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The Influence of Cutting Parameters on Surface Roughness When Milling C45 Steel Using PVD-Coated Insert

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ABSTRACT : *In this paper, we have tested the effects of cutting parameters on surface roughness when milling C45 steel with face mill using PVD-coated inserts. The cutting parameters mentioned in this study include the cutting speed, feed rate and the depth of cut. Furthermore, in this study, 20 tests in the form of Central Composite Design (CCD) are conducted. The analyzed results show that the feed rate has the greatest effect on surface roughness, followed by the effect of the cutting speed. The depth of cut has a negligible effect on surface roughness. In addition, the interaction effects of cutting parameters on surface roughness are analyzed in this paper. And then, the direction for further studies is mentioned in this paper.*

KEYWORDS *C45 steel, Cutting parameter, PVD-coated insert, Surface milling using end mill cutter, surface roughness.*

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I. INTRODUCTION

In mechanical processing, milling is a popular processing method that is widely applied and brings high productivity. Milling can be performed to process many different types of surfaces, such as plane, cylinder surface, keyhole, profiles, etc with many different materials.

The cutters for milling process have various types, such as cylindrical mill, face mill, finger cutters, etc. Machining the surface with face mill cutters for brings much higher productivity than machining with cylindrical mill cutters, thanks to the quantity of teeth for a lot of simultaneous cuts and a large-diameter mill can be used [1, 2].

The quality of machined surface when milling is evaluated by many parameters: surface roughness, surface layer‘s residual stress, etc. In particular, surface roughness has a great influence on the life of the products and it is often selected as one of the criteria for evaluation the efficiency of milling process [3-6]. The studies that surveys the effects of cutting parameters on surface roughness when milling the plane with face mill cutter has been conducted by many authors.

After experiments in the A6061 aluminum alloy milling process with face mill cutter using the hard alloy cut piece (APMT1604PDTR TC300), Pham Thi Hoa et al. [7] concluded that: (1) When changing the cutting velocity in the range of 356 m/min - 659 m/min, the chip shrinkage coefficient and surface roughness decrease; (2) When the feed rate and depth of cut increase, the chip shrinkage coefficient decreases and the surface roughness increases.

During the study on milling alloy Ti-6242, Erol Kilickap et al [8] concluded that: (1) All three cutting parameters including feed rate, cutting speed and depth of cut have a significant effect on surface roughness; (2) If the value of the feed rate and depth of cut are increased, the surface roughness will increase. Conversely, surface roughness will decrease if the value of cutting speed is increased.

Okokpujie Imhade et al. [9] tested milling the aluminum alloy 6061 under the condition of Minimum Quantity Lubrication (MQL) with a high-speed steel tool and concluded that: (1) The interaction between cutting velocity and feed rate have a great influence on surface roughness; (2) The effect of velocity on surface roughness is greater than the effect of feed rate; (3) The depth of cut has a negligible effect on surface roughness.

During the study on SKD61 steel milling with face mill using TiAlN-coated insert, Huu-That Nguyen et al. [10] concluded that: (1) All three parameters of cutting parameters including the cutting speed, feed rate, depth of cut and surface hardness of material have a significant effect on surface roughness; (2) The interaction between the cutting speed and depth of cut, the interaction between feed rate and depth of cut, the interaction between feed rate and the surface hardness of material have significant effects on surface roughness; (3) The interaction between the cutting speed and feed rate, the interaction between the cutting speed and the surface hardness of material, the interaction between the depth of cut and the surface hardness of material have a negligible effect on surface roughness.

During the study on milling AISI 316L SS steel with face mill using WC-coated insert, Muhammmad Yasir et al. [11] concluded that: (1) Two parameters: feed rate and cutting speed have significant effects on surface roughness. In particular, the effect of feed rate on surface roughness is greater than the effect of cutting speed; (2) The affecting rule of feed rate and depth of cut on surface roughness is quite complicated. When two such parameters are increased, the value of surface roughness either increases or decreases.

During the study on milling SKD61 steel, Tien Dung Hoang et al. [12], Nguyen Thanh Binh et al. [13] concluded that the feed rate is the parameter that has the most effect on surface roughness.

B. N. Pathak et al. [14] studied milling processes of two alloys, Al-1Fe-1V-1Si and Al-2Fe-1V-1Si. After this study, they concluded that: (1) All three parameters of the cutting parameters, including the depth of cut, the cutting speed and the feed rate, have almost negligible effect on surface roughness when milling alloy 1Fe-1V-1Si; (2) When milling alloy 1Fe-1V-1Si, the parameters of cutting parameters have a significant effect on Rz. However, the cutting parameters have a negligible effect on for Ra.

After experiments on milling alloy AA2014 (T4), Hasan Gökkaya [15] concluded: (1) The feed rate has a significant effect on the surface roughness, while the cutting speed has a negligible effect on surface roughness; (2) Increasing the value of the feed rate will increase surface roughness. Meanwhile, the affecting law of cutting speed on roughness is quite complicated. An increase of the value of cutting speed, either increases or decreases the value of surface roughness.

Luis Wilfredo Hernández-González et al. [16] conducted milling AISI 304 steel. Their study results affirmed that: (1) Both parameters: cutting speed and feed rate have a significant influence on surface roughness. In particular, the effect of cutting speed on surface roughness is greater than that of feed rate; (2) When the cutting speeds are 5.93 (m/min) and 11.81 (m/min): If the value of the feed rate is increased, the surface roughness will increase. When the cutting speed is 1.88 (m/min), imediately when the feed rate is increased, the surface roughness rapidly increases. However, if the feed rate continues to be increased, the surface roughness hardly changes.

The above-analyzed studies show that the effects of cutting parameters on surface roughness of the workpieces when surface milling using end mill cutter have been carried out by many authors. However, in each different case of the pair of machining material - cutting tool material, the effects of cutting parameters on surface roughness are different. Therefore, it is necessary to conduct research in specific machining conditions.

II. THE MILLING C45 STEEL USING PVD-COATED CUTTER

2.1. Experimental material

The experimental material is C45 steel that is considered the most common steel in the machine industry, with good machining and low cost. The chemical composites and properties of C45 steel are shown in Table 1 [17]. The components has the length, width, height is 80×35×35 mm, respectively (Figure 1).

Table 1. Chemical composites and properties of C45 steel [17]

Composite (%)										Properties			
C	Si	Mn	Cr	Ni	Mo	V	Ti	B	Cu	Modulus of elasticity (GPa)	Poisson´s ratio	Shear module (Gpa)	Density (kg/m^3)
0.44	0.23	0.65	0.15	0.15	0.04	0.01	0.001	0.0004	0.21	210	0.3	80	7800

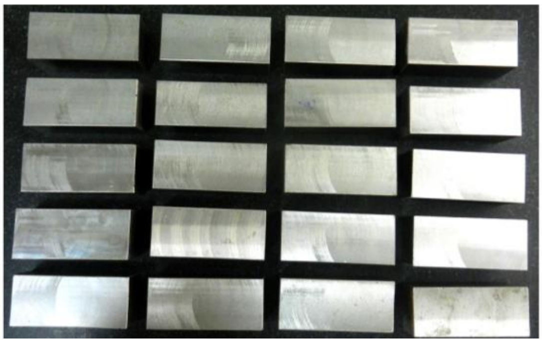

Fig.1. Conponents

2.2. Milling machine and mill tool

The tests are performed on milling machines Super MC F1.0-I/S (Figure 2). The face mill tool with four PVD-coated insert (Figure 3) is used in this study.

Fig.2. Experimantal machine

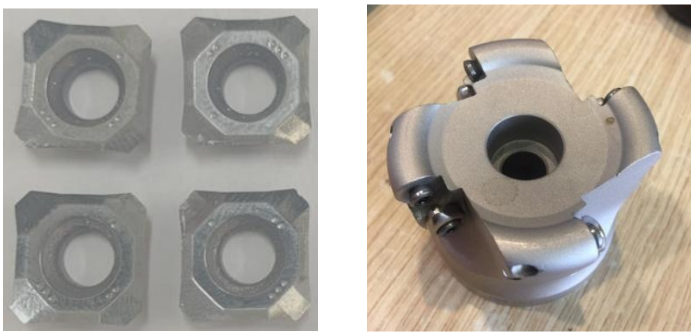

Fig.3. PVD-coated insert and mill head

2.3. Design of Experiment

Central Composite Design (CCD) test matrix is used to design of experiment in this study with 3 cutting parameters including cutting speed, feed rate and depth of cut. CCD design is a form created by combining a 2^k design, and 2^k axial points. This is the most popular design in the optimization experimant plan series because it can inherit the results of previous steps (initial test, slope test (if necessary)) [18]. As such, the numbers of tests in this study includes $2^k = 2^3 = 8$ (at coding levels of -1 and +1); 2k = 2*3 = 6 experiments at axial points (at coding levels of -α and –α, in which $\alpha = (2^k)^{1/4}$) and 6 central test points (at coding level of 0).

The values of the cutting parameters at the coding levels are presented in Table 2. The CCD matrix is presented in Table 3.

Table 2. Value of input parameters at different levels

Input parameters	Symbol	Values at test levels				
		-1.68	-1	0	1	-1.68
Cutting velocity (m/min)	v	90	118.4	160	201.6	230
Feed rate (mm/tooth)	f	0.16	0.188	0.23	0.272	0.3
Depth of cut (mm)	t	0.264	0.4	0.6	0.8	0.936

Table 3. CCD matrix and results

No.	Coding value			Actual value			Ra, µm
	v	f	t	v, m/min	f, mm/tooth	t, mm	
1	-1	-1	-1	118.4	0.188	0.4	1.422
2	1	-1	-1	201.6	0.188	0.4	0.566
3	-1	1	-1	118.4	0.272	0.4	3.894
4	1	1	-1	201.6	0.272	0.4	1.708
5	-1	-1	1	118.4	0.188	0.8	1.596
6	1	-1	1	201.6	0.188	0.8	0.488
7	-1	1	1	118.4	0.272	0.8	4.068
8	1	1	1	201.6	0.272	0.8	1.873
9	-1.68	0	0	90	0.23	0.6	3.634
10	1.68	0	0	230	0.23	0.6	0.048
11	0	-1.68	0	160	0.16	0.6	0.262
12	0	1.68	0	160	0.3	0.6	3.800
13	0	0	-1.68	160	0.23	0.264	1.240
14	0	0	1.68	160	0.23	0.936	1.525
15	0	0	0	160	0.23	0.6	1.462
16	0	0	0	160	0.23	0.6	1.459
17	0	0	0	160	0.23	0.6	1.642
18	0	0	0	160	0.23	0.6	1.557
19	0	0	0	160	0.23	0.6	1.459
20	0	0	0	160	0.23	0.6	1.622

2.4. Surface roughness tester

Surface roughness is measured by TESa-rugosurrf 10.G (Figure 4). For each component, at least 3 consecutive measurements are made. The roughness value at each test is the average of successive measurements, summarized in Table 3.

Fig.4. Surrface roughness tester

III. RESULTS ANALYSIS AND DISCUSSION

Test results are analyzed in Table 3 and analytical results are presented in Table 4 and Figure 5.

Table 4. Result analysis

Regression Statistics				
Multiple R	0.9923		Adjusted R Square	0.9708
R Square	0.9846		Standard Error	0.2030
ANOVA				
	df	*SS*	*MS*	*F*
Regression	9	26.38242	2.93138	$7.01*10^{-8}$
Residual	10	0.4119	0.04119	
Total	19	26.79432		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.4530	0.0828	17.5553	0.0000
v	-0.9065	0.0549	-16.4995	0.0000
f	0.9832	0.0549	17.8946	0.0000
t	0.0670	0.0549	1.2198	0.2505
v*v	0.1738	0.0535	3.2462	0.0088
f*f	0.2412	0.0535	4.5038	0.0011
t*t	0.0114	0.0535	0.2134	0.8353
v*f	-0.3021	0.0718	-4.2098	0.0018
v*t	-0.0326	0.0718	-0.4547	0.6591
f*t	0.0305	0.0718	0.4254	0.6795

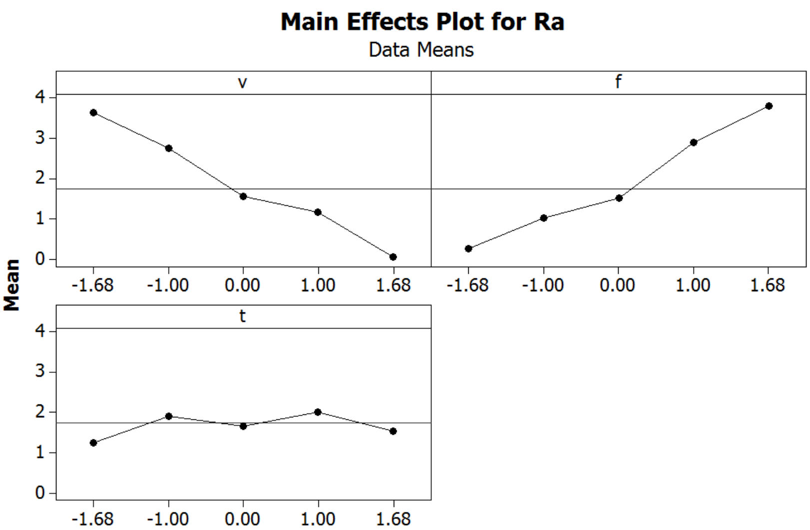

Fig.5. Effects of parameters on surface roughness

The results in Table 4 and Figure 5 show that:

- The feed rate has the greatest effect on surface roughness, followed by the effect of cutting speed. The depth of cut has a negligible effect on surface roughness.
- The roughness value will decrease as the cutting speed increases and the amount of toolpath decreases.
- Only the interaction effect between the cutting speed and the feed rate has a significant effect on surface roughness. Interaction between cutting speed and feed rate, interaction between feed rate and depth of cut have a negligible effect on surface roughness.

IV. CONCLUSIONS

This study determines the levels and rules of the influence of cutting parameters on surface roughness when milling a surface by PVD-coated cutter, material of C45 steel. The findings presented in this paper are the basis for adjusting cutting parameters when machining C45 steel using PVD-coated cutter. The determination of the optimal value of cutting parameters aimed at reaching the minimum roughness when milling C45 steel will be carried out in further studies.

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