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Surveying The Effect of Cutting Parameters on Cutting Force and Surface Roughness When Milling 42Mo Steel with Tin Coating Insert

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ABSTRACT

In this paper, an experimental study was conducted to determine the influence of cutting parameters on cutting force and surface roughness when milling 42Mo steel. The cutting parameters mentioned in this study include cutting speed, rate and depth of cut. The cutting tool used in this study was a face mill, the cutting insert coated with TIN. The results have determined the level and influence of the cutting parameters as well as the influence of the interaction between these parameters on the cutting force and surface roughness. The relationship between cutting force, surface roughness and cutting parameters has also been established in this study. The reliability of those relationships has been verified by analyzing the graph comparing the probability distributions of the balances with the normal distribution and the graph representing the relationship between the balances and the corresponding values response of the regression model.

Keywords : Cutting parameter, cutting force, surface roughness, surface milling, 42Mo steel, TIN coated milling cutter

I. INTRODUCTION

Milling is a popular machining method with high productivity and is widely used in mechanical processing. The milling method can be used to machine many different types of surfaces, with many different types of materials. Surface roughness has a great influence on the service life of products and is often chosen as one of the criteria to evaluate the efficiency of the milling process [1- 4]. Besides the surface roughness parameter, the cutting force is also often chosen as an indicator to evaluate the efficiency of the milling process, because the cutting force is a parameter that reflects the level of energy consumption (through cutting power) [5-9]. The study of milling process to find solutions to reduce cutting force, reduce surface roughness when milling has been done by many authors. Among them, the authors often focus on the study of the influence of the cutting parameters on the surface roughness and the cutting force in milling, the results of those studies are the basis for the selection of cutting parameters in each specific condition. Tien Dung Hoang et al. [10], when studying milling steel SKD61, came to the conclusion: The amplitude of the cutting force will increase if the value of the depth of cut and the feed rate is increased. Jhy-Cherng Tsai et al. [11] studied the milling of Inconel 718 with TiAlN-coated face end mills. Their study came to the conclusion: All three cutting parameters have a significant influence on the cutting force. In which, if the cutting depth increases, the cutting force will increase. Wen-Hsiang Lai [5], when studying the cutting force, came to the conclusion: the depth of cut has the greatest influence on the cutting force, when the cutting depth increases, the cutting force will increase rapidly. Research by Md. Anayet U Patwar et al. [12] came to the conclusion: (1) The feed rate has the greatest influence on the cutting force, followed by the influence of the depth of cut, and the cutting speed has little influence on the tangential force component; (2) When the feed rate and depth of cut are increased, the cutting force is increased. As for the cutting speed, when increasing the value of this parameter, it sometimes increases and sometimes decreases the cutting force. Erol Kilickap et al. [8] studied the milling of Ti-6242S alloy and made the following conclusions: (1) Feed rate, cutting speed and depth of cut all have a significant effect on cutting force; (2) The cutting force will increase if the value of the depth of cut is increased and the value of the cutting speed is decreased. When increasing the value of the feed rate, the value of the cutting force will increase rapidly. Hasan Gökkaya [13] experimentally milling the alloy AA2014 (T4) gave the following results: (1) The feed rate has a significant influence on the cutting force. When the feed rate increases, the value of the cutting force increases; (2) The cutting speed has a negligible influence on the cutting force. When the cutting speed changes 2.5 times (from 200 m/min to 500 m/min), the cutting force changes very little. Pathak et al. [14] studied the milling process of two alloys, Al-1Fe-1V-1Si and Al-2Fe-1V-1Si, and made the following comments: (1) The parameters of the cutting parameters are all good. significant effect on the cutting force when machining both materials; (2) When increasing the value of cutting depth and feed rate, the cutting force increases, and when increasing the value of cutting speed, the cutting force decreases.

Do Duc Trung et al. [15] when milling aluminum alloy A6061 with a face mill with a hard alloy cutting insert (symbol APMT1604PDTR TC300) made the following comments: (1) When changing the cutting speed in the region from 356 m/min to 659 m/min with the cutting conditions remain the same, the surface roughness decreases: (2) As feed rate and depth of cut increase, surface roughness increases. Erol Kilickap et al. [8] when studying the milling of Ti-6242S alloy, came to the conclusions: (1) All three cutting parameters have a significant influence on surface roughness; (2) If the value of feed rate and depth of cut is increased, the surface roughness will increase. Conversely, the surface roughness will decrease if the value of the cutting speed is increased. Okokpujie Imhade et al. [9] experimented with milling aluminum alloy 6061 in the condition of minimum quantity lubrication (MQL) with a high speed steel (HSS) insert and made the following comments: (1) The interaction between cutting speed and feed rate has a great influence on surface roughness; (2) Cutting speed has a greater effect on surface roughness than feed quantity. Research by Mohammed T. Hayajneh et al [2] ~~has~~ came to the conclusions: (1) Feed rate has the greatest influence on surface roughness, followed by the influence of cutting speed, depth of cut has a smaller effect on surface roughness than the influence of feed rate. knife and cutting speed; (2) The interaction between feed rate and depth of cut has the strongest influence on surface roughness, followed by the degree of influence of the interaction between cutting speed and feed, the interaction between cutting speed and depth of cut has no significant effect on surface roughness. Do Duc Trung [16] conducted a study on the influence of the cutting parameters and the hardness of the workpiece (H) on the surface roughness when milling steel, they made the comments: All three parameters including cutting speed, feed rate, depth of cut and hardness of the workpiece have a significant influence on the surface roughness. The effect of cutting speed and feed rate on surface roughness when milling AISI 316L SS steel has been studied experimentally by Muhammmad Yasir et al. [17], The cutting tool they used in this study was a milling cutter with a cut piece coated with a WC layer. From the experimental results, they made the following conclusions: (1) Both the feed rate and the cutting speed have a significant influence on the surface roughness. In which, the influence of the feed rate on the surface roughness is greater than the influence of the cutting speed; (2) The rule of influence of feed rate and depth of cut on surface roughness is quite complicated, when increasing the values of these two parameters, sometimes increases, sometimes decreases the value of surface roughness. Dražen Bajić et al [3] conducted an experiment to mill 42CrMo4 steel with TiN coated cutting tools, then they made the following observations: (1) cutting speed has little influence on surface roughness, and (2) For feed rate, when machining with a fixed depth of cut, the effect of feed rate on the surface roughness is greater than when machining with a variable depth of cut. Tien Dung Hoang et al. [10], when studying milling steel, came to the conclusion: feed rate is the parameter that has the greatest influence on surface roughness. When reducing the feed rate, increasing the cutting speed from 0 to 130 mm/min, increasing the cutting depth from 0 to 0.3 mm, the surface roughness will decrease. Do Duc Trung [18] studied the milling of steel, they made the comment: when increasing the feed rate and cutting depth, the surface roughness increases, but the influence of cutting depth on the surface roughness increases. smaller than the effect of feed rate and cutting speed. Pathak et al. [14] studied the milling of two alloys, Al-1Fe-1V-1Si and Al-2Fe-1V-1Si, from which they made the following observations: (1) all three parameters of the fabrication process. cutting has almost negligible influence on surface roughness when milling alloy 1Fe-1V-1Si; (2) When milling Al-2Fe-1V-1Si alloy, the parameters of the cutting have a great influence on the Rz criterion. But for the parameter Ra, the cutting parameters have a negligible influence. Hasan Gökkaya [13] when experimentally milling the AA2014 alloy (T4) received the following results: (1) the feed rate has a significant effect on the surface roughness, while the cutting speed has a negligible effect on the surface roughness; (2) When increasing the value of the feed rate will increase the surface roughness, meanwhile, the rule of influence of the cutting speed on the surface roughness is quite complicated, when increasing the value of the cutting speed, sometimes increase, sometimes decrease the value of surface roughness. Experimental milling of AISI 304 steel was performed by Luis Wilfredo Hernández-González et al. [19], they came to the following conclusion: both the cutting speed and the feed rate have a great influence on the surface roughness. In which the influence of the cutting speed on the surface roughness is greater than the influence of the feed rate.

From the above overview studies, it is shown that, although there have been many published studies investigating the influence of cutting parametes on cutting force and surface roughness when milling. However, in each specific machining condition, the degree and rule of influence of the cutting parameters on the cutting force and surface roughness are different, in order to apply the research results to production, it is necessary to do experimental research with each specific processing condition on machining materials and cutting tool materials. In this paper, a study will be conducted to determine the influence of cutting parameters on cutting force and surface roughness when milling 42Mo steel with a milling cutter with TIN coated inserts.

II. Milling test

2.1. Experimental materials

The test material is 42Mo steel, the chemical composition is shown in Table 1. This is a commonly used steel in the machine building industry, has good labor cost, is often used to manufacture to static loads, sometimes also to manufacture impact-resistant parts during work, parts with wear-resistant surfaces, such as shafts and gears.

Table 1. Chemical composites of 42Mo steel

Element	C	Si	Mn	P	S	Cr
Content, %	0.42	0.42	0.70	0.022	0.018	1.02

2.2. Milling machines and milling cutters

The existing CNC label milling machine C-55X was used in this study (Figure 1). The cutting tool used in this study was a face mill with 4 TIN coated cutting insert.

Figure 1. Laboratory Machine

2.3. Experiment design

The Central Composite Design matrix was used to design the experiments in this study with three cutting parameters including cutting speed, feed rate and depth of cut. Central Composite Design design is a design form formed by combining 2^k design (k is the number of input parameters), 2k axial test points and a number of test points at the center [20]. The values of the cutting parameters at the coding levels are shown in Table 2. The experimental matrix is shown in Table 3.

Table 2. Values of parameters at levels

Input parameters	Symbol	Values at ~~experimental~~ levels				
		-1.68	-1	0	1	-1.68
Cutting speed (m/min)	v	120	146.35	185	223.65	250
Feed rate (mm/tooth)	f	0.08	0.1	0.13	0.16	0.18
Cutting depth (mm)	t	0.2	0.281	0.4	0.519	0.6

Table 3. Experimental matrix and results

Exp.	Code value			Real value			I (A)		N_{cut} (KW)	P_c (N)	R_a (µm)
	v	f	t	v (m/min)	f (mm/tooth)	t (mm)	Beforre	After			
1	-1	-1	-1	146.35	0.10	0.281	95	119	9.12	62.32	0.26
2	1	-1	-1	223.65	0.10	0.281	96	103	2.66	11.89	0.47
3	-1	1	-1	146.35	0.16	0.281	105	112	2.66	18.18	0.78

4	1	1	-1	223.65	0.16	0.281	92	111	7.22	32.28	0.86
5	-1	-1	1	146.35	0.10	0.519	92	138	17.48	119.44	0.65
6	1	-1	1	223.65	0.10	0.519	92	110	6.84	30.58	0.40
7	-1	1	1	146.35	0.16	0.519	92	100	3.04	20.77	0.27
8	1	1	1	223.65	0.16	0.519	90	102	4.56	20.39	0.15
9	-1.68	0	0	120	0.13	0.4	91	99	3.04	25.33	0.16
10	1.68	0	0	250	0.13	0.4	91	110	7.22	28.88	0.26
11	0	-1.68	0	185	0.08	0.4	91	103	4.56	24.65	0.18
12	0	1.68	0	185	0.18	0.4	90	108	6.84	36.97	1.48
13	0	0	-1.68	185	0.13	0.2	90	110	7.6	41.08	0.99
14	0	0	1.68	185	0.13	0.6	89	101	4.56	24.65	0.13
15	0	0	0	185	0.13	0.4	91	100	3.42	18.49	0.29
16	0	0	0	185	0.13	0.4	90	102	4.56	24.65	0.26
17	0	0	0	185	0.13	0.4	90	102	4.56	24.65	0.37
18	0	0	0	185	0.13	0.4	90	105	5.7	30.81	0.34
19	0	0	0	185	0.13	0.4	90	109	7.22	39.03	0.57
20	0	0	0	185	0.13	0.4	90	112	8.36	45.19	0.41

2.4. Instrumentation

Surface roughness was measured by surface roughness tester SJ201 (Mitutoyo - Japan). For each test sample, measurements were made at least three times. The roughness value at each experiment is the average value of consecutive measurements.

Use an amperage meter to measure the current before and during tripping at each experiment. From there, the cutting power (Ncut) and cutting force (Pc) can be determined according to the following two equations:

$$N_{cut} = U * I \quad (1)$$

$$P_c = \frac{N_{cut}}{v} \quad (2)$$

The values of cutting force and surface roughness have been summarized in Table 3.

III. Results analysis and discussion

The experimental results are analyzed in Table 3. The results of ANOVA analysis for Pc and Ra are presented in Tables 4 and 5, respectively.

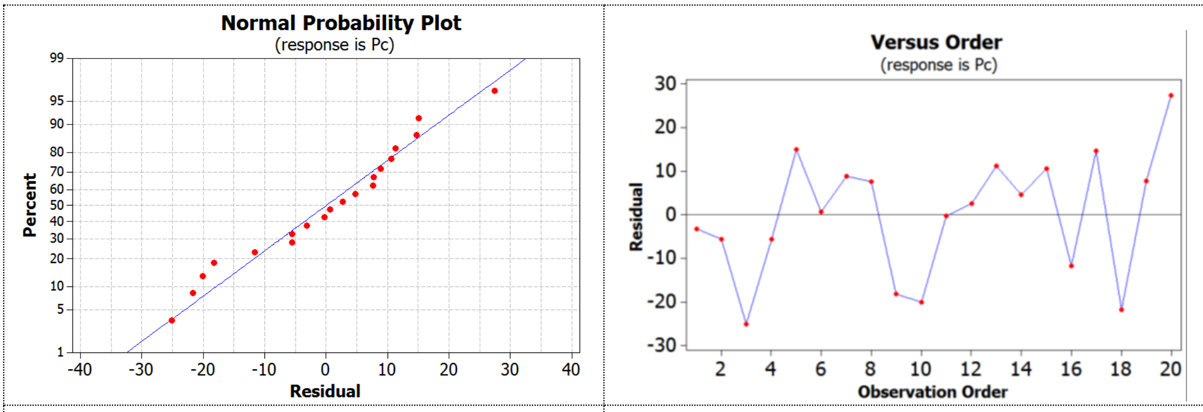
Table 4. Results of ANOVA analysis for Pc

ANOVA								
	df	SS	MS	F	Significance F			
Regression	9	6420.6795	713.4088	1.9247	0.1610			
Residual	10	3706.6520	370.6652					
Total	19	10127.33						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	30.1615	7.8516	3.8414	0.0033	12.6671	47.6560	12.6671	47.6560
v	-8.7657	5.2120	-1.6818	0.1235	-20.3788	2.8475	-20.3788	2.8475
f	-8.2018	5.2120	-1.5736	0.1466	-19.8150	3.4113	-19.8150	3.4113
t	2.8515	5.2120	0.5471	0.5963	-8.7617	14.4646	-8.7617	14.4646
v*v	0.7632	5.0796	0.1502	0.8836	-10.5549	12.0813	-10.5549	12.0813
f*f	2.0759	5.0796	0.4087	0.6914	-9.2422	13.3940	-9.2422	13.3940
t*t	2.8040	5.0796	0.5520	0.5931	-8.5141	14.1221	-8.5141	14.1221
v*f	19.1263	6.8068	2.8099	0.0185	3.9597	34.2928	3.9597	34.2928
v*t	-6.6138	6.8068	-0.9716	0.3541	-21.7803	8.5528	-21.7803	8.5528
f*t	-10.6388	6.8068	-1.5629	0.1491	-25.8053	4.5278	-25.8053	4.5278

From the results in Table 4, it can be seen that:

- Cutting speed has the greatest influence on the cutting force, followed by the influence of the feed rate, the cutting depth has the least influence on the cutting force.
- When the cutting speed and feed rate are increased, the cutting force decreases. Meanwhile, the value of the cutting force will increase if the value of the depth of cut increases.

The interaction between the cutting speed and the feed rate has a greater influence on the cutting force than the influence of the interaction between the feed rate and the depth of cut. The interaction between the occlusion velocity and the depth of cut has the least influence on the cutting force.



a) Normal Probability plot	b) Versus order plot

Fig. 2. Normal Probability and Versus order plot for P_c

Also from Table 4, the relationship between cutting force and cutting parameters is shown in equation (3). This equation is the basis for determining the value of the parameters of the cutting parameter to ensure that during the machining process, the cutting force will reach the minimum value. Regarding the reliability of this relationship, it is possible to observe a graph comparing the probability distribution of balances (Normal Probability) (displayed in points) with the normal distribution (displayed by solid lines) and the graph represents the relationship between the balances and the corresponding values of the regression model (Versus order) as shown in Figure 2.

$$P_c = 30.1615 - 8.7657 * v - 8.2018 * f + 2.8515 * t + 0.7632 * v^2 + 2.0759 * f^2 + 2.8040 * t^2 + 19.1263 * v * f - 6.6138 * v * t - 10.6388 * f * t \quad (3)$$

The observation in Figure 3a shows that the residuals are distributed very close to the normal distribution, and in Figure 3b, the points are randomly distributed, without any pattern, showing that the cutting force data in Table 3 are not affected by control factors that have any other rule than the cut-off parameters. It confirms that the relationship between cutting force and cutting parameters can be achieved reliably.

Table 5. Results of ANOVA analysis for Ra

ANOVA								
	df	SS	MS	F	Significance F			
Regression	9	1.6462	0.1829	3.2379	0.0406			
Residual	10	0.5649	0.0565					
Total	19	2.2111						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.3753	0.0969	3.8715	0.0031	0.1593	0.5912	0.1593	0.5912
v	0.0055	0.0643	0.0858	0.9333	-0.1378	0.1489	-0.1378	0.1489
f	0.1802	0.0643	2.8013	0.0188	0.0369	0.3236	0.0369	0.3236

t	-0.1725	0.0643	-2.6810	0.0231	-0.3159	- 0.0291	-0.3159	- 0.0291
v*v	-0.0711	0.0627	-1.1346	0.2830	-0.2109	0.0686	-0.2109	0.0686
f*f	0.1475	0.0627	2.3523	0.0405	0.0078	0.2872	0.0078	0.2872
t*t	0.0524	0.0627	0.8352	0.4231	-0.0873	0.1921	-0.0873	0.1921
v*f	-0.0012	0.0840	-0.0138	0.9893	-0.1884	0.1861	-0.1884	0.1861
v*t	-0.0820	0.0840	-0.9762	0.3520	-0.2693	0.1052	-0.2693	0.1052
f*t	-0.1915	0.0840	-2.2786	0.0459	-0.3787	- 0.0042	-0.3787	- 0.0042

Looking at Table 5 shows:

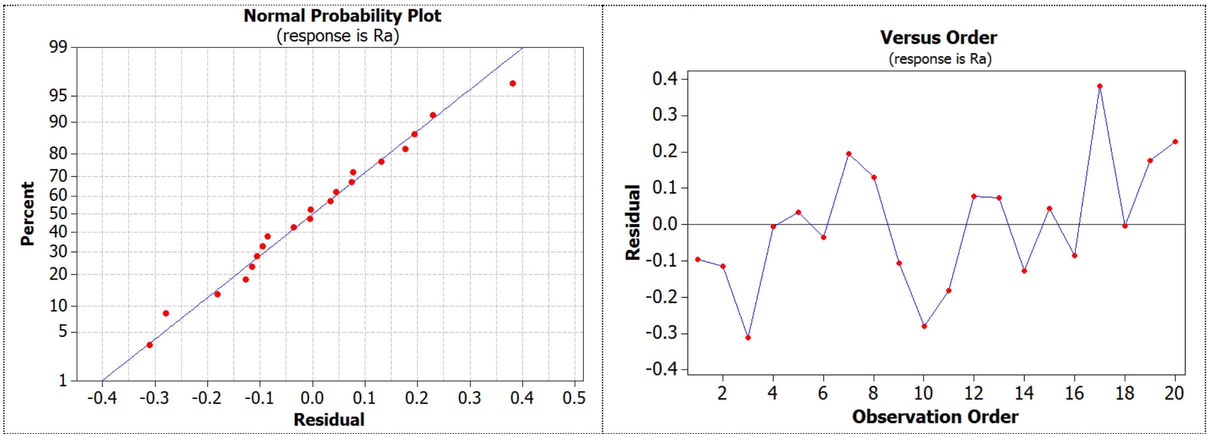
- The feed rate has the greatest influence on the surface roughness, followed by the influence of the depth of cut, the cutting speed has a negligible influence on the surface roughness.

As the feed rate increases, the surface roughness increases. Meanwhile, the surface roughness will decrease if the cutting depth increases.

Only the interaction between feedrate and depth of cut has a significant effect on surface roughness. The interaction between cutting speed and feed rate, the interaction between cutting speed and depth of cut, have negligible influence on surface roughness.

For surface texture, the graph compares the probability distribution of the residuals (Normal Probability) with the normal distribution and the plot represents the relationship between the residuals and the corresponding values of the regression model (Versus order) is shown in figure 3.

The observation in Figure 4a also shows that the residuals are distributed very close to the normal distribution, while in Figure 4b, the points are randomly distributed, without any rule showing that the surface texture data in Table 4 is not affected by control factors with any rule other than the cutting parameters. Therefore, the relationship between surface roughness and cutting parameters expressed in formula (4) has very high reliability. This relationship is the basis for selecting the value of the cutting ~~mode~~ parameters to satisfy the specific requirements of the surface roughness.



a) Normal Probability plot	b) Versus order plot

Fig. 3. Normal Probability and Versus order plot for R_a

$$R_a = 0.3753 + 0.0055 * v + 0.1802 * f - 0.1725 * t - 0.0711 * v^2 + 0.1475 * f^2 + 0.0524 * t^2 - 0.0012 * v * f - 0.0820 * v * t - 0.1915 * f * t \quad (4)$$

IV. CONCLUSION

Twenty experiments were performed according to the mixed matrix of rotation center to investigate the effect of cutting speed, feed rate and depth of cut on cutting force and surface roughness when milling 42Mo steel with TIN coated milling cutters. The results are summarized as follows:

Cutting speed has the greatest influence on cutting force, followed by the degree of influence of feed rate, cutting depth has the least influence on cutting force. As the cutting speed and feed rate increase, the cutting force decreases. Meanwhile, the value of the cutting force will increase if the value of the depth of cut increases.

The interaction between feed rate and feed rate has a greater influence on cutting force than the interaction between feedrate and depth of cut, the interaction between cutting speed and depth of cut has the least influence on the cutting force.

- The feed rate has the greatest influence on the surface roughness, followed by the degree of depth of cut, the cutting speed has a negligible effect on the surface roughness. As the feed rate increases, the surface roughness increases. Meanwhile, the surface roughness will decrease if the cutting depth increases.
- Only the interaction between feed rate and depth of cut has a significant effect on surface texture. The interaction between cutting speed and feed rate, the interaction between cutting speed and depth of cut, have negligible influence on surface roughness.

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