Investigating the Effect of Cutting Parameters on Surface Roughness and Flank Wear in the Interrupted Hard Turning of Hardened SKD 11 Steel using High CBN Inserts

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Abstract: Hard turning is a potential machining process to replace for grinding process due to large advantages such as material removal rate, good surface integrity, and friendly environment. This process is also used to process discontinuous surface parts. This study focuses on analyzing the effect of cutting parameters on surface roughness and flank wear after interrupted hard turning of SKD11 steel using CBN inserts. The effect of cutting parameters and interacted between them on the surface roughness and the flank wear were analyzed by using the full factorial design having the central trials. The results investigated that the feed rate is the most significant parameter affecting on the surface roughness in the machining process and the cutting speed strongly affects on the flank wear in the interrupted hard turning of SKD11 steel using high CBN inserts. The results of ANOVA analysis for the surface roughness and the flank wear indicated that the need to investigate and use the curve model to describe the effect of the cutting parameters on the surface roughness and the flank wear.

Keywords: Hard Turning, SKD11, CBN, Flank Wear, Surface Roughness

I. INTRODUCTION

With many outstanding advantages, hard turning is a finishing method applied more and more widely in industries. In the hard turning process, the most important thing is the selection of cutting tool material and grade. The hard turning process is commonly applied to machine the hardened alloy steel with high hardness (hardness > 45 HRC). It is used to replace the grinding process because of its preferable features such as having high accuracy, surface roughness, lower investment, creation of compressed residual stress, and not using cooling lubrication (Davim & Astakhov, 2011). Basic knowledge of each cutting tool material and its performance is important when making the correct selection. Recently, with the development of cutting tool materials, some new tool materials have been used in the hard turning process such as CBN, PCBN and ceramic (Smith & Smith, 1993). In where the CBN is the cutting tool material that can be used to machine the parts having the hardness more than 60 HRC or the parts also have irregular surfaces. The study of De Godoy & Diniz (2011) indicated that the cutting tool CBN is more effective than ceramic in the interrupted hard turning process. Oliveira et al. (2009) compared the surface roughness and the tool wear between the continuous and interrupted hard turning using PCBN insert. Other researchers analyzed the surface quality and the effect of cutting condition to the surface roughness in the interrupted hard turning process using CBN inserts (Dogra et al., 2012; Pavel et al., 2005). Nevertheless, they just investigated the influence of the flank wear on the surface roughness. Also, the effects of the cutting speed and feed rate to the surface roughness and tool wear with workpiece had the hardness of 50 HRC only. However, these researches also used the low CBN, and the light interrupted workpieces. In this study, we adopted the fully interrupted workpieces with high hardness (60-62 HRC) and the high CBN inserts. The effects of all three cutting parameters and interactions between them to the surface roughness and the flank wear in the interrupted hard turning process were analyzed by the full factorial model.

II. EXPERIMENT AND METHOD

In this research, the experiment is set up as figure 1. All the experiments were performed in the CNC turning centre QTS 200 made by Mazak Company in the Thai Nguyen university of technology's CNC lab. The CBN 7525 inserts of the Sandvik having CNGA120412S0153B-7525 code were used for this study. These inserts were made by CB7525 grade, a very tough grade and contain 90% CBN with fine grains in a ceramic binder, having Negative land and ER treated cutting edge. The workpieces are made by the hardened SKD11 steel (60HRC) and have dimension 60 mm x 110 mm. these workpieces have six axial slots cut before hardening. The chemical composition of SKD11 steel is shown in table 1.

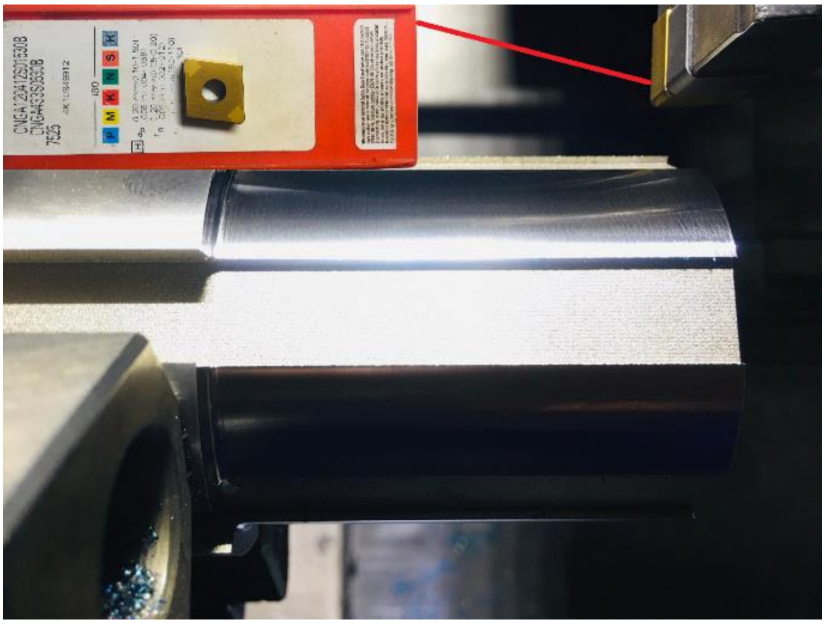

Figure 1. Devices using in the experiments

Table 1. Chemical composition of SKD11 steel

C	Si	Mn	Cr	Mo	V	Fe
1.63	0.25	0.45	11.89	0.89	0.37	Balance

Minitab 18 Software (Minitab Inc., USA) is applied to build an experimental model for this research. A full factorial model was designed with input parameters and two levels. This experimental model has 10 experiments including 8 factorial points and 2 centre points, as figure 2. The ranges of the input parameters are given in table 2. The experimental matrix and the results of the surface roughness and the flank wear are shown in table 3. The experiments were performed with the same cutting length of 500m. The surface roughness is measured by the Mitutoyo's SJ210 roughness gauge

and the flank wear width is measured by the digital microscope of Keyence company after cutting the cutting length of 200m.

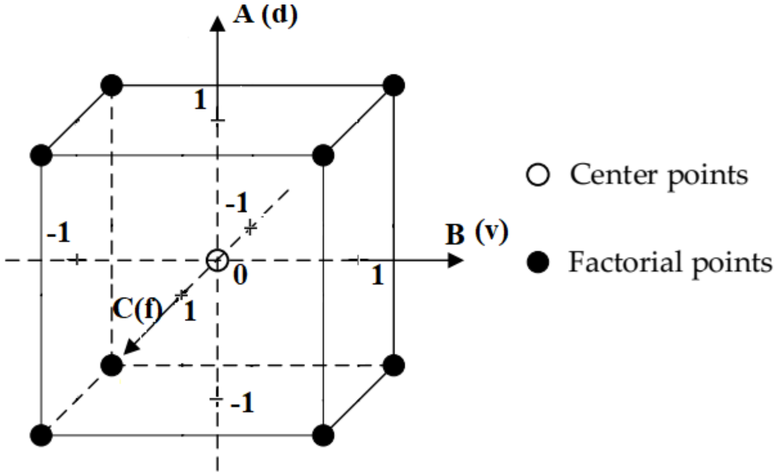

Figure 2. Full factorial design with two levels

Table 2 input parameters and their levels

Parameters	Units	Levels		
		-1	0	1
A – Depth of cut (d)	mm	0.1	0.15	0.2
B - Cutting speed (v)	m/min	120	140	160
C – Feed rate (f)	mm/rev	0.08	0.12	0.16

Table 3. Experimental matric for full factorial design

StdOrder	RunOrder	CenterPt	Blocks	d (mm)	V (m/min)	f (mm/rev)	Ra (µm)	VB (µm)
9	1	0	1	0.15	140	0.12	0.623	172
4	2	1	1	0.2	160	0.08	0.643	340
5	3	1	1	0.1	120	0.16	0.807	225.3
2	4	1	1	0.2	120	0.08	0.502	212.1
7	5	1	1	0.1	160	0.16	1.543	251.2
6	6	1	1	0.2	120	0.16	1.758	279.1
1	7	1	1	0.1	120	0.08	0.405	292.2
3	8	1	1	0.1	160	0.08	0.613	323.5
10	9	0	1	0.15	140	0.12	0.617	167
8	10	1	1	0.2	160	0.16	1.758	279.1

III. RESULT AND DISCUSSION

Analysis of the effect of the cutting parameter on the surface roughness

The ANOVA analyses for the surface roughness were made with a meaningful level of 0.05 and shown in table 4. The analysis results show that all factors and interactions between them are significantly affected to the surface roughness in the interrupted hard turning process, as Figure 3. The feed rate is the most powerful effect on surface roughness, contributing up to 72.6%. The cutting speed, cutting depth, and interactions also significantly affect to the surface roughness but contribute less than 10%.

The effects of the cutting parameters to the surface roughness are observed in Figure 4. The result shows that the surface roughness increased rapidly with increasing the feed rate from 0.08 to 0.16. But when increasing the cutting speed or cutting depth, the surface roughness increased slower. The interacted effects of the cutting parameters to the surface roughness are described in Figure 5. With the small feed rate (0.08 mm/rev) the surface roughness almost unchanged when increasing the cutting depth from 0.1 mm to 0.2 mm. However, with a large feed rate of 0.16 mm, the cutting depth affects greatly the surface roughness, the surface roughness increased by 50% when increasing the cutting depth from 0.1 to 0.2 mm. Similarly, the cutting depth affects powerfully the surface roughness when machining at a low cutting speed of 120 m/min, but affects weakly the surface roughness when turning at the high cutting speed of 160 m/min.

Table 3. Analysis of Variance for roughness surface

Source	DF	Adj SS	Adj MS	F-Value	P-Value	C%
Model	8	2.59584	0.32448	18026.65	0.006	
Linear	3	2.07016	0.69005	38336.3	0.004	
d	1	0.20898	0.20898	11610.06	0.006	8.9
V	1	0.14715	0.14715	8175.17	0.007	6.2
f	1	1.71403	1.71403	95223.67	0.002	72.6
2-Way Int.	3	0.23426	0.07809	4338.19	0.011	
d*V	1	0.0806	0.0806	4477.84	0.01	3.4
d *f	1	0.13494	0.13494	7496.67	0.007	5.7
V *f	1	0.01872	0.01872	1040.06	0.02	0.8
3-Way Int.	1	0.05595	0.05595	3108.06	0.011	
d *V*f	1	0.05595	0.05595	3108.06	0.011	2.4
Curvature	1	0.23547	0.23547	13081.61	0.006	
Error	1	0.00002	0.00002			
Total	9	2.59585				

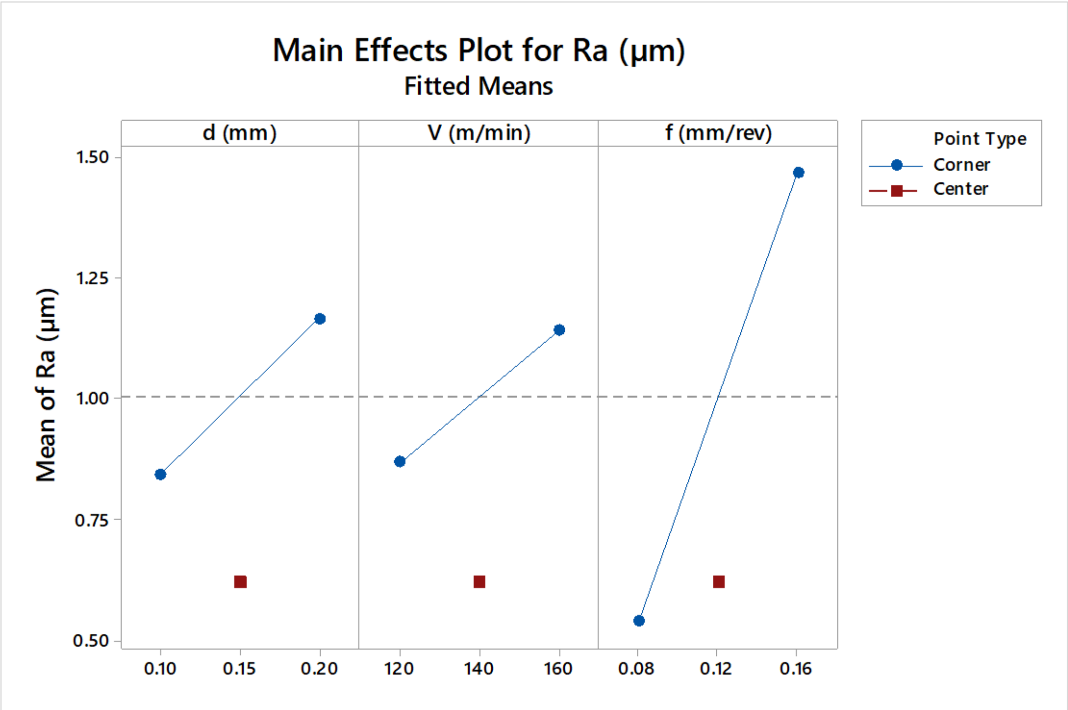

Figure 4. The main effects plot for the surface roughness

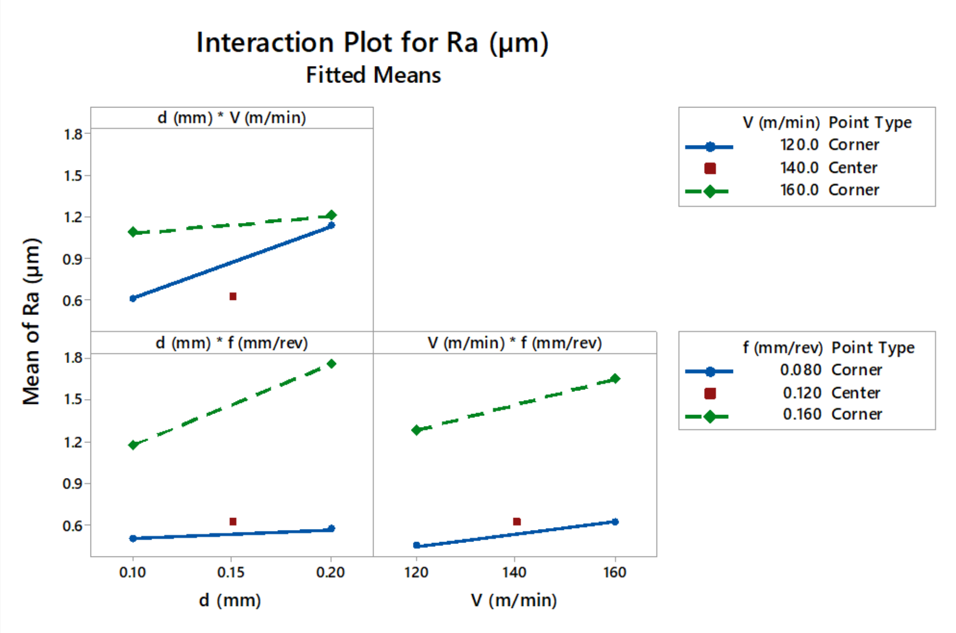

Figure 5. The interaction effect of the cutting parameter to the surface roughness

Analysis of the effects of the cutting parameters to the flank wear

The flank wear of the turning inserts is measured when machining with a cutting length of 500 m on a digital microscope. The ANOVA analysis for rear-wear is carried out with a mean of 0.05. The results of the ANOVA analysis for the flank wear are shown in table 5. The cutting speed, feed rate, the interaction V-f and d-f have P-value < 0.05, which means a significant effect on the flank wear in the interrupted hard turning process using CBN inserts. The results of ANOVA analysis also showed the need to investigate and use the curve model to describe the effect of the cutting parameters on the flank wear.

Table 5. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	31812.9	3976.6	318.13	0.043
Linear	3	6538.2	2179.4	174.35	0.056
d (mm)	1	41.0	41.0	3.28	0.321
V (m/min)	1	4282.8	4282.8	342.62	0.034
f (mm/rev)	1	2214.5	2214.5	177.16	0.048
2-Way Interactions	3	5484.9	1828.3	146.26	0.061
d (mm)*V (m/min)	1	624.8	624.8	49.98	0.089
d (mm)*f (mm/rev)	1	2639.0	2639.0	211.12	0.044
V (m/min)*f (mm/rev)	1	2221.1	2221.1	177.69	0.048
3-Way Interactions	1	1875.8	1875.8	150.06	0.052
d (mm)*V (m/min)*f (mm/rev)	1	1875.8	1875.8	150.06	0.052
Curvature	1	17914.1	17914.1	1433.12	0.017
Error	1	12.5	12.5		
Total	9	31825.4			

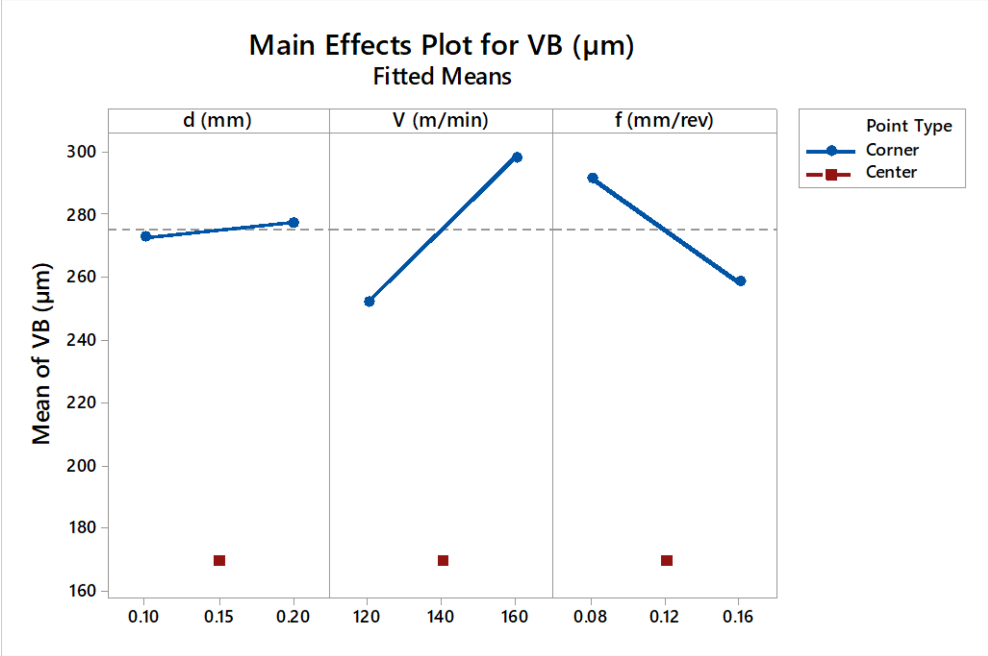

Figure 6. The main effects of the cutting parameters to the flank wear

Figure 6 describes the effects of the process parameters of cutting to the flank wear in the interrupted hard turning the hardened SKD11 steel (60HRC) using CBN inserts. The result shows that the cutting speed is the most influential factor in the flank wear. In the investigated range, the feed rate is also a significant effect on the flank wear but less. Cutting depth influences very little to the flank wear. The interacted effects between the cutting parameters to the flank wear were shown in figure 7. The results showed that the interaction of V&F and D&F was largely influenced on the flank wear. With a low cutting speed of 120 m/min, the flank wear does not change with increasing feed rate and depth of cut. With a cutting speed of 160 m/min, the flank wear increases with a reduction in the feed rat from 0.16 to 0.08 mm/rev and decreases with reducing the cutting depth from 0.2 mm to 0.1 mm. With a small cutting depth, the flank wear increases with the feed rate decreases to 0.08 mm/rev.

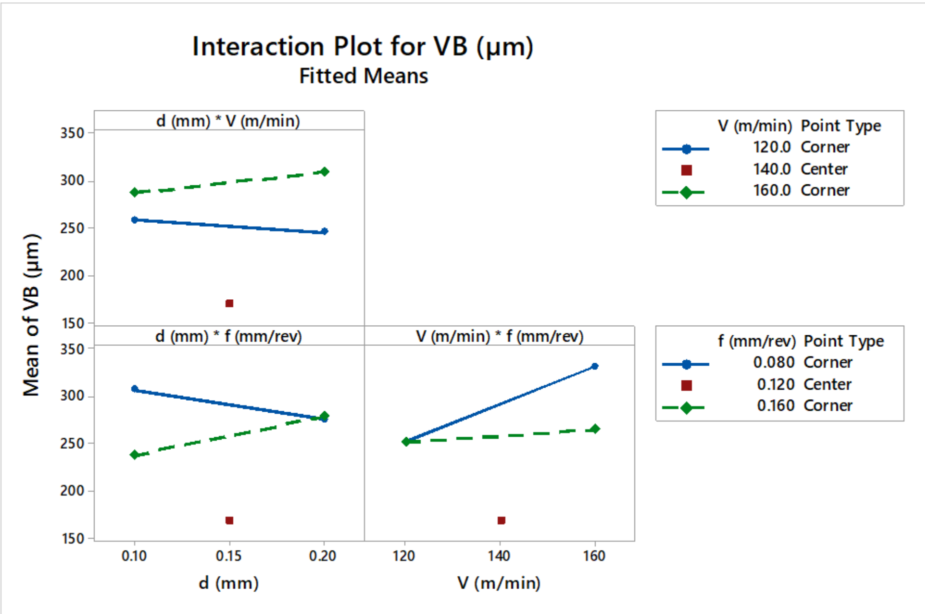

Figure 7. The interaction effects of the cutting parameters to the flank wear

IV. CONCLUSION

The effects of cutting parameters on the surface roughness and the flank wear in the interrupted hard turning process of hardened SKD11 (60HRC) using high CBN inserts have been analyzed by using the full factorial design. The feed rate is the most powerful factor effecting on the surface roughness, the surface roughness increase with increasing the feed rate. And the cutting speed strongly affects on the flank wear in the interrupted hard turning of SKD11 steel using high CBN inserts. The results also indicated that the lineal model is not suitable for describing the effect of the cutting parameters on the surface roughness and tool wear in the interrupted hard turning process using high CBN inserts. A response Surface Methodology design should be applied for determining the curve model to describe these effects.

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