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Effect of Cutting Parameters on Surface Roughness in External Cylindrical Grinding of SUJ2 Steel

Nguyen Duy Chien[1], Do Thi Kim Lien[2]
[1,2]Faculty of Mechanical Engineering, Viet Hung Industrial University, Vietnam
*Email: kimlien.viu@gmail.com

***Abstract*— *This paper presents a study on the influence of cutting parameters on surface roughness when externally grinding SUJ2 steel using an Al_2O_3 grinding wheel. Three characteristic cutting parameters are considered in this study: workpiece speed, depth of cut, and longitudinal feed rate. The parameter chosen to evaluate the grinding process is the surface roughness of the workpiece. Experiments were conducted with 15 experimental points according to a Box-Behnken experimental design. After analyzing the experimental results, it was determined that all three cutting parameters have a significant effect on surface roughness. The degree of influence of the interaction between cutting parameters on surface roughness was also analyzed in this study. This study also established a regression model for the relationship between surface roughness and cutting parameters, with a determination coefficient of 96.69%. This relationship is the basis for selecting and controlling the values of cutting parameters to achieve the required surface roughness of the workpiece. Finally, the directions for further research are also mentioned in this paper*.

***Keywords*— *External cylindrical grinding of SUJ2 steel, Al_2O_3 grinding wheel, cutting parameters, surface roughness*.

I. INTRODUCTION

In mechanical machining, external cylindrical grinding is a commonly used method, often used for finishing important surfaces [1-4]. The quality of the surface when externally grinding is evaluated through many parameters. Among them, surface roughness has a great influence on the working ability of the machine part and is often used as an indicator to evaluate the quality of the workpiece [1-4]. SUJ2 steel is a type of material widely used in machine manufacturing to manufacture stamping dies, cutting tools, etc., thanks to its outstanding advantages: high hardness, high wear resistance, low quenching stress... [5]. Research on the fine grinding of SUJ2 steel has been conducted by a number of studies: Research on cutting force, surface roughness, and grinding chip thickness when using minimum lubrication-cooling technology [6]; The influence of cutting parameters on the surface layer hardness when grinding with CBN wheel [7, 8]; The influence of cutting parameters on cutting force when grinding with interrupted grinding wheel (non-continuous grinding wheel) [9]; Evaluation of the machinability of metal-bonded CBN grinding wheels manufactured by electroplating in Vietnam [10]; The influence of cutting parameters on surface roughness when grinding with CBN wheel [11]; etc. Al_2O_3 grinding wheel manufactured by Hai Duong Grinding Wheel Joint Stock Company (Vietnam) is a commonly used wheel in the mechanical machining industry in Vietnam. In addition, this type of wheel is also being exported to countries such as Sri Lanka, Indonesia, and South Korea with a relatively large annual output. However, there is currently no published research on the effect of cutting parameters on surface roughness when externally grinding SUJ2 steel with an Al_2O_3 grinding wheel. In this paper, experimental research is conducted to determine the level of influence of cutting parameters on surface roughness when grinding SUJ2 steel on an external cylindrical grinding machine with an Al_2O_3 grinding wheel.

II. EXPERIMENTAL SYSTEM

The experiments were conducted on a cylindrical grinding machine, using Al2O3 grinding wheels.

The workpiece material was SUJ2 steel. Before the experiment, the samples were machined through turning, heat treatment to achieve a hardness of 58HRC, and semi-finishing grinding, similar to actual production processes. The test samples had a diameter of Ø30. The chemical composition of the main elements of SUJ2 steel after heat treatment is presented in Table 1.

TABLE 1. Chemical composition of the main elements of SUJ2 steel

Element	C	Mn	Si	Cr	V	Mo	Ni
%	1,46	0,34	0,23	12,5	0,23	0,46	0,28

Measuring equipment: SJ201 surface roughness tester manufactured by Mitutoyo, Japan (Figure 1).

Figure 1. SJ201 surface roughness tester

Coolant: Tectylcool-240 5% solution, flood cooling method, flow rate of 40 liters/minute.

Dressing tool: Multi-point diamond dresser with the code 3908-0088C.

III. EXPERIMENTAL DESIGN

The experiment was conducted according to a Box-Behnken design, a commonly used experimental design for optimization

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experiments [12]. The input parameters were carefully chosen to ensure optimal grinding of high-hardness materials, in line with the capabilities of the experimental machine. The values at the coded levels of the experimental variables are shown in Table 2.

TABLE 2. Values at the coded levels of the experimental variables

Parameter	Symbol	Unit	Value at levels		
			-1	0	1
Workpiece velocity	v	m/min	22	26	30
Depth of cut	t	mm	0.01	0.02	0.03
Feed rate	f	mm/rev	4	6	8

TABLE 3. Experimental design matrix

Trial.	Code value		
	v	t	f
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

A Box-Behnken experimental design for 3 experimental variables (v, t, f) in the coded form of the parameters was created using Minitab 16 software as shown in Table 3.

IV. Results and Discussion

The grinding experiments on SUJ2 steel were conducted according to the sequence in Table 3. At each experimental point, three samples were ground, and the surface roughness of each sample was measured at least three times. The surface roughness value at each experimental point is the average of the consecutive measurements, and the results are presented in Table 4.

TABLE 4. Experimental results

Trial.	Cutting parameters						R_a (μm)
	Code value			Real value			
	v	t	f	v (m/min)	t (mm)	f (mm/rev)	
1	-1	-1	0	22	0.01	6	0.83
2	1	-1	0	30	0.01	6	0.90
3	-1	1	0	22	0.03	6	1.55
4	1	1	0	30	0.03	6	2.56
5	-1	0	-1	22	0.02	4	1.66
6	1	0	-1	30	0.02	4	1.48
7	-1	0	1	22	0.02	8	1.68
8	1	0	1	30	0.02	8	2.96
9	0	-1	-1	26	0.01	4	1.13
10	0	1	-1	26	0.03	4	1.01
11	0	-1	1	26	0.01	8	1.59
12	0	1	1	26	0.03	8	3.09
13	0	0	0	26	0.02	6	0.96
14	0	0	0	26	0.02	6	0.98
15	0	0	0	26	0.02	6	0.90

From the data in Table 4, the results of the ANOVA analysis for surface roughness are presented in Table 5.

TABLE 5. Results of ANOVA analysis

	df	SS	MS	F	Significance F			
Regression	9	7.6559	0.8507	16.2364	0.0034			
Residual	5	0.2620	0.0524					
Total	14	7.9178						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.9467	0.1322	7.1635	0.0008	0.6070	1.2864	0.6070	1.2864
v	0.2733	0.0809	3.3770	0.0197	0.0653	0.4813	0.0653	0.4813
t	0.4689	0.0809	5.7943	0.0022	0.2609	0.6769	0.2609	0.6769
f	0.5053	0.0809	6.2446	0.0015	0.2973	0.7134	0.2973	0.7134
v * v	0.3786	0.1191	3.1781	0.0246	0.0724	0.6848	0.0724	0.6848
t * t	0.1376	0.1191	1.1548	0.3004	-0.1686	0.4438	-0.1686	0.4438
f * f	0.6209	0.1191	5.2120	0.0034	0.3146	0.9271	0.3146	0.9271
v * t	0.2363	0.1144	2.0644	0.0939	-0.0579	0.5305	-0.0579	0.5305
v * f	0.3659	0.1144	3.1975	0.0241	0.0718	0.6601	0.0718	0.6601
t * f	0.4035	0.1144	3.5260	0.0168	0.1093	0.6977	0.1093	0.6977

The results in Table 4 show that:

- All three cutting parameters - workpiece speed, depth of cut, and feed rate - greatly influence the surface roughness. This is more evident when observing Figure 2. Specifically, for workpiece speed, when the workpiece speed increases from 22 m/min to 26 m/min, the surface roughness changes little. However, when the cutting speed value increases from 26 m/min onwards, the surface roughness increases rapidly. For the depth of cut, when the value of the depth of cut increases, the surface roughness increases rapidly. When the feed rate increases from 4 mm/rev to 6 mm/rev, the surface roughness changes little, but if the value of the feed rate increases from 6 mm/rev onwards, the surface roughness increases very rapidly.

- Regarding the interaction effects between the parameters: the interaction between the depth of cut and the feed rate has the greatest effect on surface roughness, followed by the level of influence of the interaction between the workpiece speed and the feed rate. The interaction between the workpiece speed and the depth of cut has little effect on surface roughness. Observing Figures 3, 4, and 5 will further clarify these observations.

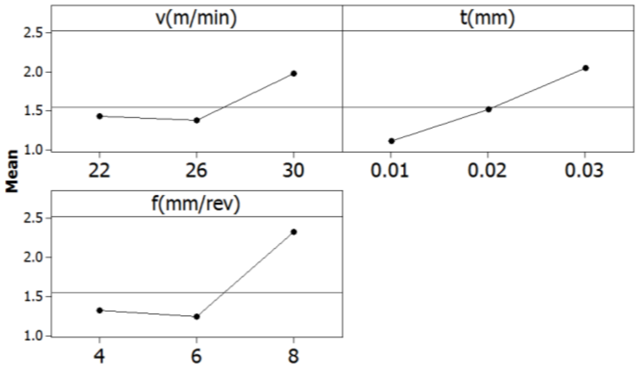

Figure 2. Effect of parameters on Ra

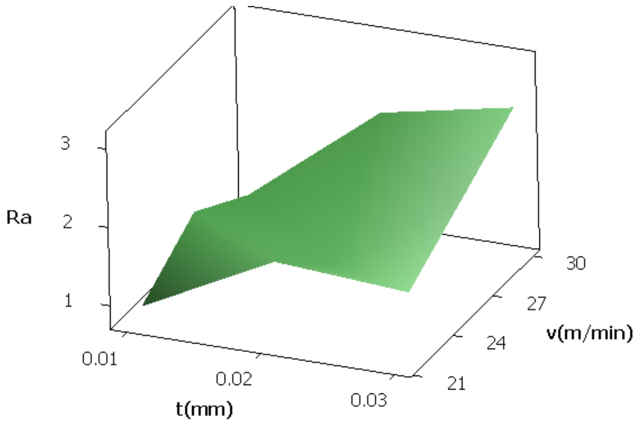

Figure 3. Interaction effect of parameters v and t on Ra

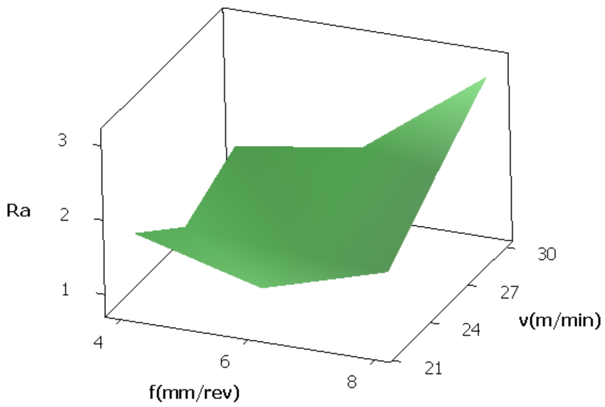

Figure 4. Interaction effect of parameters v and f on Ra

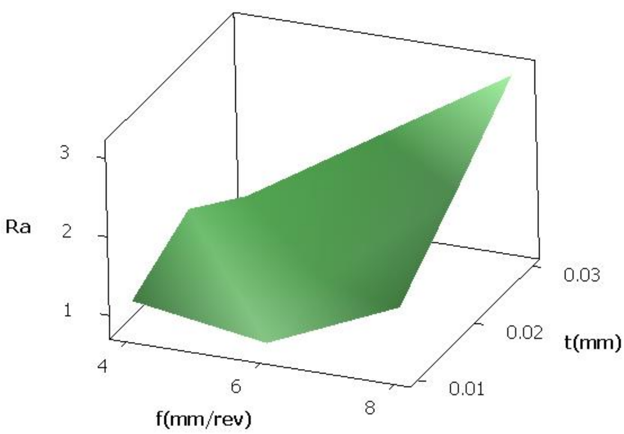

Figure 5. Interaction effect of parameters t and f on Ra

Also, from the results in, the relationship between surface roughness and cutting parameters is expressed in the form of a regression equation in formula (1), in which the cutting parameters are determined according to the coded value. This equation has a determination coefficient R2 = 0.9669, very close to 1, which proves that equation (1) has a very high fit (compatibility) compared to the experimental data. Using this relationship to predict surface roughness, then comparing it with the experimental value. The results are illustrated in Figure 6.

$$Ra = 0.9467 + 0.2733*v + 0.4689*t + 0.5053*f + 0.3786\,v^2 + 0.1376*t^2 + 0.6209*f^2 + 0.2363*v*t + 0.3659*v*f + 0.4035*t*f \quad (1)$$

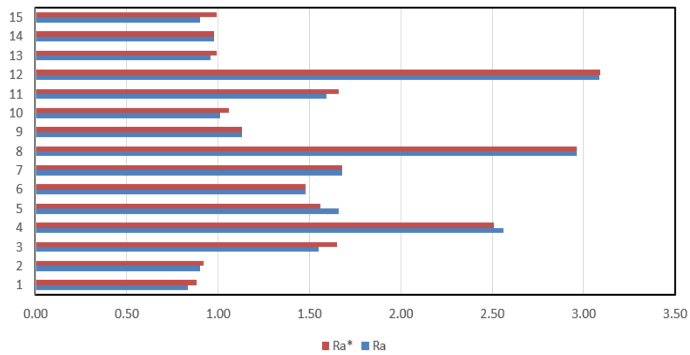

Figure 6. Surface roughness values when experimenting and when calculated according to equation (1)

Observing Figure 6, it can be seen that the surface roughness value calculated according to equation (1) is very close to the value when experimenting. The average deviation between the calculated results and the experimental results is only about 6.12%. This shows that the regression model presented in formula (1) is completely suitable for use in predicting surface roughness when grinding SUJ2 steel with an Al2O3 grinding wheel on a cylindrical grinding machine.

V. CONCLUSIONS

Several conclusions can be drawn from this study:

- ✓ The grinding process of SUJ2 steel with Al2O3 grinding wheel was conducted in this study to determine the influence of cutting parameters, including workpiece speed, depth of cut, and feed rate, on surface roughness. The influence of the interaction between cutting parameters on surface roughness was also investigated. This study has also established the relationship between surface roughness and cutting parameters, which is the basis for selecting the values of cutting parameters to ensure the value of surface roughness of the workpiece in each specific case.
- ✓ The effects of dressing parameters, coolant technology on surface roughness and the determination of the optimal values of process parameters to achieve a workpiece surface with low roughness are the directions for further research.

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