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Investigation of cutting parameter effects on hard turning of AISI H13 tool steel using carbide tool

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Abstract
The present work shows an experimental investigation on the effect of cutting parameters including cutting speed, feed rate and depth of cutting hard turning of AISI H13 steel (55HRC) using carbide tool. Analysis of variance (ANOVA) was implemented to investigate the effects of investigated cutting parameters on hard turning performance in terms of cutting force components. The results of this work show that hard turning under dry condition could be considered as the alternative solution for grinding process in order to improve the productivity while remaining the good surface quality. Moreover, the complete elimination of cutting fluid not only reduces the manufacturing cost but also make the dry hard turning environmental friendly and suitable for sustainable production.
Keywords: *Hard turning, machining, hardened steel, cutting parameter, dry*

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I. Introduction

In recent years, the demand for processing hard materials has high requirements for productivity as well as surface quality [1]. The traditional solution for processing hardened steels is mainly grinding; however, low productivity and environmental pollution from the use of cutting fluids are the main disadvantages of this method [2]. To overcome this problem, hard machining technology has been researched and developed and this technique has increasingly shown outstanding advantages. Hard machining is a cutting process using the cutting tool with geometrically defined cutting edges to directly cut heat-treated steels with the hardness range of 45-70 HRC [2].

Some common hard machining methods such as hard turning, hard milling, hard broaching, etc. Hard turning is widely used and has shown advantages in terms of productivity, surface quality and manufacturing cost. Due to the high cutting temperature and cutting forces generated from the cutting zone, this process always requires the use of cutting tools with high hardness, wear resistance, good heat resistance [3]. Therefore, coated carbide, ceramic, CBN, and diamond tools have been widely applied to hard turning process [3-6].

Furthermore, being able to process in the dry condition, the cutting fluids are completely eliminated and have minimized the negative environmental impacts caused by the discharge of the used coolant. Therefore, dry hard turning is considered an environmentally friendly machining method, very suitable for sustainable machining trend nowadays [7]. AISI H13 chromium hot-work steel is widely used in hot and cold work tooling applications like die, molds, and shafts due to its excellent combination of high toughness and fatigue resistance [8].

The studies on the application of turning for machining hardened steels using coated carbide inserts are still not much. Therefore, the author made the experimental study on the effects of cutting speed, feed rate and cutting depth on cutting force components F_x, F_y, F_z in hard turning process of AISI H13 steel.

II. Methodology

2.1. Materials

The samples of AISI H13 alloy steel have the chemical composition shown in Table 1 and the mechanical properties shown in Table 2. The hardness of AISI H13 workpiece is 55HRC.

Table 1 – Chemical composition in % of AISI H13 tool steel

Element	Content (%)
Chromium, Cr	4.75-5.50
Molybdenum, Mo	1.10-1.75
Silicon, Si	0.80-1.20

Vanadium, V	0.80-1.20
Carbon, C	0.32-0.45
Nickel, Ni	0.3
Copper, Cu	0.25
Manganese, Mn	0.20-0.50
Phosphorus, P	0.03
Sulfur, S	0.03

Table 2. The mechanical properties of H13 tool steel

Properties	Metric	Imperial
Tensile strength, ultimate (@20°C	1200 - 1590 MPa	174000 - 231000 psi
Tensile strength, yield (@20°C	1000 - 1380 MPa	145000 - 200000 psi
Reduction of area (@20°C)	50.00%	50.00%
Modulus of elasticity (@20°C)	215 GPa	31200 ksi
Poisson's ratio	0.27-0.30	0.27-0.30

2.2 Experiment design

The experiment is carried out according to the factorial design 2^{k-p} with four variables (k = 3) with the help of Minitab 19 software. The input cutting parameters and their levels are given by Table 1.

Table 3. The input cutting parameters and their levels

Input machining parameters	Low	High
Cutting speed, V (m/min)	120	160
Feed rate, F (mm/rev)	0.05	0.15
Depth of cut, a_p (mm)	0.3	0.5

III. RESULTS AND DISCUSSION

The ANOVA analysis with 95% confidence level is carried out for cutting force components F_x, F_y, F_z with R^2 equal to 99.99%, 99.99% and 99.98%, respectively (Tables 4-6), which indicates that the experimental data fit very well with the experimental design model. It can be seen that the linear interactions of cutting speed, feed rate, and cutting depth have the p-values smaller than the significance level (0.05). It means that they have the significant influences on the response parameters F_x, F_y, F_z. For 2-way interaction, V*F contributes the strong impact on cutting force F_x, whereas V*a_p and F*a_p cause the little influence (Table 4). From the Table 5, V*F and F*a_p indicates the significant effects, but V*a_p has a little influence on F_y. Also, V*F, V*a_p and F*a_p all have the strong effects on F_z (Table 6). The observations can be also seen in the Pareto chart in Figures 1-3. From those, the feed rate has strongest effect on the cutting force components. The main reason is when the feed rate increases, the cross-cut section of the cut layer grows, so the cutting forces go up. The regression models for cutting force components are given by Equations 1-3.

Table 4. ANOVA results of cutting parameters on cutting force F_x

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	17619.3	2517.0	27259.18	0.000
Linear	3	17550.8	5850.3	63357.55	0.000
V	1	287.1	287.1	3109.60	0.000
F	1	17239.7	17239.7	186703.02	0.000
a_p	1	24.0	24.0	260.02	0.000
2-Way Interactions	3	68.5	22.8	247.19	0.000
V*F	1	68.4	68.4	740.68	0.000
V* a_p	1	0.0	0.0	0.13	0.727
F* a_p	1	0.1	0.1	0.76	0.409
3-Way Interactions	1	0.0	0.0	0.02	0.886
V*F*a_p	1	0.0	0.0	0.02	0.886
Error	8	0.7	0.1		
Total	15	17620.0			

Table 5. ANOVA results of cutting parameters on cutting force F_y

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	61361.2	8765.9	30165.45	0.000
Linear	3	60852.6	20284.2	69802.61	0.000
V	1	74.3	74.3	255.55	0.000
F	1	60770.9	60770.9	209126.58	0.000
a_p	1	7.5	7.5	25.69	0.001
2-Way Interactions	3	506.0	168.7	580.47	0.000

V*F	1	501.0	501.0	1723.97	0.000
V*a_p	1	0.1	0.1	0.43	0.532
F* a_p	1	4.9	4.9	17.00	0.003
3-Way Interactions	1	2.6	2.6	8.95	0.017
V*F*a_p	1	2.6	2.6	8.95	0.017
Error	8	2.3	0.3		
Total	15	61363.6			

Table 6. ANOVA results of cutting parameters on cutting force F_z

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	7	20908.3	2986.9	12576.44	0.000
Linear	3	19961.7	6653.9	28016.41	0.000
V	1	59.2	59.2	249.32	0.000
F	1	19882.4	19882.4	83715.41	0.000
a_p	1	20.1	20.1	84.51	0.000
2-Way Interactions	3	944.9	315.0	1326.17	0.000
V*F	1	941.3	941.3	3963.21	0.000
V* a_p	1	1.0	1.0	4.17	0.075
F* a_p	1	2.6	2.6	11.12	0.010
3-Way Interactions	1	1.7	1.7	7.34	0.027
V*F*a_p	1	1.7	1.7	7.34	0.027
Error	8	1.9	0.2		
Total	15	20910.2			

$$F_x = -6.39 + 0.0151V + 378.7F + 17.1a_p + 2.022\,V{*}F - 0.0250\,V{*}a_p - 29\,F{*}a_p + 0.113\,V{*}F{*}a_p \quad (1)$$

$$F_y = -44.13 + 0.2730V + 1834.7F - 44.7a_p - 3.983\,V{*}F + 0.447\,V{*}a_p + 453\,F{*}a_p - 4.03\,V{*}F{*}a_p \quad (2)$$

$$F_z = 159.67 - 0.9454V - 521.1F - 9.5a_p + 8.990\,V{*}F + 0.206\,V{*}a_p + 381\,F{*}a_p - 3.30V{*}F{*}a_p \quad (3)$$

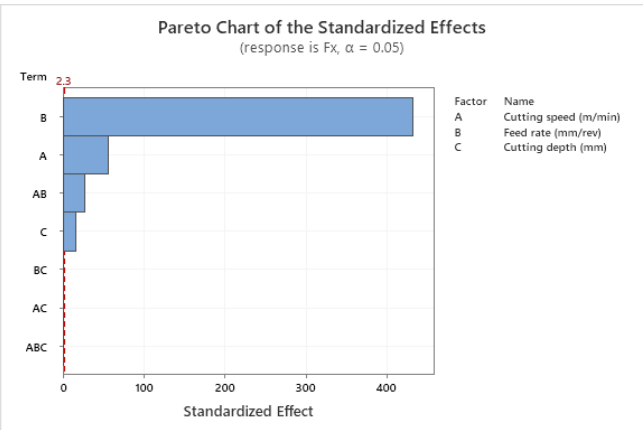

Figure 1. Pareto chart of effects of input machining factors on cutting force F_x

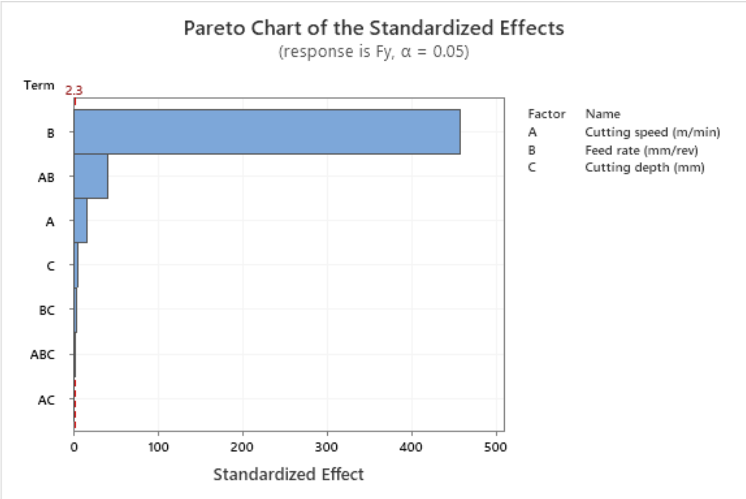

Figure 2. Pareto chart of effects of input machining factors on cutting force F_y

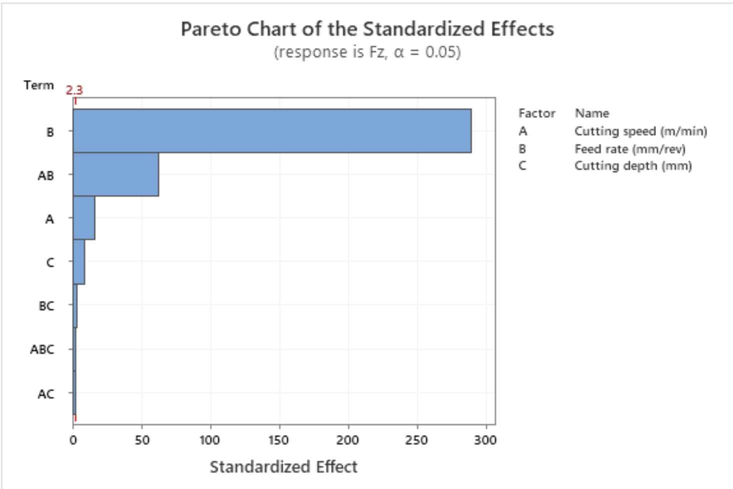

Figure 3. Pareto chart of effects of input machining factors on cutting force F_z

On the other hand, the interaction effects of cutting speed and feed rate also have strong influences on the cutting forces F_y, F_z. The increase in cutting condition in hard machining will accelerate the cutting forces and cutting temperature, which strongly influence the wear rate and the tool life of carbide tools. The more investigation is needed to be made in order to optimize the values of cutting parameters for minimal cutting forces and surface roughness.

IV. CONCLUSION

Hard turning process using coated carbide tool was successfully carried out under dry condition. The influence of cutting parameters consisting of cutting speed, feed rate, and depth of cut on hard turning performance was investigated in terms of cutting force components. Based on ANOVA results, the input machining variables presented the strong influence on cutting forces, in which feed rate caused the most significant effect on the response. The interaction effect of cutting speed and feed rate strongly affect the tangential force and thrust force.

In further research, more investigations will be concentrated on optimizing cutting condition. In addition, more focus will be given to investigate the influence on the surface quality.

Acknowledgments

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