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Investigated the flank wear of high CBN inserts in the fully interrupted hard turning process

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Abstract
The machining discontinuous surface process encounters many difficulties. Selecting an appropriate combination of tool material and cutting parameters is crucial to minimize tool wear. This paper utilizes the face central composite design to identify the impact of cutting parameters on the flank wear of high CBN inserts in a fully interrupted hard turning process. The findings indicate that cutting speed exerts the most significant influence on flank wear. A predictive model for flank wear was developed based on these cutting parameters. An optimized model was also proposed, suggesting the ideal parameters (V-120 m/min, f-0.167 mm/rev, and d-0.139 mm) for the minimizing flank wear 120.46 µm. A validation experiment at these conditions measured a CBN insert wear of 137.1 µm, showing a 13.8% deviation from the predicted result. Furthermore, the study conducted a preliminary analysis and forecasted the wear pattern of tools in interrupted hard turning using TiN-coated CBN inserts.

Keywords: *Discontinuous, cutting tool, hard machining, wear, CBN*

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I. INTRODUCTION

Nowadays, the hard turning process is an alternative to grinding when machining parts with hardness above 45 HRC due to its advantages, such as high precision, improved surface finish, lower investment costs, generation of compressive residual stress, and the elimination of cooling lubrication [1] & [2]. Alloy steel parts like SKD11, often treated with heat for enhanced durability and wear resistance, are increasingly used [3]. Many of these parts also feature irregular surfaces. The standard tools for both hard turning and interrupted turning processes are made of CBN or ceramic, known for their high hardness and chemical stability [4]. CBN inserts are commonly used in hardened steel intermittent hard turning, due to special properties such as high hardness, high heat transfer capacity, low thermal expansion, and high toughness [5] & [7]. Therefore, CBN inserts have higher wear resistance and longer life than Ceramic chips in intermittent hard turning [6]. Pavel's 2002 study showed that when the hard turning of 1137 steel with CBN inserts is intermittent, mechanical wear mainly occurs [8]. However, this study only stopped analyzing the wear mechanism for low CBN inserts and workpiece materials with hardness below 50 HRC. In 2012, Dogra et al. analyzed the machined surface quality and tool life when machining using coated carbide chips and CBN tools. The results of the study showed that mechanical wear occurred at low speeds and diffusion wear occurred at high cutting speeds when hard turning with CBN inserts [9]. C.E.H. Ventura analyzed the influence of cutting edge geometries on CBN tool wear in interrupted hard turning [10]. The results showed that the tool with a single chamfered cutting edge gave the least tool wear as it strengthened the cutting edge without significantly raising mechanical and thermal loads. Attrition was identified as the primary wear mechanism across all micro geometries. Nayak, M. and Sehgal, R. (2019), studied the effects of several CBN grades, cutting speeds, and feed rates on cutting forces and tool wear in Continuous and Interrupted Hard Turning of AISI D6 Steel. This study developed a mathematical model that showed the effects of cutting parameters on shear forces and tool wear with CBN inserts [11]. The results showed that Abrasion, diffusion, and tribo-chemical wear occurred mainly in interrupted hard turning. However, this research also focused on the hard turning process with light interrupted workpieces and low CBN inserts. Therefore, the study focused on analyzing the effects of process parameters and their interactions in the fully interrupted hard turning of the fully interrupted workpieces with high hardness (60-62 HRC) and the high CBN inserts.

II. MATERIAL AND METHOD

The interrupted hard turning process is performed under dry machining conditions on the QTS-200 of Mazak turning center at Thai Nguyen University of Technology. This research used the workpieces made by SKD11 steel having high hardness (60-62 HRC) with the diameter of 60 mm x length 100 mm and six grooves in the cylinder surface (Figure 1). The SKD11 steel used in the study is an alloy steel having excellent wear resistance and exceptional toughness, with the composition as in Table 1. The machining process uses Sanvik's CBN inserts with code CNGA120412S0123B-7525. These inserts have a high CBN content (90%) and coated with TiN. The flank wear was measured by a Keyence electron microscope and analyzed by SEM scanning electron microscope.

Figure 1. The experimental process

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

In this study, three cutting parameters of the interrupted hard turning process were selected, including the cutting speed, feed rate, and depth of cut. A 2k factorial experimental design was applied with eight corner points and two center points to evaluate the influence of the investigated variables on backside wear. After the ANOVA analysis for the flank wear was performed by using the 2k experimental model, a response surface method with face central composite design (RSM-FCCD model) was proposed with 6-star points around the center and added four center points. The RSM-FCCD experimental model was used to analyze the relationship between three input parameters of the cutting process and the flank wear.

Table 2. Input parameters and their levels

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

Table 3. Experimental matrix for the RSM-FCCD design

Std Order	Run Order	Pt Type	d (mm)	V (m/min)	f (mm/rev)	VB (μm)
19	1	0	0,15	140	0,12	167
17	2	0	0,15	140	0,12	172
7	3	1	0,1	160	0,16	251,2
2	4	1	0,2	120	0,08	212,1
18	5	0	0,15	140	0,12	159
8	6	1	0,2	160	0,16	279,1
6	7	1	0,2	120	0,16	137,1
12	8	-1	0,15	160	0,12	172,7
13	9	-1	0,15	140	0,08	210
4	10	1	0,2	160	0,08	340
15	11	0	0,15	140	0,12	162,3
16	12	0	0,15	140	0,12	160,8
10	13	-1	0,2	140	0,12	225,7
11	14	-1	0,15	120	0,12	153,7
9	15	-1	0,1	140	0,12	192
1	16	1	0,1	120	0,08	292,2
5	17	1	0,1	120	0,16	225,3
20	18	0	0,15	140	0,12	168,1
3	19	1	0,1	160	0,08	323,5
14	20	-1	0,15	140	0,16	170,3

III. RESULTS AND DISCUSSION

3.1 The influence of survey variables on the flank wear

The flank wear of CBN inserts is measured by electron microscope, after the cutting length of 200m, the results are shown in Table 3. The results of ANOVA analysis for the flank wear with experimental model RSM - FCCD are shown in Table 4. The results indicated that the factors of cutting speed (V), feed rate (f) and interactions d*d, f*f and d*V significantly affect the flank wear because their P-values are smaller than the reference P-value (0.05). Depth of cut (d), interactions V*V and d*f & V*f have very little effect on the flank wear.

Figure 2 shows the main effects of the investigated cutting parameters on the average value of the flank wear in hard turning of interrupted surfaces using CBN inserts. The results show that the flank wear increases rapidly and continuously with increasing cutting speed, which is consistent with the theory of hard machining. Meanwhile, the flank wear of CBN inserts increases when the depth of cut is reduced from 0.15 mm to 0.1 mm or the feed rate is reduced from 0.12 mm/rev to 0.08 mm/rev. At the same time, the flank wear also increases when the depth of cut is increased from 0.15 to 0.2 mm or the feed rate is increased from 0.14 to 0.16 mm/rev. This can be explained by the fact that when the depth of cut is small or the feed rate is small, the chip thickness is too thin, causing the sliding phenomenon, and making the cutting tool wear faster.

Table 4 Analysis of variance for the flank wear

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	63550.5	7061.2	17.51	0.000
Linear	3	22702.0	7567.3	18.76	0.000
d (mm)	1	813.6	813.6	2.02	0.186
V (m/min)	1	11978.5	11978.5	29.70	0.000
f (mm/rev)	1	9909.9	9909.9	24.57	0.001
Square	3	35182.4	11727.5	29.08	0.000
d *d	1	7756.6	7756.6	19.23	0.001
V *V	1	153.0	153.0	0.38	0.552
f*f	1	3256.0	3256.0	8.07	0.018
2-Way Interaction	3	5666.0	1888.7	4.68	0.027
d*V	1	5655.2	5655.2	14.02	0.004
d*f	1	1.4	1.4	0.00	0.955
V*f	1	9.5	9.5	0.02	0.881
Error	10	4033.4	403.3		
Lack-of-Fit	5	3909.9	782.0	31.68	0.001
Pure Error	5	123.4	24.7		

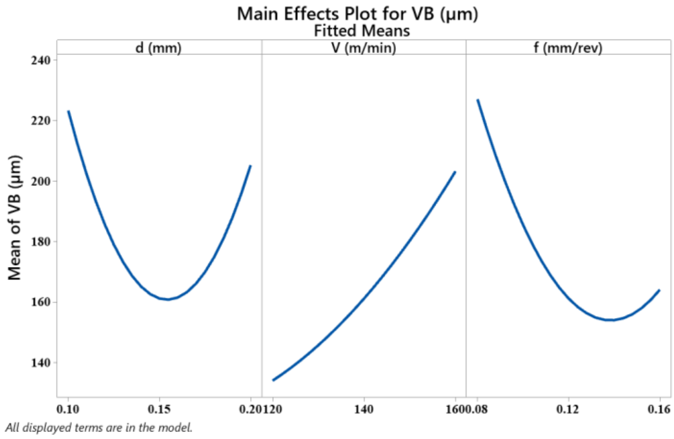

Figure 2. Effects of cutting parameters on the flank wear

Figure 3 illustrates the interaction between the survey factors on the flank wear. The results indicated that the interaction V*d is the most effect factor the flank wear in the fully interrupted hard turning process using CBN inserts. With a small cutting depth of 0.1 mm, the flank wear increases slowly when the cutting speed increases from 120 m/min to 160 m/min. With a larger cutting depth, the flank wear increases rapidly when the cutting speed increases from 120 m/min to 160 m/min.

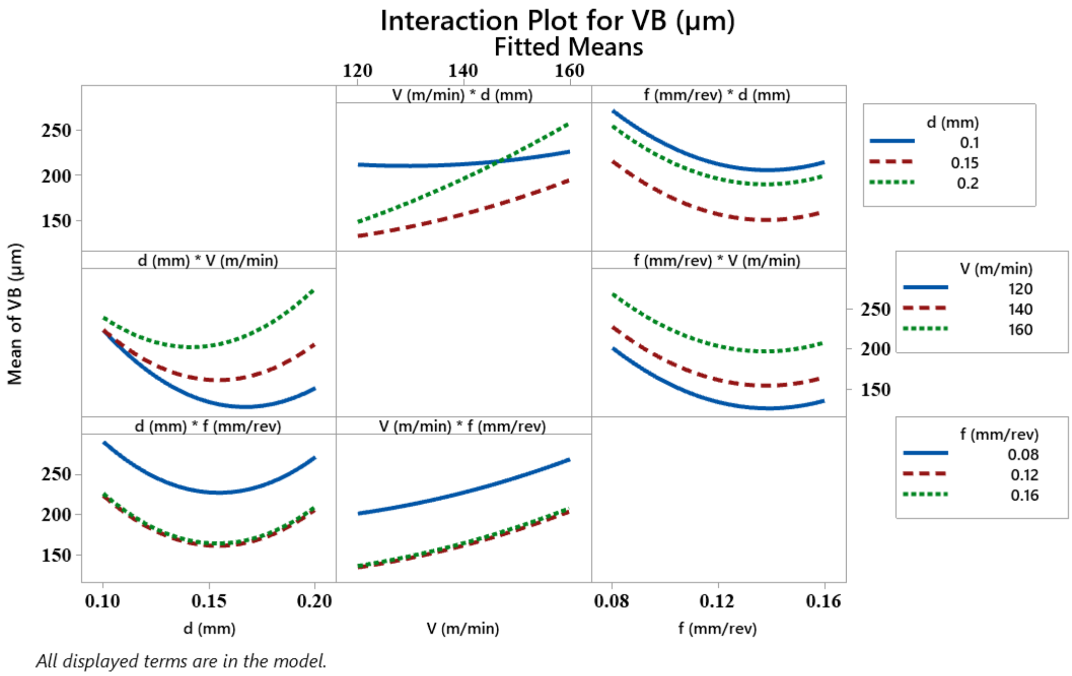

Figure 3. Interactive effect of cutting parameters on the flank wear

Figure 4 shows the contour diagram of the flank wear of CBN inserts. The plots show the influence of the cutting speed and feed rate on the flank wear amount with a cutting depth of 0.15mm. The results show that the flank wear amount can be less than 150 µm when using a feed rate of 0.11 - 0.16 mm/rev and a cutting speed of about 120 - 135 m/min. When the cutting speed increases to 160 m/min, the flank wear amount increases rapidly. Thus, with the contour diagram, technicians can easily select a set of technological parameters with a certain flank wear value range.

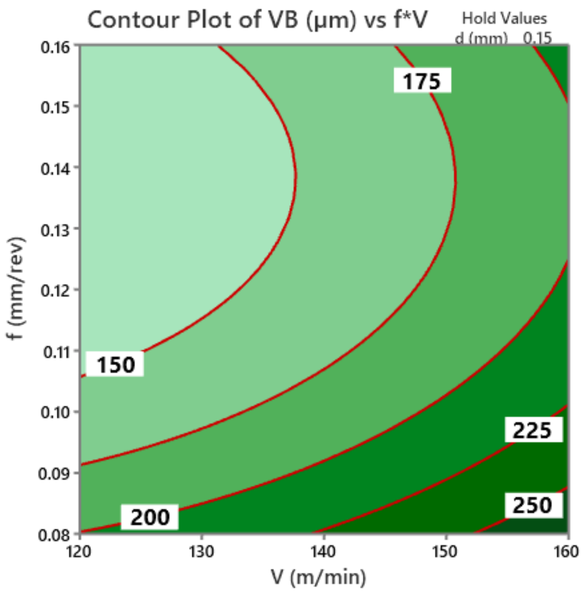

Figure 4. Contour graph of the flank wear

3.2. Minimizing the flank Wear

The flank prediction model for the interupted hard turning process has been constructed through regression by using the FCCD experimental model with a reliability of 95%. The experimental results show that a reliable and useful statistical model based on ANOVA analysis has been thus established. The second-order equation of the flank wear in related to cutting parameters are described in the following equation:

VB=1778 – 10300.d- 7.64 V - 6170 f + 21244 d *d +0.0186 V*V + 21506 f *f + 26.59 d*V + 206 d*f + 1.36 V*f

Where VB (µm) is the flank wear length; V (m/min) is the cutting speed; f (mm/rev) is the feed rate; d (mm) is the cutting depth.

The value of R-square (R-sq) showed that 94.03 % of the differences in the investigated parameters were presented in the mathematical model. The value of the adjusted R-square is determined as 88.66%, which is a modified version of R-squared that has been adjusted for the number of predictors in the model. The prediction R-square (R-sq (pred)) investigates that predicted model is supposed to illustrate about 55.22% of the variability in new data and is suitable to the value of the adjusted R-square. Therefore, this mathematical model is suitable for predicting the flank wear in the interrupted hard turning process using CBN inserts.

The optimal parameters for the flank Wear in hard turning of discontinuous surfaces of SKD11 steel with CBN inserts were determined using the optimization function in Minitab. The minimization objective was chosen since smaller flank Wear is better. The optimization results are shown in Figure 5. The flank wear reached its minimum value (120.46 µm) at a depth of cut of 0.167 mm, a cutting speed of 120 m/min, and a feed rate of 0.139 mm/rev.

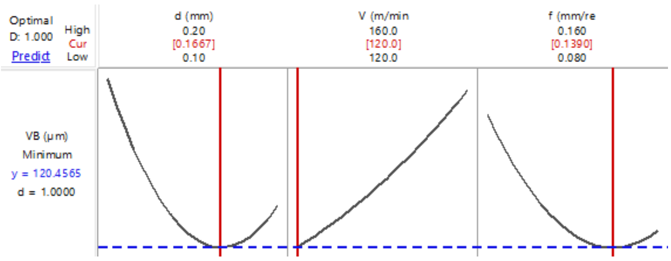

Figure 5. Optimal cutting conditions for minimal flank wear

The optimum cutting conditions were used in the verification experiment and the tool wear was measured after cutting a length of 200m, as shown in Figure 6. The results showed that there was coating peeling, mechanical wear due to parallel scratches on the back face, and also adhesion on the cutting edge. The main reason is the enormous heat generated from the cutting zone combined with the very high hardness of the workpiece, which promotes the wear rate. The measured flank wear was 137.1 µm, which deviated from the predicted value of 13.8%.

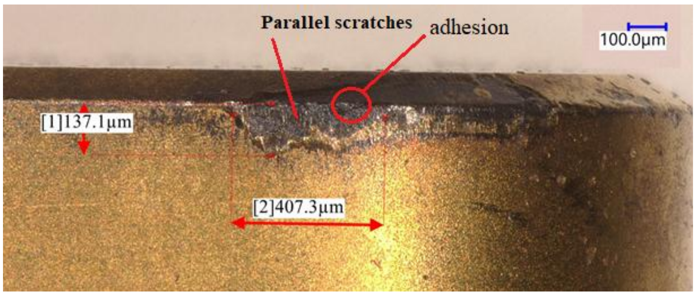

Figure 6. Tool wear investigation

IV. CONCLUSION

In this study, the face central composite design (RSM-FCCD) was used to assess the effects of machining parameters on the flank wear of CBN inserts in the fully interrupted hard turning process. The effect of cutting speed reveals the most powerful influence on the flank wear of CBN insert in the interrupted hard turning process. A predicted flank wear model has been determined based on the cutting parameters in this process. An optimized model for the flank wear was also determined and proposed the optimum set of parameters (V-120 m/min, f-0.167 mm/rev and d-0.139mm). The minimum flank wear was estimated as 120.46 µm at these optimal conditions. The study also performed a verification experiment at this optimal cutting condition, the measured CBN insert wear was 137.1 µm, which deviated 13.8% from the predicted result. In addition, the study also preliminarily analyzed and predicted the tool wear pattern that occurs when impact hard turning with TiN-coated CBN inserts.

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