Experimental Investigation Into The Effect Of Cutting Parameters On Surface Roughness In EN9 Steel Milling

Nguyen Manh Ha*, Hoang Van Huynh
College of Economics and Techniques, Thainguyen University, Vietnam
*Email: hazin252555@gmail.com

Summary - *This paper presents an experimental investigation into the impact of cutting parameters on surface roughness during the milling of EN9 steel. Three key cutting parameters were considered: cutting speed, feed rate, and depth of cut. Surface roughness was used as a metric to evaluate the milling process. Experiments were conducted on a vertical milling machine, utilizing a Box-Behnken experimental design to generate 18 experimental runs. The influence of individual and interactive effects of the input parameters on surface roughness was analyzed. Subsequently, an optimization problem was formulated to identify the optimal parameter settings that minimize surface roughness. The optimized parameter values were validated through experimental verification. Finally, potential avenues for future research were discussed.*

Keywords- *milling, EN9 steel, surface roughness, cutting mode, optimization*

I. INTRODUCTION

Milling is a widely used machining process known for its high productivity and versatility in machining various surfaces and materials. Surface roughness, a critical factor influencing product longevity, is often used as a benchmark to evaluate the effectiveness of milling and other cutting processes. Numerous studies have explored the influence of cutting parameters on surface roughness to optimize milling operations. Previous research has investigated the impact of cutting parameters on the surface roughness of different materials, such as AISI 304 steel [5], Al-1Fe-1V-1Si and Al-2Fe-1V-1Si [13], AISI 316L SS steel [6], Ti-6242S alloy [7], 6061 aluminum alloy [8], SKD61 steel [9], 42CrMo4 steel [3], and AA2014 (T4) alloy [10]. These studies have generally concluded that cutting speed, feed rate, and depth of cut significantly affect surface roughness. However, the specific influence of each parameter and their interactions can vary depending on the material, cutting tool, and machining conditions. While these studies provide valuable insights, it's important to note that the optimal cutting parameters can differ significantly between different materials and machining setups. Therefore, conducting experimental research tailored to specific machining conditions, including material and tool selection, is crucial for achieving desired surface roughness and optimizing the milling process. This paper aims to contribute to this body of knowledge by investigating the influence of cutting parameters on surface roughness when milling EN9 steel.

II. MILLING PROCESS EXPERIMENT

The experimental sample used is EN9 steel (BS – England 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 EN9 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 EN9 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

The Box-Behnken mixed 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	0.930
2	0	1	1	240	0.36	0.624	2.020
3	1	0	-1	312	0.24	0.336	0.670
4	0	0	0	240	0.24	0.48	0.860
5	1	1	0	312	0.36	0.48	1.220
6	0	-1	-1	240	0.12	0.336	0.690
7	0	0	0	240	0.24	0.48	0.820
8	1	-1	0	312	0.12	0.48	0.720
9	0	0	0	240	0.24	0.48	0.870
10	0	-1	1	240	0.12	0.624	0.720
11	1	0	1	312	0.24	0.624	0.620
12	-1	1	0	168	0.36	0.48	1.190
13	0	0	0	240	0.24	0.48	0.820
14	-1	-1	0	168	0.12	0.48	0.830
15	-1	0	-1	168	0.24	0.336	0.820
16	0	1	-1	240	0.36	0.336	1.880
17	-1	0	1	168	0.24	0.624	1.020
18	0	0	0	240	0.24	0.48	0.880

III. 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.

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 part velocity 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].

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 you continue to increase the feed rate, the surface roughness increases rapidly.

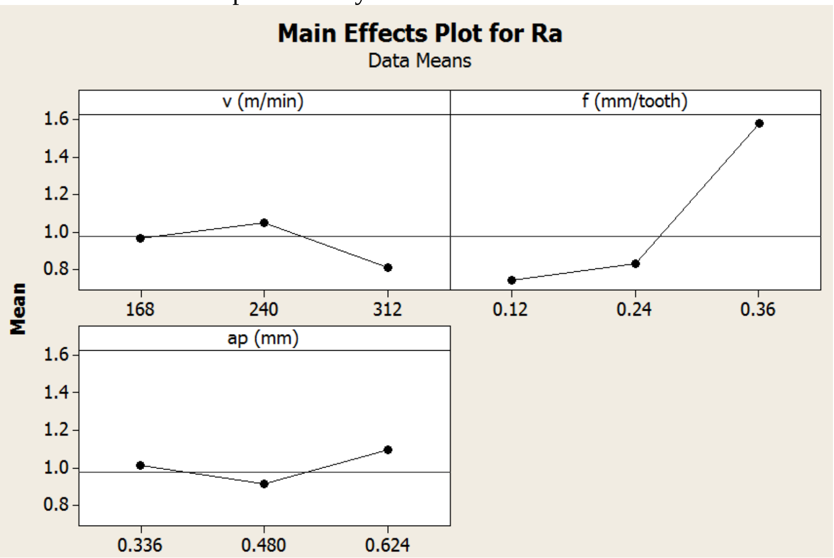

Fig 1. Influence of cutting parameters on surface roughness

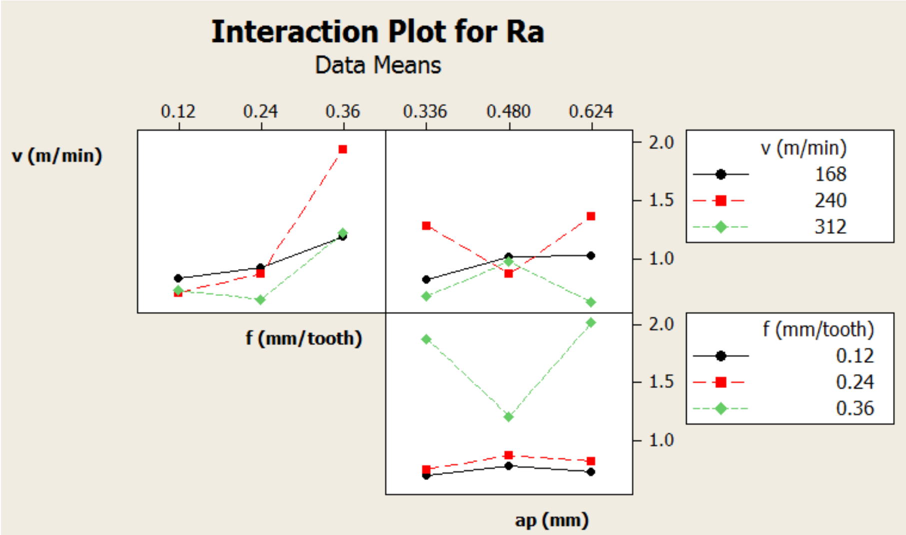

Fig 2. Effect of interactions between parameters on surface roughness

- 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.

IV. 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.

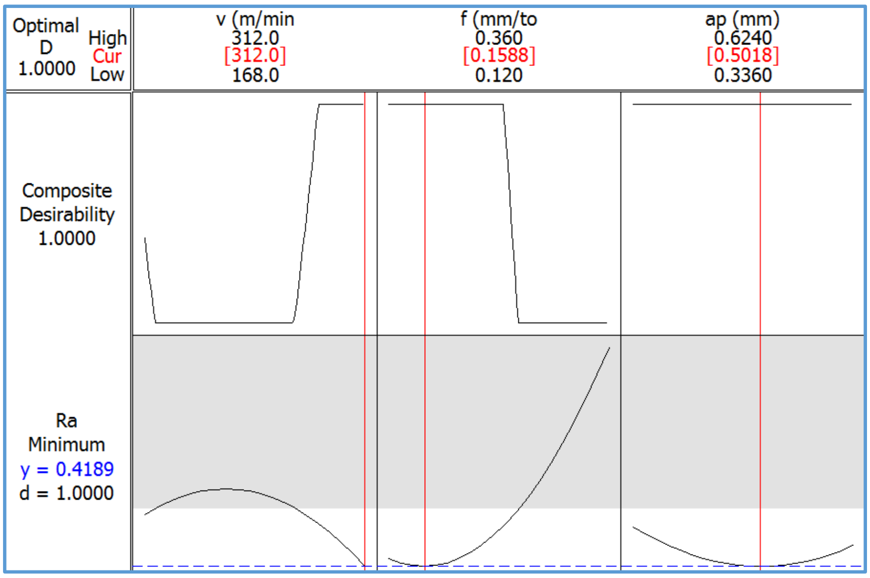

Fig 3. Optimization Graph

The results in Fig 3 show that the optimal values of cutting speed, feed rate, and depth of cut are 312 m/min, 0.1588 mm/tooth, and 0.5018 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 0.4189 µm. Thus, the difference between experimental and predicted results is only about 1.21%.

V. CONCLUSION

The experimental process of milling EN9 steel was performed in this study. Determination of optimal values of cutting mode parameters has also been carried out. Some conclusions are drawn as follows:

- Of the three cutting mode 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, 0.1588 mm/tooth, and 0.5018 mm, respectively. When machining with these values of cutting parameters, the surface roughness has the smallest value, about 0.4189 μm.
- Determining the values of cutting parameters to simultaneously ensure goals such as minimum surface roughness, minimum cutting force, and maximum material removal capacity are directions for further research.

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