Investigation of The Effects of Cutting Parameters on Surface Roughness When Grinding 3X13 Steel using CBN Grinding Wheel

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***Abstract*—This paper presents experimental study to survey the effect of cutting parameters on surface roughness when 3X13 steel grinding with CBN grinding wheel. The cutting parameters mentioned in this study include velocity of workpiece, feed-rate and depth of cut. Experimental grinding process based on the Box-Behnken experimental design. Analysis of test results with Minitab 16 statistical software show that the velocity of workpiece has the greatest effect on surface roughness, followed by the insignificant effects of feed-rate, depth of cut on surface roughness. In addition, the study builds the relationship between surface roughness and cutting parameters. This relation allows to predict the surface roughness when 3X13 steel grinding by CBN grinding wheel.**

Keywords — Surface grinding; cutting parameter; 3X13 steel; CBN grinding wheel

I. Introduction

The invention of super hard abrasive material-Cubic Boron Nitride (CBN), has contributed to significantly improving the economic-technical efficiency of grinding method. This abrasive is significantly applied by advanced industrial countries in mechanical processing since the 70s of the 20^{th} century. The CBN material is almost twice as hard as that of aluminum oxide and its heat resistance is up to 1500^0C. Due to the extremely high hardness, the grinding wheel made of CBN is capable of maintaining very small tolerance and the cutting process is stable, which creates a high and stable machining surface quality. In addition, CBN grinding wheel is capable of removing regular residues on the surface of the workpiece without compensating for the wear of grinding wheel [1].

There have been a number of studies surveying the effect of technology parameters and machining conditions on surface roughness when grinding with CBN wheel for different materials. Nguyen [2] surveyed the effect of cutting speed, depth of cut and velocity of workpiece when surface grinding of steel KSD11. The study shows that all three parameters of the cutting parameters affect the roughness of the workpiece. In particular, the cutting speed has the greatest effect, followed by the effect of the velocity of workpiece, the depth of cut with the least effect on surface roughness. Lee et al. [3] experimentally surveyed the effect of depth of cut, feed-rate and cooling air temperature on surface roughness when grinding SK-41C tool steel. Their study shows that the feed-rate has the greatest effect on surface roughness, followed by the effect of the depth of cut, cooling air temperature with an insignificant effect on surface roughness. Mamun et al. [4] surveyed the effect of cutting speed, depth of cut and feed-rate on the roughness of the workpiece when grinding AISI 1045 steel, using two methods of cooling lubrication, including Minimum Quantity Lubricants (MQL) and dry grinding. In addition, in this study, they compared the roughness of the surface when grinding with CBN wheel and aluminum oxide wheel. Their study shows that when grinding with the technology of MQL, the surface roughness will be lower than the surface roughness in dry grinding. In the MQL and dry grinding, when using CBN wheel, the surface roughness will be lower than the surface roughness when using aluminum oxide wheel. Surface roughness will rapidly increase if the value of feed-rate increases. Dung et al. [5] experimentally surveyed the effects of velocity of workpiece when grinding SKD11 and SUJ2 steels. According to the results of their study, for both types of used steel, when the velocity of workpiece increases, the surface roughness increases. Ky et al. [6] implemented grinding of 9CrSi alloy steel with CBN wheel to survey the effects of cutting speed, feed-rate and depth of cut on the roughness of the workpiece. Their study states that the depth of cut has a much greater effect on surface roughness than the effect of cutting speed and feed-rate.

In this article, the experimental study is conducted to survey the effect of velocity of workpiece, feed-rate and depth of cut on surface roughness when 3X13 steel grinding by CBN grinding wheels.

II. Grinding Experiment

A. *Components*

The omponents are the 3X13 steel of 62HRC. This is a high-alloy steel of very high chemical corrosion resistance and known as stainless steel. This steel is often used to fabricate workpiece that work in environments of chemical corrosives, heavy loads (types of bearing). The components have dimensions of length x width x height are 50 mm x 50 mm x 10 mm respectively. Table I shows the equivalent symbols of this steel according to a number of different standards. The chemical composition of this steel is presented in Table II.

TABLE I. EQUIVALENT SYMBOLS OF 3X13 STEEL ACCORDING TO SOME STANDARDS

ГОСТ	AISI	WNr	JIS	GB
3X13	420	1.2083	SUS 420J2	2083

TABLE II. CHEMICAL COMPOSITION OF 3X13 STEEL

C (%)	Si (%)	Mn (%)	Cr (%)	S (%)
0.42	1.00	1.00	13.00	< 0.005

B. *Design of experiment*

The Box-Behnken experimental design is used in this study, with three input parameters known as cutting parameters, including velocity of workpiece, feed-rate and depth of cut. With this form of design, each parameter will have three values (corresponding to three coding levels -1, 0 and 1). Values at levels of parameters are shown in Table III. Experimental matrix for fifteen experiments is presented in Table IV.

TABLE III. VALUES OF PARAMETERS AT LEVELS

Parameter	Unit	Values at levels		
		-1	*0*	*1*
Velocity of workpiece, v	m/min	5	10	15
Feed-rate, f	mm/stroke	3	4	5
Depth of cut, t	mm	0.01	0.015	0.02

TABLE IV. EXPERIMENTAL DESIGN MATRIX

Run	Cutting parameters						Ra
	Coding values			*Actual value*			
	v	*f*	*t*	*v (m/min)*	*f (mm/str)*	*t (mm)*	
1	-1	-1	0	5	3	0.015	0.55
2	1	-1	0	15	3	0.015	0.86
3	-1	1	0	5	5	0.015	0.83
4	1	1	0	15	5	0.015	0.93
5	-1	0	-1	5	4	0.010	0.93
6	1	0	-1	15	4	0.010	0.90
7	-1	0	1	5	4	0.020	0.82
8	1	0	1	15	4	0.020	0.99
9	0	-1	-1	10	3	0.010	1.22
10	0	1	-1	10	5	0.010	1.36
11	0	-1	1	10	3	0.020	1.48
12	0	1	1	10	5	0.020	1.44
13	0	0	0	10	4	0.015	1.46
14	0	0	0	10	4	0.015	1.54
15	0	0	0	10	4	0.015	1.50

C. *Grinding conditions*

In addition to the cutting parameters shall be adjusted in each experiment as shown in Table IV. The experimental process is conducted with the processing condition parameters as shown in Table V.

TABLE V. EXPERIMENTAL CONDITIONS

Surface grinder	APSG-820/2A
Grinding wheel	HY-180x13x31.75-100# (Korea)
Roughness tester	SJ201 (Japan)
Technology of cooling lubrication:	Oil emulsion 10%, method of overflow irrigation, flow of 4.6 liters/minute
Cutting speed:	26 m/s
Depth of dressing	0.01 mm
Feed of dressing	150 mm/min

III. RESULT ANALYSIS

Experimental results are presented in Table IV. The Minitab 16 statistical software is used to analyze the experimental results. The regression model information is presented in Fig. 1. The levels of the effect of cutting parameters on surface roughness are presented in Fig. 2.

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Estimated Regression Coefficients for Ra
Term          Coef   SE Coef        T      P
Constant    -3.961      1.08   -3.662  0.015
v            0.495      0.06    8.869  0.000
f            1.266      0.39    3.265  0.022
t           28.500     65.75    0.433  0.683
v*v         -0.023      0.00  -13.216  0.000
f*f         -0.121      0.04   -2.733  0.041
t*t       -150.000   1774.31   -0.085  0.936
v*f         -0.010      0.01   -1.232  0.273
v*t          2.000      1.70    1.173  0.294
f*t         -9.000      8.52   -1.056  0.339
S = 0.0852350   PRESS = 0.5372
R-Sq = 97.48%   R-Sq(pred) = 62.70%   R-Sq(adj) = 92.94%
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Fig. 1. *Regression model information*

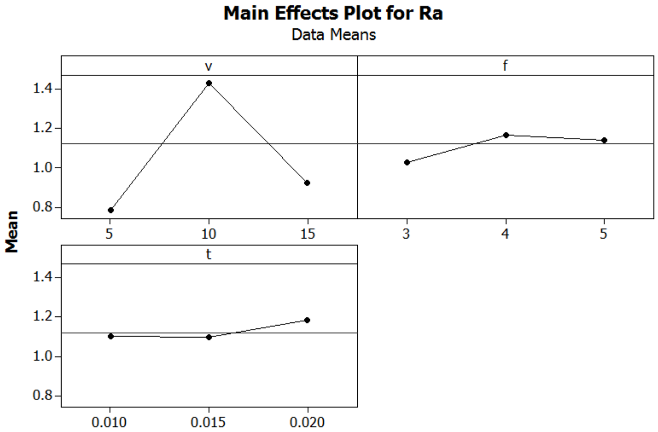

Fig. 2. *Effect of each cutting parameter on surface roughness*

The results in Fig. 1 and Fig. 2 show that:

- Velocity of workpiece has the greatest effect on surface roughness. Next is the levels of effect of feed-rate and the depth of cut. However, the depth of cut has a insignificant effect on surface roughness of the workpiece.

- When the velocity of workpiece increases from 5 to 10 m/min, the surface roughness increases. However, if the velocity of workpiece continues to be increased, the surface roughness decreases.

- When the feed-rate increases from 3 to 4 mm/stroke, the surface roughness tends to increase. However, if the feed-rate continues to be increased, the surface roughness tends to decrease.

- Also based on in Fig. 1, the relationship between surface roughness with the cutting parameters is developed as follows:

$$R_a = -1.961 + 0.495 * v + 1.266 * f + 28.5 * t - 0.023 * v^2 - 0.121 * f^2 - 150 * t^2 - 0.01 * v * f + 2 * v * t - 9 * f * t \quad (1)$$

The regression equation (1) has a coefficient of determination R^2 equivalent to 0.9748, very close to 1. This shows that this model has a very high fitness with experimental data. Use this model to calculate the value of surface roughness, then compare with the roughness value in experiment. The results are as shown in Fig. 3.

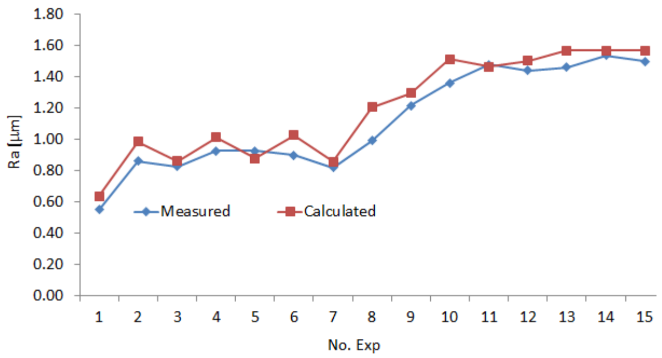

Fig. 3. *Comparison of roughness during calculation and experiment*

The results in Fig. 3 show that the value of surface roughness calculated by formula (1) is very close to the roughness value in experiment. This shows that the regression model presented in equation (1) can be used to predict surface roughness when 3X13 steel grinding by CBN grinding wheels.

IV. Conclusions

Some conclusions drawn from this study when 3X13 steel grinding by CBN grinding wheel are presented as follows:

(1) The velocity of workpiece has great effect on the surface roughness, followed by the effect of feed-rate. The depth of cut has an insignificant effect on surface roughness.

(2) The rule of effects of cutting parameters on surface roughness is quite complicated. The increase of the value of cutting parameters sometimes increases and sometimes reduces surface roughness.

(3) The regression model showing the relationship between surface roughness and cutting parameters is also developed in this study. It can be used to predict surface roughness when grinding, in order to reduce the time to adjust the machine, trial machini

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