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Optimizing Cutting Parameters for Surface Grinding of SUS440C Steel

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Abstract *- Surface roughness is a crucial parameter that significantly influences the performance and service life of machined components. This study aimed to determine the optimal values of cutting parameters for surface grinding of SUS440C steel. A total of 15 experiments were conducted based on a Box-Behnken experimental design. The input parameters, including workpiece speed, feed rate, and depth of cut, were varied in each experiment. Surface roughness was measured at each experiment. The effects of individual cutting parameters and their interactions on surface roughness were analyzed. Subsequently, a regression model representing the relationship between surface roughness and cutting parameters was established. A genetic algorithm (GA) was employed to solve the optimization problem and determine the optimal values of cutting parameters to minimize surface roughness.*

Keywords *- Surface grinding, SUS440C steel, surface roughness, optimization, genetic algorithm.*

I. INTRODUCTION

In general mechanical machining, grinding is the most commonly used method when high precision and low roughness surfaces are required [1]. Plane grinding is often used to machine many flat surfaces on components in various industries such as automotive, mining, mold making, etc. [2]. Among many parameters to evaluate the plane grinding process such as surface roughness, cutting force, cutting temperature, surface layer structure, cutting productivity, etc., surface roughness is the most commonly used parameter [3, 4]. The reason is that surface roughness has a great influence on the working ability as well as the service life of the component surface [5-7], and on the other hand, measuring surface roughness is considered simpler than measuring other parameters such as cutting force or cutting temperature [8-10]. To create a component surface with low roughness, many studies have optimized the cutting mode when grinding different types of materials, such as optimizing the cutting mode when grinding En24 steel [11], optimizing the cutting mode when grinding ШХ15 steel [12], optimizing the cutting mode when grinding ASTM A36 steel [13], optimizing the cutting mode when grinding 90CrSi steel [14], optimizing the cutting mode when grinding AISI 316 steel [15], optimizing the cutting mode when grinding Mild steel [16], etc.

SUS440C steel is a type of stainless steel with high wear resistance, which is a type of steel designated according to the Japanese JIS-G4303 standard. This type of steel is equivalent to 440C steel according to the American ASTM A276 standard, equivalent to 9Cr18Mo steel according to the Chinese GB standard. This type of steel is often used to manufacture components requiring high precision such as load-bearing components operating in corrosive and strongly oxidizing environments without lubrication, and various types of dies.

This study optimizes the cutting mode when grinding SUS440C steel to ensure the lowest possible surface roughness. Section 2 of this article presents the experimental system and how to build the experimental matrix. The experimental results and analysis of the experimental results are presented in Section 3. The conclusions drawn are the content in the final part concluding this study.

II. MATERIALS AND METHODS

2.1 Workpiece

The workpiece was SUS440C steel with the main chemical composition as shown in Table 1. The steel workpiece had dimensions of 50 mm in length, 30 mm in width, and 10 mm in height.

2.2 Experimental Setup

Figure 1 shows a photograph of the flat grinding machine used in the experiment, model APSG-820/8A manufactured by ACRA, Taiwan.

Surface roughness was measured three times in each experiment using an SJ201 surface tester (Figure 2), and the surface roughness in each experiment was calculated as the average of the consecutive measurements.

2.3 Experimental Design

The experimental matrix was constructed in a Box-Behnken design, which is a commonly used design for optimization experiments [17]. In this design, each input parameter includes three values corresponding to three coded levels -1, 0, and 1. The values of the input parameters at the levels were selected according to some published literature and summarized in Table 2 [18, 19]. The experimental matrix with a total of 15 experiments is summarized in Table 3.

TABLE 1: Chemical composition of SUS440C steel

C(%)	**Si (%)**	**Mn (%)**	**P (%)**	**S (%)**	**Cr (%)**	**Ni (%)**	**Mo (%)**
0.95 - 1.20	≤ 1.00	≤ 1.00	≤ 0.04	≤ 0.03	16 - 18	≤ 0.06	≤0.75

Figure 1: APSG-820/8A flat grinding machine

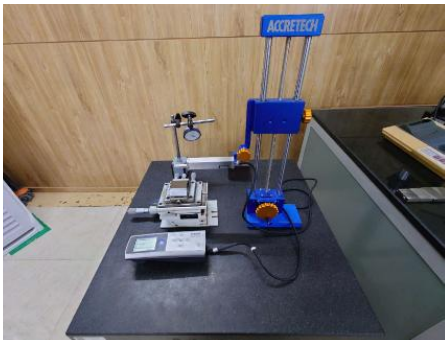

Figure 2: SJ201 surface tester

TABLE 2: Values of cutting parameters at different levels

Parameter	**Unit**	**Code symbol**	**Real symbol**	**Value at level**		
				-1	0	1
Workpiece velocity	m/ min	x_1	V	5	8	11
Feed-rate	mm/ stroke	x_2	S	3	5	7
Depth of cut	mm	x_3	t	0.01	0.015	0.02

TABLE 3: Experimental matrix

Exp.	**Code value**			**Real value**		
	x_1	**x_2**	**X_3**	**V (m/min)**	**S (mm/stroke)**	**t (mm)**
1	0	1	1	8	7	0.02
2	0	0	0	8	5	0.015
3	0	0	0	8	5	0.015
4	1	0	1	11	5	0.02
5	-1	-1	0	5	3	0.015
6	0	-1	-1	8	3	0.01
7	0	1	-1	8	7	0.01
8	1	-1	0	11	3	0.015
9	1	0	-1	11	5	0.01
10	-1	1	0	5	7	0.015
11	1	1	0	11	7	0.015
12	-1	0	-1	5	5	0.01
13	0	-1	1	8	3	0.02
14	-1	0	1	5	5	0.02
15	0	0	0	8	5	0.015

III. RESULTS AND DISCUSSION

Experiments were conducted in the order specified in Table 3, and the results are presented in Table 4.

Minitab 16 statistical software was used to compare the influence of each parameter on surface roughness, and the results are shown in Figure 3.

Figure 3 shows that the feed rate has a significant impact on surface roughness, followed by the depth of cut, and finally the workpiece speed.

TABLE 4: Experimental results

Exp.	**Cutting parameter**			**Surface roughness**			
	V (m/min)	**S (mm/stroke)**	**T (mm)**	**Ra_1 (µm)**	**Ra_2 (µm)**	**Ra_3 (µm)**	**Ra (µm)**
1	8	7	0.02	1.098	1.043	0.906	1.016
2	8	5	0.015	0.695	0.668	0.704	0.689
3	8	5	0.015	0.669	0.658	0.641	0.656
4	11	5	0.02	0.618	0.641	0.653	0.637
5	5	3	0.015	0.433	0.480	0.442	0.452
6	8	3	0.01	0.462	0.469	0.471	0.467
7	8	7	0.01	0.586	0.599	0.552	0.579
8	11	3	0.015	0.542	0.603	0.574	0.573
9	11	5	0.01	0.638	0.606	0.579	0.608
10	5	7	0.015	0.601	0.600	0.614	0.605
11	11	7	0.015	0.928	0.918	0.904	0.917
12	5	5	0.01	0.757	0.770	0.764	0.764
13	8	3	0.02	0.676	0.663	0.633	0.657
14	5	5	0.02	0.726	0.793	0.732	0.750
15	8	5	0.015	0.761	0.761	0.757	0.760

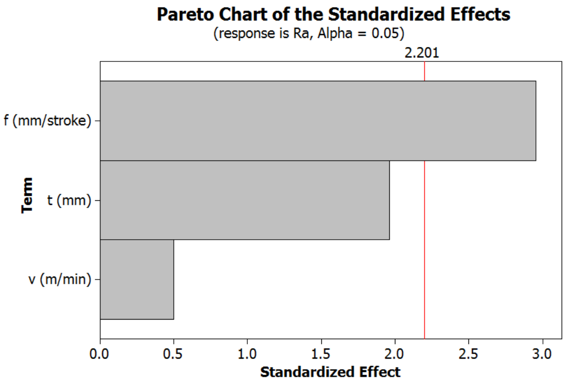

Figure 3: Influence of parameters on surface roughness

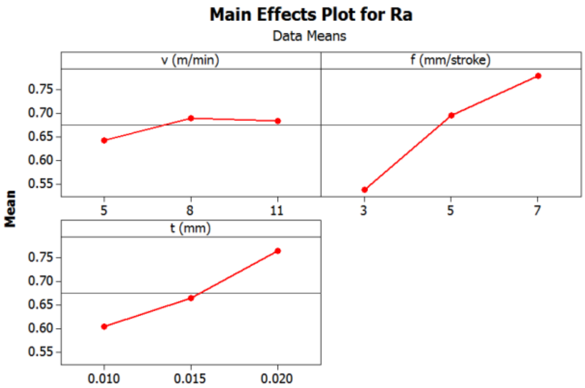

Figure 4: Effect of each cutting parameter on surface roughness

Figures 4 and 5 respectively show the independent effects of each cutting parameter and the interaction effects between each pair of cutting parameters on surface roughness.

Figure 4 shows that as the values of the cutting parameters increase, the value of surface roughness also increases. Notably, increasing the feed rate causes surface roughness to increase rapidly. Similarly, increasing the depth of cut also causes roughness to increase rapidly.

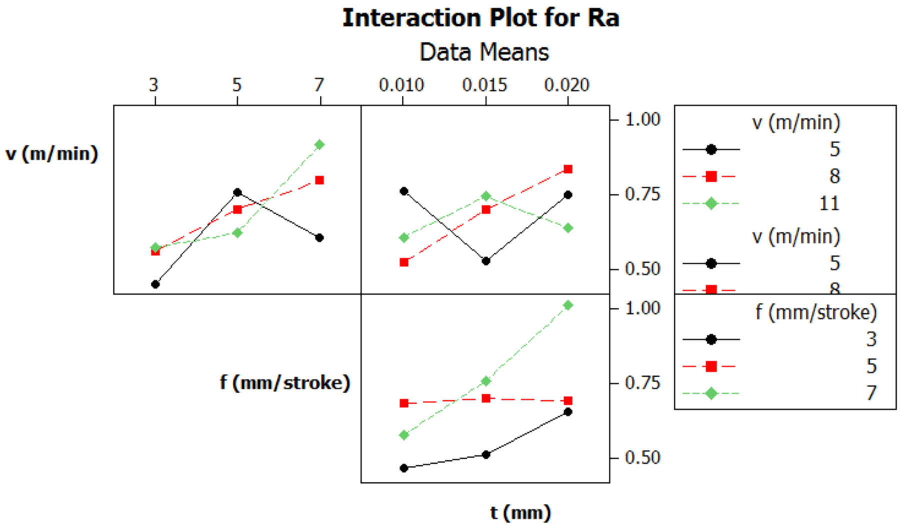

Figure 5: Interaction effect of parameters on surface roughness

Figure 5 shows that the interaction effect of pairs of cutting parameters on surface roughness is very complex. Specifically:

When the workpiece speed is 5 m/min, if the feed rate is increased from 3 mm/stroke to 5 mm/stroke, the roughness increases rapidly, but if the feed rate continues to increase, the roughness decreases rapidly.

In the two cases when the workpiece speed is 8 m/min and 11 m/min, if the feed rate is increased, the surface roughness increases.

When the cutting speed is 5 m/min, if the depth of cut increases from 0.01 mm to 0.015 mm, the roughness decreases, but if the depth of cut continues to increase, the roughness increases rapidly.

In the case of a workpiece speed of 8 m/min, if the depth of cut increases, the surface roughness increases very rapidly.

When the cutting speed is 11 m/min, if the depth of cut increases from 0.01 mm to 0.015 mm, the roughness increases rapidly, but if the depth of cut continues to increase, the roughness decreases rapidly.

When the feed rate is 3 mm/stroke or 7 mm/stroke, if the depth of cut increases, the surface roughness also increases. However, in the case of a feed rate of 5 mm/stroke, the change in depth of cut has a negligible effect on surface roughness.

The above observations show that the influence of the cutting parameters and the interaction between them on surface roughness is very complex. This leads to the need to solve an optimization problem to ensure a low surface roughness.

From the experimental results, the regression equation of surface roughness was constructed as shown in equation (1). Note that in this equation, x1, x2, and x3 represent the coded form of the cutting parameters.

$$\begin{aligned} R_a = 0.7016 &+ 0.0205x_1 + 0.1209x_2 + 0.0804x_3 \\ &- 0.0275x_1^2 - 0.0374x_2^2 \\ &+ 0.0157x_3^2 + 0.0476x_1x_2 \\ &+ 0.0108x_1x_3 + 0.0617x_2x_3 \end{aligned} \quad (1)$$

The GA algorithm was used to solve the optimization problem. To solve the optimization problem using the GA algorithm, the parameters including population size, maximum generation, crossover probability, mutation probability, and mutation parameter were selected with corresponding values of 150, 100, 0.25, 0.05, and 4 [20, 21]. Figure 6 illustrates the graph of the change in surface roughness during the process of gene individuals mating. Accordingly, the minimum surface roughness is 0.4748 mm, corresponding to the values of the parameters x1 = 0.9999, x2 = -0.9998, and x3 = -0.9402.

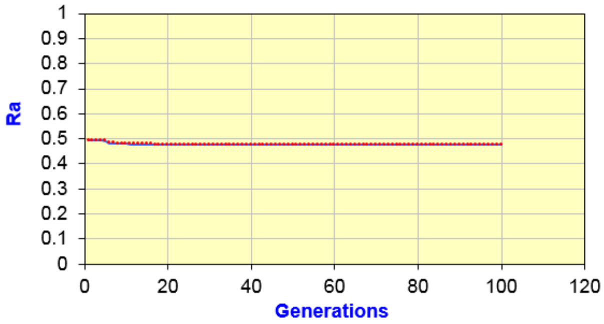

Figure 6: Change in surface roughness

Thus, the optimal values of workpiece speed, feed rate, and depth of cut are 10.99 m/min, 3.0 mm/stroke, and 0.011 mm, respectively.

IV. CONCLUSION

This study conducted flat grinding experiments on SUS440C steel, varying three cutting parameters in each experiment: workpiece speed, feed rate, and depth of cut. The GA algorithm was employed to solve the optimization problem. Several conclusions can be drawn:

- ✓ Feed rate has the most significant impact on surface roughness, followed by depth of cut, and finally workpiece speed.
- ✓ To ensure a low surface roughness, the optimal values are: workpiece speed of 10.99 m/min, feed rate of 3.00 mm/stroke, and depth of cut of 0.011 mm.

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