	0.24	0.336	0.683
16	0	1	-1	240	0.36	0.336	1.567
17	-1	0	1	168	0.24	0.624	0.850
18	0	0	0	240	0.24	0.48	0.733

2. Results and discussion

The experimental process was performed in the order shown in Table 4, the surface roughness value at each experiment has also been included in this table. Minitab 16 statistical software was used to build a graph of the influence of input parameters on surface roughness as shown in Figure 1. The interaction effect between input parameters on surface roughness is presented in Figure 2.

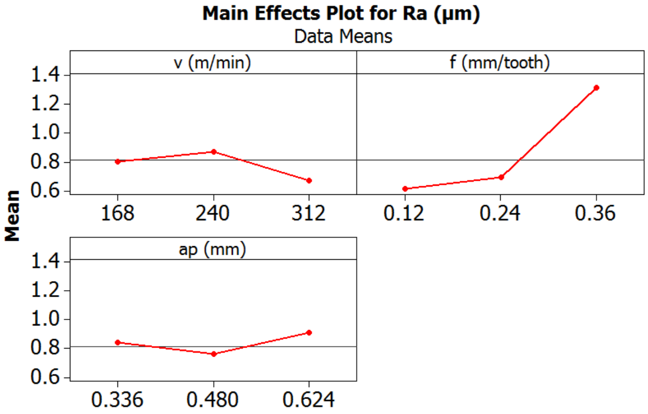

Fig 1. Influence of cutting parameters on surface roughness

Observing fig 1 shows:

- Of the three parameters surveyed, the feed rate is the parameter that has the greatest influence on surface roughness. Meanwhile, cutting speed and cutting depth have negligible influence on surface roughness. However, if considered in detail, it can be seen that the cutting speed has a greater influence on surface roughness than the influence of depth of cut.

When the feed rate increases, the surface roughness increases rapidly, this is also consistent with published studies on the milling process [12].

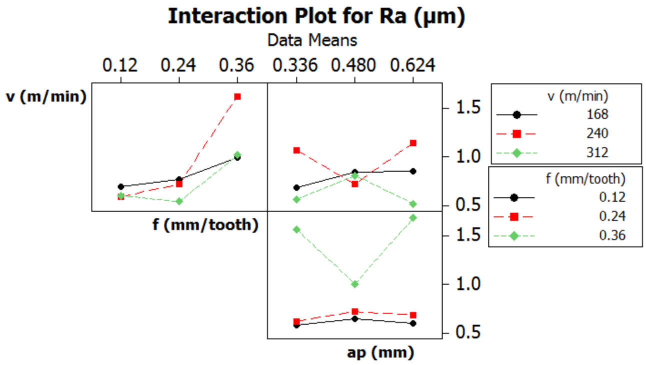

Fig 2. Effect of interactions between parameters on surface roughness

Observing figure 2 shows:

- When the cutting speed is 168 m/min: if the feed rate is increased, the surface roughness increases slowly.

- When the cutting speed is 240 m/min: when the feed rate increases from 0.12 to 0.24 mm/tooth, the surface roughness increases slowly, but if continue to increase the feed rate, the surface roughness increases rapidly.

- When the cutting speed is 312 m/min: when increasing the feed rate from 0.12 to 0.24 mm/tooth, the surface roughness decreases, but if the feed rate increases from 0.24 to 0.23 mm/tooth, the surface roughness increases rapidly.

- When machining with a cutting speed of 168 m/min: if the cutting depth is increased, the surface roughness will increase slowly.

- If the cutting speed is 240 m/min: surface roughness will decrease rapidly if the cutting depth increases from 0.336 to 0.480 mm, but if the cutting depth continues to increase, the surface roughness will increase rapidly.

- In the case of machining with a cutting speed of 312 m/min: when the cutting depth increases from 0.336 to 0.480 mm, the surface roughness increases rapidly, but if the cutting depth continues to increase, the surface roughness decreases rapidly.

- When the feed rate is 0.12 mm/tooth and 0.24 mm/tooth, the depth of cut has almost no effect on the surface roughness.

- When machining with a feed rate of 0.36 mm/tooth: if the depth of cut increases from 0.336 mm to 0.48 mm, the surface roughness will decrease rapidly, but if the depth of cut continues to increase, the surface roughness will increase fast.

3. Optimize the milling process

Minitab 16 statistical software was again used to solve the milling process optimization problem. The optimization graph is presented in Figure 3.

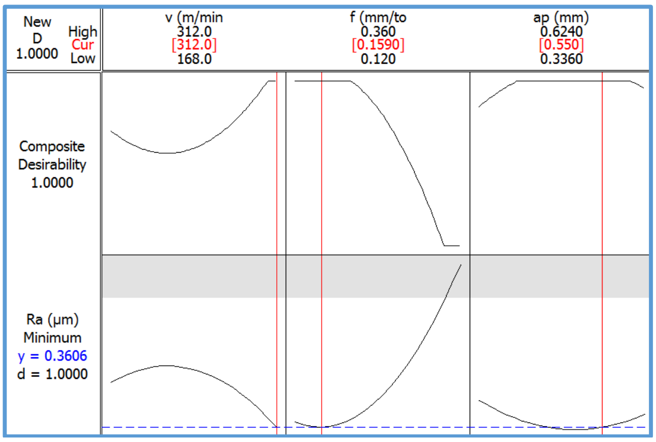

Fig 3. Optimization Graph

The results in Fig 3 show that the optimal values of cutting speed, feed rate, and depth of cut are 312 m/min, 0.159 mm/tooth, and 0.55 mm, respectively. The resulting expectation function has a value of 1, which means that the probability of achieving the smallest surface roughness when machining with the optimal set of cutting parameters is 100%. The optimal set of parameters was also used to conduct the milling process with 5 steel samples. The average value of surface roughness in 5 experiments is 0.368

µm. Thus, the difference between experimental and predicted results is only about 2.01%.

5. Conclusion

The experimental process of milling S45C steel was performed in this study. Determination of optimal values of cutting parameters has also been carried out. Some conclusions are drawn as follows:

- Of the three cutting parameters including cutting speed, feed rate, and cutting depth, only feed rate is the parameter that has a significant influence on surface roughness. When increasing the feed rate, the surface roughness increases rapidly. Cutting speed and depth of cut have negligible influence on surface roughness.

- The optimal values of cutting speed, feed rate, and depth of cut are 312 m/min, 0.159 mm/tooth, and 0.55 mm, respectively. When machining with these values of cutting parameters, the surface roughness has the smallest value, about 0.368 µm.

- Determining the values of cutting parameters to simultaneously ensure goals such as minimum surface roughness, minimum cutting force, and maximum material removal rate (MRR) sare directions for further research.

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