MULTI-RESPONSE OPTIMIZATION FOR DETERMINING OPTIMAL CUTTING PARAMETERS IN THE HARD TURNING TUNGSTEN CARBIDE USING CBN INSERTS

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ABSTRACT

In recent years, sintered tungsten carbide has been used to manufacture molds or steel rolling shafts. The Cubic Boron Nitride is a super hard material used to machine hard-to-cut substances as tungsten carbide. The aim of the research is to decide the optimal slitting conditions in the hard turning tungsten carbide with both the reactions (the quality surface and the flank wear). This study has designed an RSM model with trial points in the center of the face. Analysis of variance performed with the quality surface along with flank wear showed that the experimental data set was statistically significant. The composite desirability for the quality surface along with flank wear was determined. The outcomes of optimizing multi responses using the composite desirability showed that the composite desirability obtain the maximum value 0.9487 with depth of cut 0.1 mm, cutting speed 36 m/min and feed rate 0.11 mm/rev. Hence, the contour plot for the composite desirability with the feed rate 0.11 mm/rev indicated that the composite desirability is greater than 0.9 with the cutting speed less 50 m/min and the cutting depth less 0.2 mm.

KEYWORDS: Hard Turning, Tungsten Carbide, Multi-Response, Optimization, Surface Roughness, Flank Wear

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INTRODUCTION

Cermeted tungsten carbide WC were growing more widely employed for dies as well as shapes because of their higher mechanical attributes like high strength, high hardness and high wear resisting features at high temperature etc. However, the forming of product from the blank by EDM, grinding or polishing is very difficult, has high cost and is quite time consuming. In recently years, with the development of material technology, many new cutting device substances may be utilized for the hard substance machining process. Several researchers analyzed methods to enhance the effectiveness of machining cermeted tungsten carbide process using the milling and turning method.

Some authors studied and analyzed the consequences of the cutting variables on the surface roughness in the hard machining tungsten carbide. Kim et al. (2012) experimented on the consequences of variables turning procedure with a chamfered diamond edge on the quality surface by using simulated and investigational method. The study determined that turning tungsten carbide procedure utilizing the chamfered device produced better surface roughness than using the conventional tool. Coppini et al. (2013) analyzed the effects of the cutting variables on the quality surface in the firm turning tungsten carbide WC utilizing the full factorial design. However, this study only investigates with the low cutting speed from 10 m/min to 30 m/min and uses with two levels. Coppini et

al. (2018) contrast to the quality surface in the internal turning sintered tungsten carbide using PCD inserts with those in the grinding process. The results showed that the achieved surface roughness in the internal turning sintered tungsten carbide is identical to those normally acquired in milling functions, hence can substitute milling in commercial activities. Other research studies (Zębala et al., 2015; Zębala & Kowalczyk, 2014; Zębala & Kowalczyk, 2015) also analyzed the influence of cutting variables on quality surface in WC-Co turning process PCD inserts. However, most of these studies only used the lesser scope of cutting speed as well as used PCD inserts.

Other researchers investigated the tool wear in the tungsten carbide machining process. HEO et al. (2003) analyzed the influences of machining conditions on the tool wear as well as cutting force in the firm turning cemented tungsten carbide using PCD inserts. The results of this research showed that the tool wear rate increases with boosting of the cutting rate. Wu et al. (2018) examined the influences of the tool wear on the cutting pressure in the micro milling of tungsten carbide employing PCD tool. The study's results showed that the most wear is on the tip and the flank face. Liu et al. (2003) also noticed that the flank wear is the main type of wear in machining tungsten carbide with CBN inserts. Okada et al. (2016) analyzed the tool wear behaviour and cutting pressure in the cutting of tungsten carbides utilizing a diamond covered ball end mill.

In brief, there are many researchers who examined the consequences of the cutting variables on a single response (the quality surface or the tool wear) in the machining sintered tungsten carbide. This study aims at the maximization of various cutting variables for multi-response the quality surface and the flank wear by using the response with Face Central Composition design. We focused the turning sintered tungsten carbide 25 wt% Co having high hardness 82.5 HRA with the CBN inserts.

EXPERIMENT DETAIL

In the current research, Ra and FW were observed in investigating the machining operation of the turning tungsten carbide process using CBN inserts. Ra and FW are analysis with the cutting parameters including the cutting speed, depth of cut as well as feed rate. The experiments are performed on the CNC turning center of Mazak Company, as figure 1. The cutting device used in the turning tungsten carbide process was the CBN inserts having code ISO CNGA120408-DNC250 and made by DINE tool manufacturer (Korea). This research used the tungsten carbide work pieces having high hardness (82.5 HRA) and having 25%wt cobalt binder of Zhuzhou Better Company. The quality surface of the turning surface has estimated through Mitutoyo's SJ210 irregular gauge (Figure 1). The flank wear of CBN tool are measured with machining distance 100m by the by digital microscope VHX-7000 by Keyence. The value levels of the cutting parameters in the turning process were selected based on the proposal of the cutting device manufacturer (DINE) and the outcomes of earlier studies and shown in table 1.

Response surface methodology with face central composite design (RSM-FCCD) model is used to design the experimental matrix included 18 trials with 6-face central trials, 8 corner trials and 4 center trials, shown in table 2. All trials were performed with random experimental order (run Order) designed by Minitab 18 software.

Table 1: The Value Levels of the Cutting Parameters

Parameters	Units	Levels		
		-1	0	1
Depth of cut (d)	mm	0.1	0.25	0.4
Cutting speed (V)	m/min	30	50	70
Feed rate (f)	mm/rev	0.1	0.15	0.2

Table 2: The Experimental Matrix and Results

Std. Order	Run Order	Pt Type	Blocks	d (mm)	V (m/min)	f (mm/rev)	FW (μ m)	Ra (μ m)	dc
12	1	-1	1	0.25	70	0.15	326.7	0.633	0.3309
10	2	-1	1	0.4	50	0.15	219.4	0.727	0.6940
14	3	-1	1	0.25	50	0.2	282.2	1.239	0.4126
1	4	1	1	0.1	30	0.1	147.8	0.312	0.9692
19	5	0	1	0.25	50	0.15	237.7	0.566	0.6798
7	6	1	1	0.1	70	0.2	285.8	1.577	0.3248
3	7	1	1	0.1	70	0.1	307	0.224	0.4807
5	8	1	1	0.1	30	0.2	163.4	1.361	0.6235
13	9	-1	1	0.25	50	0.1	214	0.190	0.8258
20	10	0	1	0.25	50	0.15	230.1	0.567	0.7012
4	11	1	1	0.4	70	0.1	350.5	0.424	0.1515
8	12	1	1	0.4	70	0.2	355.9	2.210	0.0000
15	13	0	1	0.25	50	0.15	235	0.551	0.6908
17	14	0	1	0.25	50	0.15	233.4	0.540	0.6976
11	15	-1	1	0.25	30	0.15	189.2	0.727	0.7670
9	16	-1	1	0.1	50	0.15	186	0.533	0.8234
18	17	0	1	0.25	50	0.15	237.2	0.557	0.6832
16	18	0	1	0.25	50	0.15	234	0.571	0.6894
6	19	1	1	0.4	30	0.2	170.5	1.443	0.5815
2	20	1	1	0.4	30	0.1	181.9	0.363	0.8745

Figure 1: Experimental Set Up.

RESULTS AND DISCUSSIONS

Effect of Cutting Parameters on Surface Roughness

ANOVA analysis for the quality surface in the firm turning tungsten carbide was performed with a significance level of 0.05. The results of ANOVA analysis using RSM-FCCD model are presented in Table 3. The P value of the design was lower than 0.0001 (statistically significant). The influences of investigated elements, as well as their interactions on quality surface, were presented in the pareto diagram (figure 2). The feed rate (FR) has the strongest consequence on the quality surface in the hard turning tungsten carbide. And other factors included depth of cut (DOC), cutting speed (CTS) along with interactions (CTS*FR, CTS*CTS, DOC*CTS and FR*FR) significantly affect on the quality surface. Additionally, DOC*DOC and DOC * FR interactions have a weak influence on quality surface.

Figure 2. Pareto Chart for Surface Roughness.

Table 3: The Result of Analysis ANOVA for the Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	5.12717	0.56969	58.37	0.000
Linear	3	4.20040	1.40013	143.46	0.000
DOC	1	0.13433	0.13433	13.76	0.004
CTS	1	0.07436	0.07436	7.62	0.020
FR	1	3.99171	3.99171	409.00	0.000
Square	3	0.71095	0.23698	24.28	0.000
DOC*DOC	1	0.02804	0.02804	2.87	0.121
CTS*CTS	1	0.06295	0.06295	6.45	0.029
FR*FR	1	0.09494	0.09494	9.73	0.011
2-Way Interaction	3	0.21582	0.07194	7.37	0.007
DOC*CTS	1	0.06119	0.06119	6.27	0.031
DOC*FR	1	0.02703	0.02703	2.77	0.127
CTS*FR	1	0.12760	0.12760	13.07	0.005
Error	10	0.09760	0.00976		

Lack-of-Fit	5	0.09691	0.09691	2.01	0.112
Pure Error	5	0.00069	0.00014		
Total	19	5.22477			

The consequence of cutting rate, depth of cut along with feed rate on the main of the quality surface is described in figure 3. The plot show that Ra changes slightly when changing the cutting speed and depth of cut, but increases rapidly while boosting the feed rate from 0.1 mm/rev to 0.2 mm/rev. The optimal cutting parameters for the surface roughness also are determined by using response optimizer function in Minitab, as figure 4. The results investigated that the quality surface obtain the least value with the depth of cut 0.1mm, cutting rate 30m/min and feed rate 0.1 mm/rev.

Figure 3: The Main Effects Plot for the Surface Roughness.

Figure 4: The Optimal Cutting Parameters for the Surface Roughness.

Effect of Cutting Parameters on Flank Wear

The outcomes of ANOVA test show that most of the investigated factors have a strong effect on the flank wear excluding interactions DOC*FR and DOC*DOC because of most factors having a low P value. The outcomes have been shown in

the pare to chart for the flank wear (Figure 5). The Pareto chart shows that the feed rate is the greatest effect element on the flank wear succeeded through DOC, CTS*FR, FR*FR, CTS, CTS*CTS and DOC*CTS.

Table 4: The Result of Analysis ANOVA for the quality Surface

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	68278.3	7586.5	28.86	0.000
Linear	3	63630.6	21210.2	80.69	0.000
DOC	1	3541.9	3541.9	13.47	0.004
CTS	1	59768.4	59768.4	227.38	0.000
FR	1	320.4	320.4	1.22	0.295
Square	3	3942.4	1314.1	5.00	0.023
DOC*DOC	1	2439.1	2439.1	9.28	0.012
CTS*CTS	1	1783.7	1783.7	6.79	0.026
FR*FR	1	670.8	670.8	2.55	0.141
2-Way Interaction	3	705.2	235.1	0.89	0.477
DOC*CTS	1	655.2	655.2	2.49	0.145
DOC*FR	1	0.0	0.0	0.00	0.993
CTS*FR	1	50.0	50.0	0.19	0.672
Error	10	2628.5	262.9		
Lack-of-Fit	5	2590.0	2590.0	1.99	0.137
Pure Error	5	38.6	7.7		
Total	19	70906.8			

Figure 5: Pareto Chart for the Flank Wear.

Figure 6 describes the effect of the cutting parameter in hard turning tungsten carbide on the flank wear of CBN insert. The result arrived was that the tool wear increases rapidly with tool wear from 30 m / min to 70 m / min. Besides, the amount of back wear increases with increasing the depth of cut from 0.1 mm to 0.3 mm. However, the flanks wear decreases if the cutting depth continues to increase to 0.4 mm. The results of optimizing the cutting states for the flank

wear show that the flank wear reaches to the minimum value with the depth of cut 0.1mm, cutting rate 30m/min and feed rate 0.1364 mm/rev.

Figure 6: Main Effects Plot for the Flank Wear.

Figure 7: The Optimal Cutting Parameters for the Flank Wear.

MULTI-RESPONSE OPTIMIZATION

Response optimization is useful to assess the impact of cutting variables on the quality surface or the flank wear. However, the quality surfaces, as well as the flank wear, reach to the minimum value with different cutting parameters. Whereas, the best combined cutting parameters should produce the minimum quality surface as well as flank wear. The optimized cutting parameters were determined by using the multi – response optimization method. This technique was initiated by Derringer and Suich (1980) for optimizing quality characteristic problems in the industry. This method used the composite desirability (D) determined following the equation (1).

$$D = \sqrt[r_1 + r_2 + \dots + r_n]{d_1^{r_1} \cdot d_2^{r_2} \cdot d_3^{r_3} \dots d_n^{r_n}} \quad (1)$$

In where: d_i is the desirability for each response

w_i is the importance of the each response

n is the number of responses in the research

If the importances of the responses are the same, the composite desirability function can be modified as equation (2).

$$D = \sqrt[n]{d_1 \cdot d_2 \cdot \dots \cdot d_n} \quad (2)$$

The input factors using maximal composite profitability were observed to be the most favourable variable states. The desirability functions for each response are determined by transforming the estimated responses into the scale-free values ranged from 0 to 1.

If it is desirable to least a response, the individual profitability was computed as:

$$d_i = \begin{cases} 1 & \text{if } y_i \leq L_i \\ \left(\frac{y_i - L_i}{U_i - L_i} \right)^{w_i} & \text{if } L_i < y_i < U_i \\ 0 & \text{if } y_i \geq U_i \end{cases} \quad (3)$$

If it is desirable to maximize a response, the individual profitability was computed as:

$$d_i = \begin{cases} 0 & \text{if } y_i \leq L_i \\ \left(\frac{y_i - L_i}{U_i - L_i} \right)^{w_i} & \text{if } L_i < y_i < U_i \\ 1 & \text{if } y_i \geq U_i \end{cases} \quad (4)$$

If it is desirable to aim a response, the individual profitability was computed as:

$$d_i = \begin{cases} 0 & \text{if } y_i \leq L_i \\ \left(\frac{y_i - L_i}{T_i - L_i} \right)^{w_i} & \text{if } L_i < y_i < T_i \\ 1 & \text{if } y_i = T_i \\ \left(\frac{U_i - y_i}{U_i - T_i} \right)^{w_i} & \text{if } T_i < y_i < U_i \\ 0 & \text{if } y_i \geq U_i \end{cases} \quad (5)$$

In where: d_i is the desirability

w_i is the weight of the each response

y_i is the measured value of response

L_i lowest value of response

U_i highest value of response

T_i target value of response

In the research, The desirability's for the quality surface as well as flank wear were calculated by equation (3) because they are desirable to maintain the minimum value. Their weight and important values are kept constant and equal to 1. So the composite desirability is calculated by equation (2) and the results are indicated in table 1.

Figure 8 depicts the effective plot of the both reactions (the surface roughness and the flank wear) as well as the maximization outcomes. The perpendicular lines within the cells depict present best parametric positions; also the parallel dotted lines depict the present reaction values. The value of mixture profitability (D) has noted as 0.9487. The current optimal cutting parameter settings are depth of cut 0.1 mm, cutting speed 36 m/min and feed rate 0.11 mm/rev. To indicate the responsiveness of the outcomes, contour plots for composite profitability with holding feed rate 0.11 mm/rev have been plotted as represented in Figure 9. The near-optimal region was located close to the left hand corner region of the plot with a higher mixture profitability value and it gradually reduces as moving right as well as upwards. Based on the contour plot, a suitable cutting condition with the feed rate 0.11 mm/rev, the cutting rate was less than 50 m/min and the cutting depth is lower than 0.2 mm can be selected so that the composite desirability is greater than 0.9.

Figure 8: The Optimal Cutting Parameters for the Multi-Response Optimization.

Figure 9: The Contour Plot for the Composite Desirability with Holding Feed Rate 0.11 mm/rev.

CONCLUSIONS

In this study, the effects of cutting variables on the quality surface as well as the flank wear in the hard turning tungsten carbide using the CBN inserts are investigated and studied by using the RSM model. Outlining the primary characteristics, the succeeding determinations can be presented:

- Examination of differences performed with the quality surface and flank wear showed that the experimental data set was statistically significant. The cutting speed, cutting depth and their square have a strong effect on the flank wear, and the feed rate (FR) has the strongest effect on the quality surface in the hard turning tungsten carbide using CBN tool.
- The composite desirability for the quality surface as well as flank wear was determined. The composite desirability obtained the maximum value 0.9487 with depth of cut 0.1 mm, cutting speed 36 m/min and feed rate 0.11 mm/rev.
- The contour plot for the composite desirability with the feed rate 0.11 mm/rev indicated that the composite desirability is greater than 0.9 with the cutting speed less 50 m/min and the cutting depth less 0.2 mm.

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