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Experimental study on turning performance of 9CrSi hardened steel

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Abstract
Hard cutting processes have been playing the growing important role in machining field, in which the cutting parameters are still the crucial factors determining the machining performance. In this paper, the work aims to investigate the effect of cutting parameters on surface roughness R_q in hard turning process of 90CrSi steel (60HRC). Box-Behnken experimental planning design was utilized to study the influences of cutting speed, feed rate and depth of cut on surface roughness R_q. The experimental results exhibit that feed rate has the strongest effect on R_q, followed by the cutting speed, while the depth of cut has little influence. The interaction effect between the feed rate and depth of cut significantly influences on surface roughness R_q. Moreover, the technological guide for choosing cutting speed, feed rate and depth of cut was recommended for further studies.
Keywords: *Hardened steel, hard turning, cutting speed, feed rate, depth of cut, surface roughness.*

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I. INTRODUCTION

In metal cutting field, turning is still the most commonly used cutting process for machining cylindrical parts. This process still contributes a significant proportion of the material removal volume. Turning is the process of using a single cutting tool to perform a reciprocating motion combined with the circular motion of the workpiece to form the primary cutting motion. The depth of cut is obtained from the reciprocating motion perpendicular to the axis of rotation of the workpiece. The selection of the appropriate cutting parameters determines the efficiency of the turning process, especially when turning hard materials. For heat-treated steels often having high hardness and strength, it is often necessary to use cutting tool materials with high hardness and strength as well as good wear resistance such as carbide, ceramics, CBN, and so on. PCBN cutting tool inserts were used for hard turning of the engine crankpins [3]. The obtained results showed that the good surface quality and tool life can be achieved by using CBN cutting tool material. The feed rate has the strongest influence on surface roughness, followed by cutting speed. The depth of cut has little effects. The abrasive flank wear accelerates with the increase of cutting temperature and cutting force. Another study on investigation of CBN tool performance and wear behavior in finish hard turning of hardened AISI 52100 steel. The abrasive wear was the main mechanism and the transferred layer on the flank wear may cause the adhesion of the binder compound, which significantly influences the tool wear [4]. Surface roughness obtained turning process is strongly affected by feed rate and cutting speed [5]. Among the cutting force components, the thrust force has the highest value, and it is very sensitive to workpiece hardness and tool wear evolution. One parameter that determines the efficiency of the cutting process and determines whether hard turning can be used as an alternative to the grinding process is the quality of the machined surface [6]. Therefore, studying the effect of cutting mode parameters on machined surface roughness has practical and technical significance [7]. Accordingly, the author is motivated to study the influences of cutting speed, feed rate and depth of cut on surface roughness R_q in hard turning of 90CrSi (60HRC) using carbide tool.

II. MATERIAL AND METHODS

The experimental set up was shown in Figure 1. The coated carbide inserts were used. Surface roughness R_q values were measured by SJ-210 Surface Roughness Tester (Japan). The 90CrSi steel samples (60HRC) were used and the chemical composition is given by Table 1.

Table 1 – Chemical composition in % of 90CrSi steel

Element	C	Si	Mn	Ni	S	P	Cr	Mo	W	V	Ti	Cu
Weight (%)	0.85-0.95	1.20-1.60	0.30-0.60	Max 0.40	Max 0.03	Max 0.03	0.95-1.25	Max 0.20	Max 0.20	Max 0.15	Max 0.03	Max 0.3

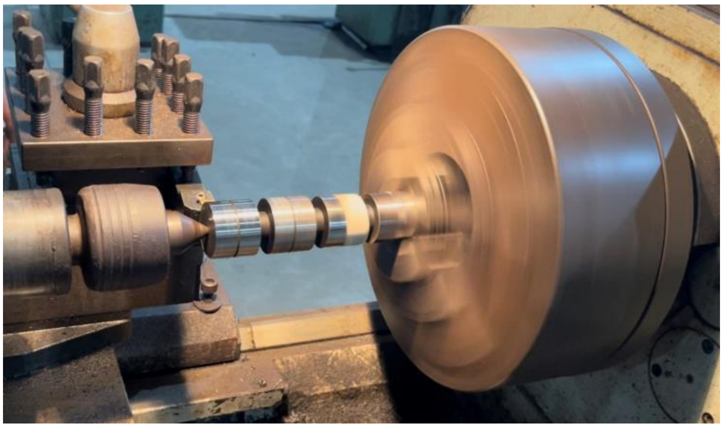

Figure 1. The experimental set up

The Box-Behnken design of three factors and their levels is given by Table 2. The cutting trials were implemented by following the Box-Behnken design, and the values of surface roughness R_q were measured three times right after each trial. The measured surface roughness values were taken by the average values.

Table 2. Factorial design of three factors and their levels

Input machining parameters	Low level	High level
Cutting speed, V (*rpm*)	650	950
Feed rate, f (*mm/rev.*)	0.05	0.15
Depth of cut, a_p (*mm*)	0.1	0.2

III. RESULTS AND DISCUSSION

The hard turning experiments were conducted by following the Box-Behnken experimental design, and the R_q values were collected and processed. The ANOVA analysis result is shown in Table 3. The Pareto chart of the effects of input variables on R_q is shown in Figure 2. The main effects and interaction effects of the input parameters on the surface roughness R_q are shown in figures 3, 4.

Table 3. Results of the ANOVA analysis of surface roughness R_q

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.072355	0.008039	301.85	0.000
Linear	3	0.072202	0.024067	903.66	0.000
V (rev/min)	1	0.000648	0.000648	24.33	0.004
f (mm/rev)	1	0.071442	0.071442	2682.43	0.000
t (mm)	1	0.000112	0.000112	4.22	0.095
Square	3	0.000143	0.000048	1.79	0.265
V (rev/min)*V (rev/min)	1	0.000054	0.000054	2.04	0.213
f (mm/rev)*f (mm/rev)	1	0.000069	0.000069	2.60	0.168
t (mm)*t (mm)	1	0.000041	0.000041	1.54	0.270
2-Way Interaction	3	0.000009	0.000003	0.11	0.949
V (rev/min)*f (mm/rev)	1	0.000004	0.000004	0.15	0.714
V (rev/min)*t (mm)	1	0.000001	0.000001	0.04	0.854
f (mm/rev)*t (mm)	1	0.000004	0.000004	0.15	0.714
Error	5	0.000133	0.000027		
Lack-of-Fit	3	0.000128	0.000043	18.36	0.052
Pure Error	2	0.000005	0.000002		
Total	14	0.072488			

The regression equation for surface roughness R_q is given below:

R_q (µm) = 0.6081 - 0.000336*V + 1.377*f - 0.312*t + 0.000000*V*V+ 1.73*f*f + 1.33*t*t + 0.000133*V*f - 0.000067*V*t + 0.40*f*t (1)

From Figure 2, the feed rate has the strongest influence on R_q, followed by cutting speed. The depth of cut has little effect. From Figure 3, it can be seen that with increasing feed rate, the surface roughness values rapidly go up. On the other hand, the R_q values tend to decrease with the growth of cutting speed. For the increase of depth of cut, R_q rises very little. Among the investigated parameters, the interaction effect between feed rate and depth of cut has the greatest influence on surface roughness, while the other interaction effects have little influences (Figure 4).

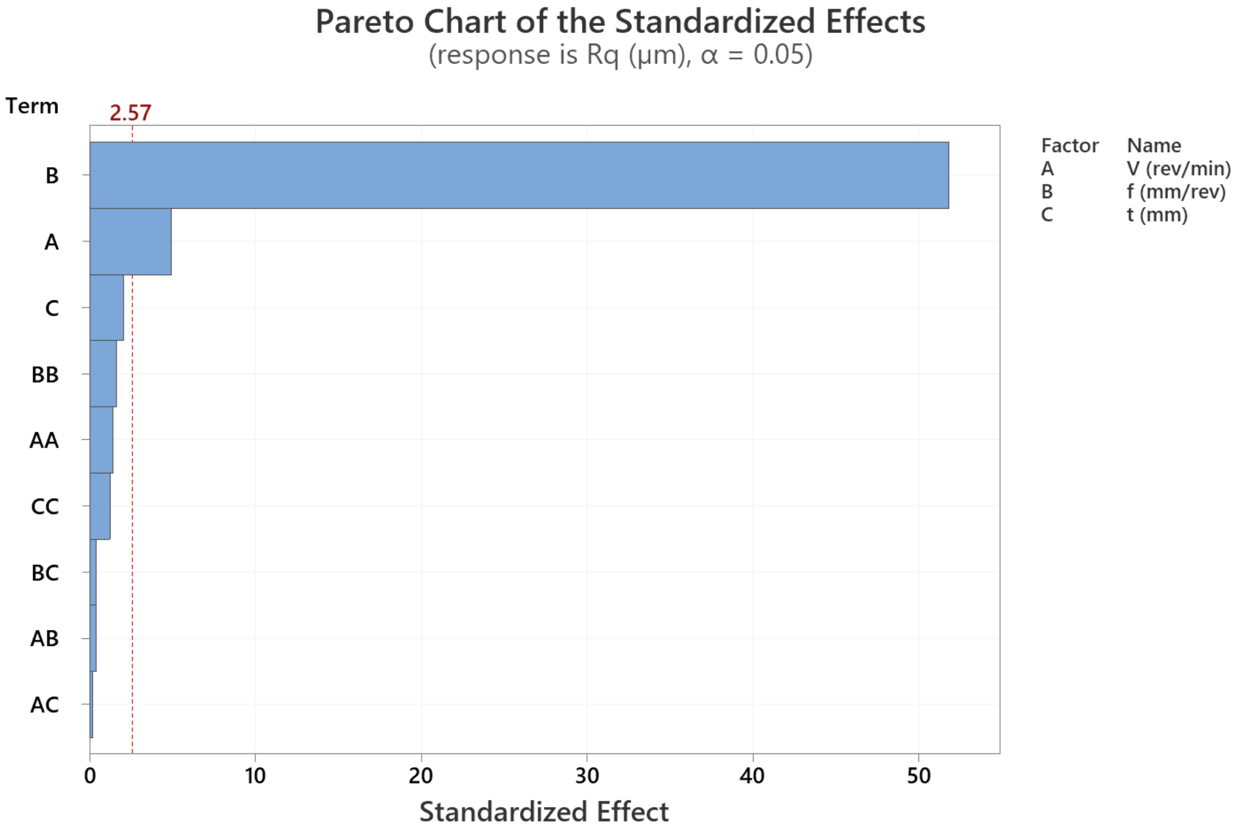

Figure 2. Pareto chart of input variables on surface roughness R_q

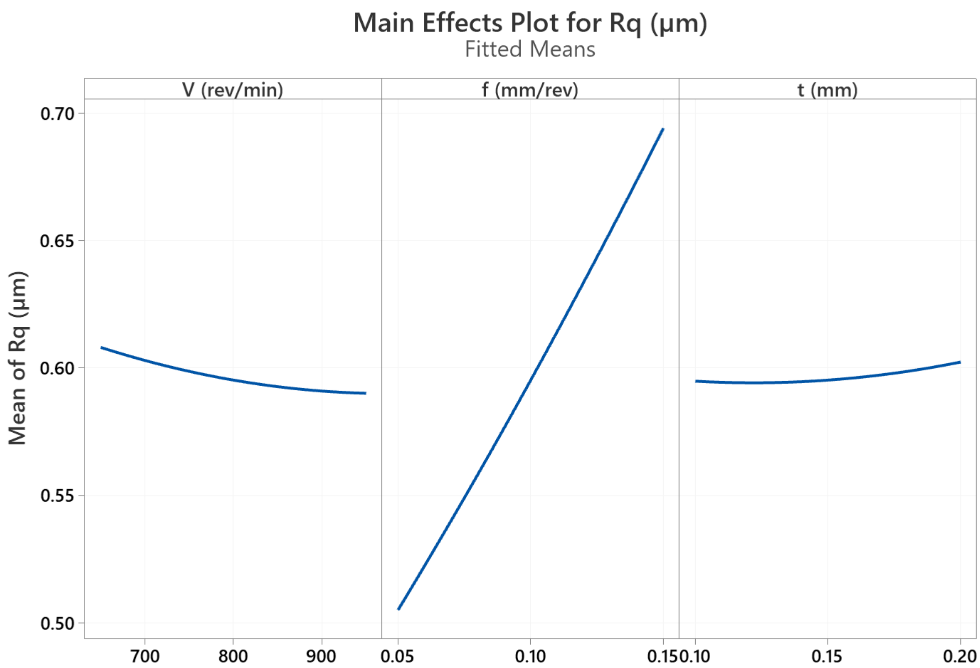

Figure 3. Main effects of input variables on surface roughness R_q

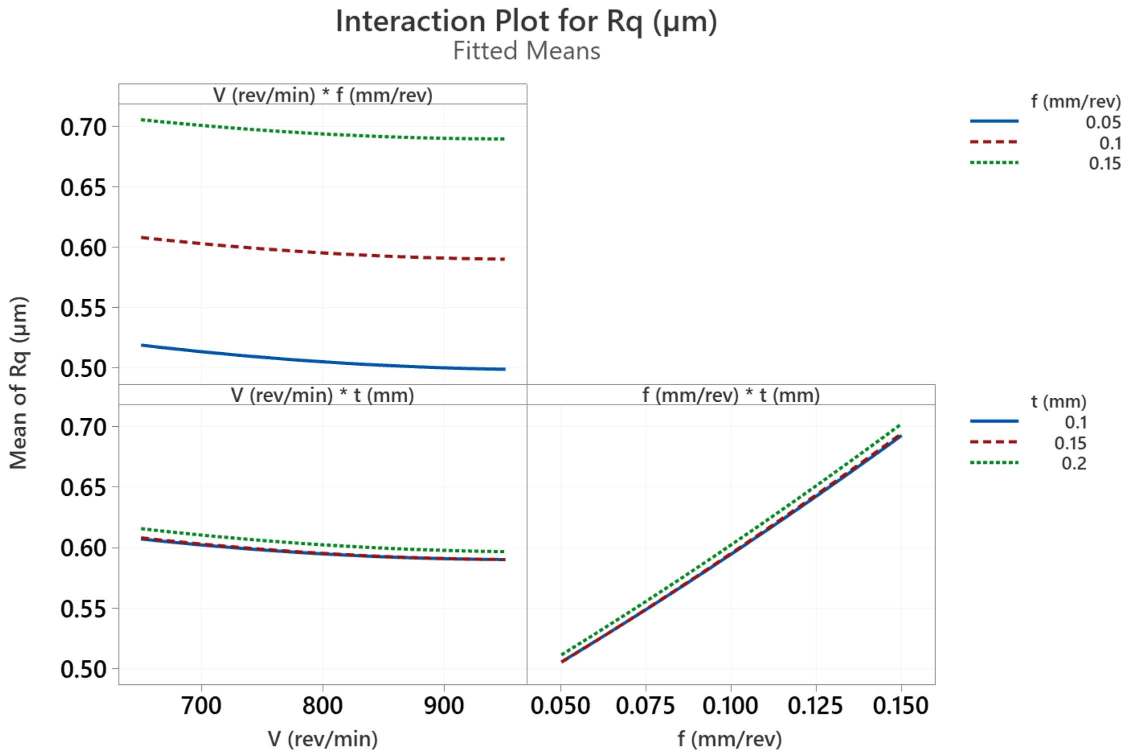

Figure 4. Interaction effects of input variables on surface roughness R_q

IV. CONCLUSION

In this work, the effects of cutting speed, feed rate and depth of cut were studied and investigated in hard turning process of 90CrSi steel (60HRC). The Box-Behnken experimental planning design with the help of Minitab 19 software was applied. The main effects and interaction effects of input machining parameters were evaluated to reveal that feed rate and the interaction between feed rate and depth of cut contribute the strong impact on the objective function R_q. The research results play an important role for future studies in choosing the cutting parameters for turning of hardened steels. This is also a very important factor that determines the efficiency of the cutting process because the heat and force generated during the hard cutting process are very large. In further research, more investigation should be focused on optimizing the cutting parameters and surface microstructure.

Acknowledgments

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