World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:5, No:11, 2011

The Effect of High-speed Milling on Surface Roughness of Hardened Tool Steel

Manop Vorasri, Komson Jirapattarasilp* and Sittichai Kaewkuekool

Abstract**—**The objective of this research was to study factors, which were affected on surface roughness in high speed milling of hardened tool steel. Material used in the experiment was tool steel JIS SKD 61 that hardened on 60 ±2 HRC. Full factorial experimental design was conducted on 3 factors and 3 levels (3^3 designs) with 2 replications. Factors were consisted of cutting speed, feed rate, and depth of cut. The results showed that influenced factor affected to surface roughness was cutting speed, feed rate and depth of cut which showed statistical significant. Higher cutting speed would cause on better surface quality. On the other hand, higher feed rate would cause on poorer surface quality. Interaction of factor was found that cutting speed and depth of cut were significantly to surface quality. The interaction of high cutting speed associated with low depth of cut affected to better surface quality than low cutting speed and high depth of cut.

Keywords**—**High-speed milling, Tool steel, SKD 61 Steel, Surface roughness, Cutting speed, Feed rate, Depth of cut

I. Introduction

TOOL steel is the important material to produce the mold and die for industries such as forging die for automotive part industry. SKD 61 is tool steel that recommended using for hot working. High hardness and withstands wear are important properties and also has relatively high resistance to shock. In order to use for die, this material must be machined by turning or milling operation and hardened by heat treatment process with approximately hardness 60 HRC. The milling operation has been the process for making mold and die. In order to obtain better surface finish, the suitable setting of cutting parameters is important before the process takes place [1]. So, there are several factors affected to quality of surface such as cutting speed, feed rate, depth of cut, characteristics of tool [1],[2]. Furthermore, there are several researches to study the factors affected to surface quality that material machining such as turning [3],[4], grinding [5],[6] and milling [1],[7]. This factor of milling could be affected to quality of product especially surface finish based on the condition of machining.

Manop Vorasri was with the Department of Production Technology Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi 126 Pracha-utid Rd. Bangmod, Thongkru District, Bangkok 10140, Thailand.

Komson Jirapattarasilp is with the Department of Production Technology Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi 126 Pracha-utid Rd. Bangmod, Thongkru District, Bangkok 10140, Thailand (e-mail: komson.jir@kmutt.ac.th).

Sittichai Kaewkuekool is with the Department of Production Technology Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi 126 Pracha-utid Rd. Bangmod, Thongkru District, Bangkok 10140, Thailand (e-mail: sittichai.kae@kmutt.ac.th).

*Corresponding Author

Therefore, based on these conditions to have better surface roughness for vertical milling material especially hardened tool steel, the objectives of this research were to study the factors, which were cutting speed, feed rate, and depth of cut affected to surface roughness of hardened tool steel.

II. Tool and Equipment

This study was done by use material which was tool steel grade JIS SKD 61. The fifty four specimens were machined in dimension of 50 mm wide, 200 mm long and 25 mm thick, as shown in Figure 1 and heat treatment by hardening process that the hardness has been between 60 ±2 HRC. The property and chemical composition of prepared specimen are showed in table I. The experiments were run on CNC high-speed milling machine '*Twinhorn VH650*'. The cutting tool was carbide polycrystalline vapor deposit coated tool with 14 mm diameter end milling tool holder. The machine and cutting tool are shown in Figure 2 and 3. The data, surface average roughness (Ra), were measured by surface roughness tester '*Mahr MarSurf PS1*'.

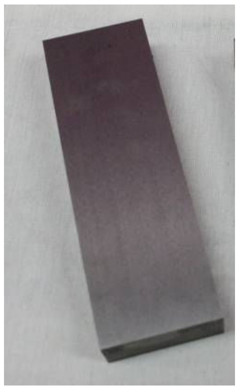

Fig. 1 Specimen:Hardened SKD61

TABLE I
THE CHEMICAL COMPOSITION AND HARDNESS OF SPECIMEN TOOL STEEL JIS SKD61.

Chemical Composition (%)					Hardness
C	Si	Mn	P	S	*(HRC)*
0.32	1.05	0.40	5.20	1.40	60 2

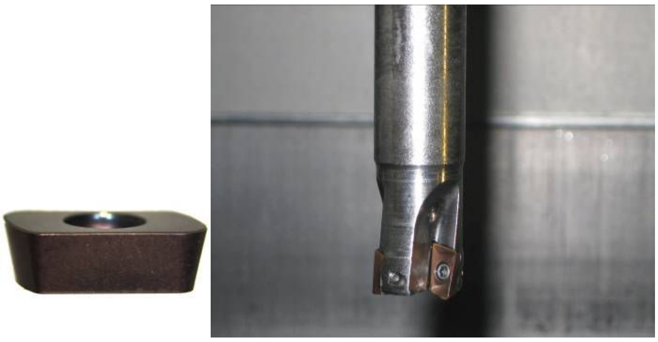

Fig. 2 Cutting Tool : Carbide PVD Coated Cutter

Fig. 3 CNC high-speed milling machine '*Twinhorn VH650*'

III. Experimental Design

Factorial design was applied with 3 factors and 3 levels (3^3 designs) for this experiment. Factors consist of cutting speed (V), feed rate (f), and depth of cut (d). Each factor was set at three levels. Cutting speed was set up at 300, 450, and 600 meter per minute, feed rate was at 500, 1,000, and 1,500 millimeter per minute, and depth of cut was indicated in 0.1, 0.3 and 0.5 millimeter as shown in Table II. These factors were tested by plot study with twelve runs before running the actual experiment.

The actual experiment was run by two replicates which run randomly selected. Then, the response of each trial were measured for surface roughness that using average roughness (Ra) value. The measuring was done on the machined surface with three points measuring of each specimen. Data was collected and used to analysis by statistical methods to finding the factors affected to surface roughness.

IV. Results and Discussion

The main findings of this experiment were main factors and interaction of factors that affected to surface roughness of hardened tool steel SKD 61 in high-speed vertical milling with carbide PVD coated tool.

TABLE II
EXPERIMENTAL DESIGN (3^3DESIGN) AND RANDOM RUN

Depth of cut (mm)	Cutting Speed (m/min)	Feed rate (mm/min)		
		500	1,000	1,500
0.1	300	4 23	48 51	18 19
	450	20 25	7 24	27 47
	600	41 53	29 38	6 13
0.3	300	22 54	9 43	16 31
	450	12 26	35 50	3 36
	600	10 44	2 32	28 40
0.5	300	34 37	5 15	8 42
	450	49 52	11 21	33 45
	600	39 46	17 30	1 14

A. *Pilot Study*

The initial setting factors to run for appropriate levels of high speed milling of SKD 61steel was determined by pilot study. The normality test of data from pilot study was test and showed in Figure 3. The result was showed that the pilot test was significantly normality of both results. That means the experimental factors were appropriate levels for experiment.

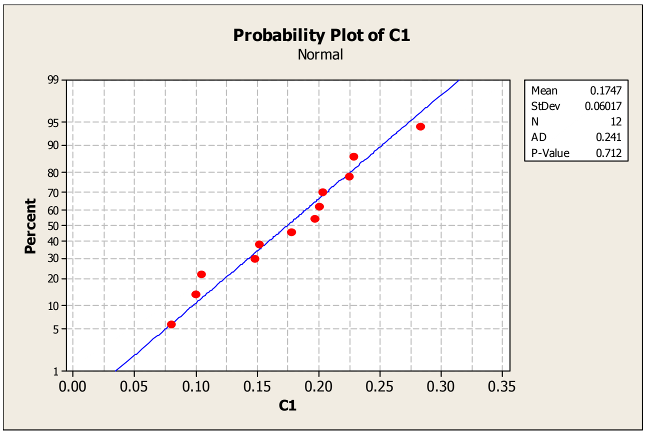

Fig. 4 Normality test for pilot study of surface roughness

B. *Surface Roughness Results*

The results of full factorial design experiment was surface roughness for vertical milling of SKD 61 steel as showed in Table III and analyzed for normality test is showed in Figure 5 that was significantly. An analysis of variance (ANOVA) for surface roughness was showed in Table IV. The ANOVA results indicated that factors affected to surface roughness were depth of cut and feed rate as showed significantly different at the level of .01, and cutting speed significantly different at the level of .05. It means that the depth of cut and the feed rate were most influencing factors to surface roughness than cutting speed in high-speed milling. Moreover, The ANOVA showed that factor interaction was only found between the depth of cut with cutting speed.

TABLE III
RESULTS OF SUSRFACE ROUGHNESS

Depth of cut (mm)	Cutting Speed (m/min)	Feed rate (mm/min) 500	1,000	1,500
0.1	300	0.0800	0.1510	0.2035
		0.1235	0.1120	0.1475
	450	0.0963	0.1583	0.1650
		0.1553	0.1745	0.1973
	600	0.1000	0.1775	0.2000
		0.1335	0.1368	0.1873
0.3	300	0.1160	0.1800	0.2350
		0.1680	0.2943	0.3548
	450	0.0828	0.1648	0.1973
		0.1915	0.2028	0.2303
	600	0.0875	0.1323	0.2623
		0.0638	0.1608	0.2458
0.5	300	0.1968	0.2830	0.2283
		0.2205	0.3085	0.3023
	450	0.1055	0.2318	0.3140
		0.2365	0.3175	0.3755
	600	0.1043	0.1480	0.2245
		0.1338	0.1778	0.2555

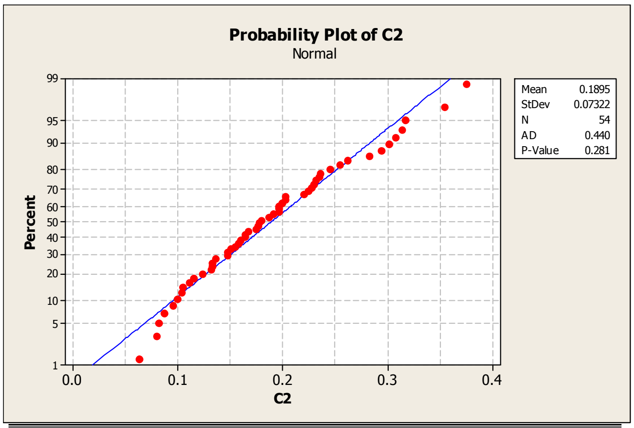

Fig. 5 Normality test of surface roughness

C. *Factor Interactions*

The factor interaction, as showed in ANOVA, was found between the depth of cut with cutting speed. The depth of cut in associated with the cutting speed was influenced to the surface roughness as shown in Figure 7. It means that the both of cutting speed level in low depth of cut would produce the lower surface roughness. However, at high depth of cut, the higher cutting speed can be made better quality of surface than lower cutting speed. In the other hand, cutting speed could not be affected to surface roughness at low depth of cut.

In order to test of different between levels of feed rate factor affected to surface roughness, the Least Significant Different (LSD) method was used for analyzing and comparing levels of feed rate. The LSD result for feed rate was showed that It was significantly different for both levels of feed rate as showed in Table V. The comparison of levels is presented in Figure 7. As analysis, the less feed rate would affect to lower surface roughness. On the other hand, the higher feed rate would cause on poorer surface finish and it means that the lower feed rate, the better surface quality as showed in Figure 6.

TABLE IV
ANOVA RESULT OF SURFACE ROUGHNESS

	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.235ᵃ	26	.009	4.979	.000
Intercept	1.939	1	1.939	1.068E3	.000
Depth of Cut	.060	2	.030	16.440	.000
Cutting Speed	.020	2	.010	5.371	.011
Feed	.104	2	.052	28.731	.000
Depth of cut * Cutting Speed	.026	4	.006	3.541	.019
Depth of cut* Feed	.008	4	.002	1.100	.377
Cutting Speed *Feed	.004	4	.001	.558	.695
Depth of cut * Cutting Speed * Feed	.014	8	.002	.947	.496
Error	.049	27	.002		
Total	2.223	54			
Corrected Total	.284	53			

R Squared = . .827 (Adjusted R Squared = .661)

TABLE V
LSD RESULTS OF LEVEL OF FEED RATE

(I) Feed Rate	(J) Feed Rate	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
500	1,000	-.062014*	.0142060	.000	-.091162	-.032866
	1,500	-.107250*	.0142060	.000	-.136398	-.078102
1,000	500	.062014*	.0142060	.000	.032866	.091162
	1,500	-.045236*	.0142060	.004	-.074384	-.016088
1500	500	.107250*	.0142060	.000	.078102	.136398
	1000	.045236*	.0142060	.004	.016088	.074384

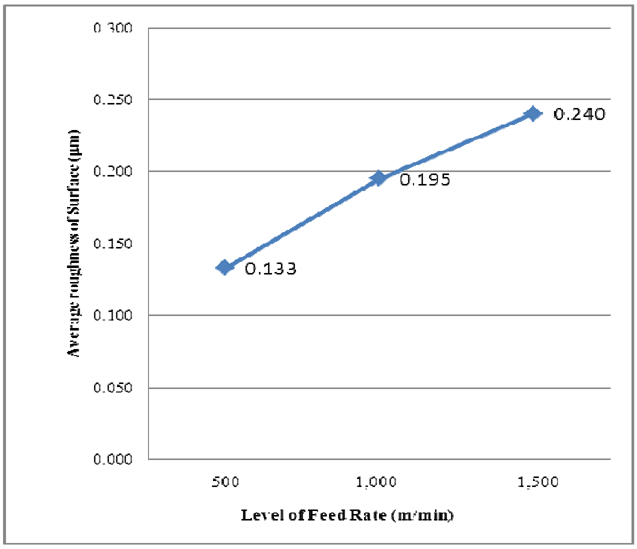

Fig. 6 Comparison of feed rate level

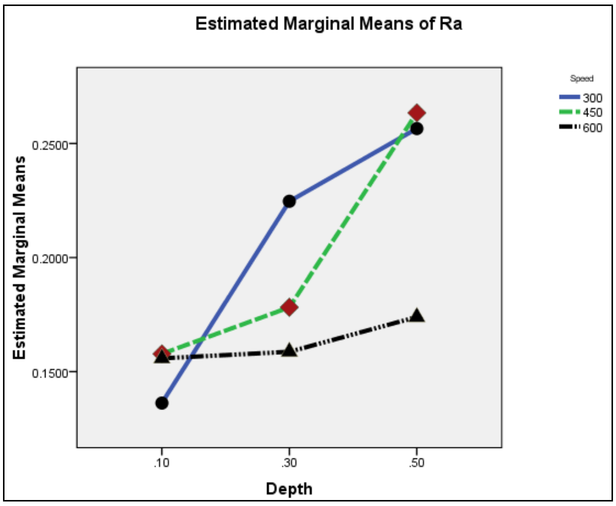

Fig. 7 Interaction between Depth of cut and Cutting speed

IV. Conclusion

The experiment in high-speed vertical milling of tool steel JIS SKD 61 with carbide PVD coated cutting tool, it could be concluded that depth of cut, feed rate and cutting speed were mainly affected to surface roughness. Moreover, the interaction between cutting speed and depth of cut was found that means the effect of cutting speed with depth of cut influenced on the response. Some concluding as following;

- Depth of cut, cutting speed and feed rate were main factors to affect the quality of surface finish.
- Lower feed rate would be cause of better surface quality.
- Higher cutting speed would be cause of better surface quality.
- Lower feed rate would be increase the better surface roughness.
- The interaction of cutting speed in associated with the depth of cut was influenced to the surface roughness
- At high cutting speed with low depth of cut would be better surface quality more than low cutting speed.

References

[1] M.Y. Wang, H.Y. Chang, "*Experimental study of surface roughness in slot end milling AL2014-T6"* International Journal of Machine Tools and Manufacture .Vol. 44, no.1(2004), pp 51-57.

[2] G.T.,Smith, Advanced Machining, *The Handbook of cutting Technology*, Dept of Engineering and Naval Architecture Southampton, Institute of Higher Education, Southampton, 1988

[3] O.B.Abouelatta, J.Madl, *"Surface roughness prediction based on cutting parameters and tool vibrations in turning operations*", Journal of Materials Processing Technology. Vol. 118, no. 1-3 (2001), pp. 269-277.

[4] S.Kaewkuekool, K.Jirapattarasilp,and K.Pechkong, "*A Study of Influence Factors Affecting to Surface Roughness in Stainless Steel Turning",* The Proceeding of The International Conference on Computer Engineering and Technology . 2009 ICCET '08 , Volume 2,(2009), p. 299-302.

[5] K.Jirapattarasilp, J.Rukijkanpanich "*The experiment of high-speed grinding of a gemstone: cubic zirconia*" Int J. of Adv Manu Tech. Vol.33, no.11-12 (2007) pp.1136-1142.

[6] K.Jirapattarasilp, S.Kaewkuekool ,and P.Klahan, "*The study of influenced factors affecting to quality of cylindrical grinding harden AISI 4140 steel*", The Proceeding of The 2nd International Conference on Mechanical and Electronics Engineering (ICMEE), Vol 2 (2010), p 329-333.

[7] D.K.Baek, T.J. Ko,and H.S. Kim, "*Optimization of feedrate in a face milling operation using a surface roughness model*" International Journal of Machine Tools and Manufacture, Vol.41, no.3 (2001), pp 451-462.