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Response Surface Methodology Approach on Effect of Cutting Parameter on Tool Wear during End Milling of High Thermal Conductivity Steel -150 (HTCS-150)

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Abstract. This paper presents a study of development the tool life's mathematical model during the milling process on High Thermal Conductivity Steel 150 (HTCS-150) 56 HRC. Using response surface methodology, the mathematical models for tool life have been developed in terms of cutting speed, feed rate and depth of cut. Box-Behnken techniques is a part of Response Surface Methodology (RSM) has been used to carry out the work plan to predict, the tool wear and generate the numerical equation in relation to independent variable parameters by Design Expert software. Dry milling experiments were conducted by using two levels of cutting speed, feed rate and depth of cut. In this study, the variable for the cutting speed, feed rate and depth of cut were in the range of 484-553 m/min, 0.31-0.36 mm/tooth, and 0.1-0.5 mm, width of cut is constantly 0.01mm per passes. The tool wear was measured using tool maker microscope. The effect of input factors that on the responds were identified by using mean of ANOVA. The responds of tool wear then simultaneously optimized. The validation of the test reveals the model accuracy 5% and low tool wear under same experimental condition.

1. Introduction

In the modern manufacturing process, tool and die is one of the most demanding tasks in manufacturing engineering, especially in the automotive industry to make the main body part. Complexity of workpiece geometries is high and different level of hardness as well as short cycle time is a part of the main difficulties on these precision industries. Simultaneously, quality conditions become more essential due to enhanced competition and quality attentiveness. The performance of cutting tool during machining is very important, it's because tool wear directly affects the efficiency, cost efficiency and precision of machining [1-3]. Due to the tool wear are very significantly effect to quality and cost of the manufacturing process, tool wear is becoming an important study topic to maximize the application of tool and minimize the wear to reduce the effect of wear on the product. The selection of Cutting tool is a main issue when doing machining. High strength and toughness, high wear resistance, chemical stability, high hardness at high temperature and thermal shock resistance are the criteria of cutting tool material.

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Predictive models of tool life can be applied to help the manufacturer to maximize utilization the cutting tool. Predictive has become important for manufacturers to increase the process efficiencies and part quality.

Response surface methodology is a tool that combination of statistical and mathematical methods that are suitable for modelling the correlation between input and the output response of the machining process [4], Many researchers have been applying the RSM model for understanding the effects of different input parameters on machining process. Wang et al. [5] study the effect of tool geometry and cutting condition on surface roughness as their response when slot end milling of Al 2014-T6. They generate a surface roughness mathematical model for both wet and dry cutting settings using RSM. The main influence parameter affecting dry cutting model where the concavity, feed rate, cutting speed and relief angles, while for the wet model, they were feed rate and concavity angles. They found that the increasing of relief angles, feed rate and concavity will increase the surface roughness and reducing tool life.

This research paper focuses on the generation of mathematical modelling of tool wear when milling High Thermal Conductivity Steel-150 (HTCS-150) in dry cutting and make optimization of the parameter to get the lowest tool wear after 1000 passes or 60 meters long.

2. Methodology

The experiments were carried out using a commercial 5-axis MAZAK Variaxis CNC milling machine with maximum spindle speed 12000rpm at 15 kW output on continuous rating condition with 1µm accuracy. Mitsubishi ballnose end mill cutter grade number VP15TF, two cutter insert shown in Figure 1 are as experiment cutter insert with radius tolerance of ±6 µm for high accuracy, finish machining, the cutter insert will fit on the tool holder to attach to the machine. The nominal cutting tool diameter of 20 mm with a double tooth and incline angle, $\alpha = 0°$. The dimension of workpiece for this experiment was a 60 mm x 60 mm x 10 mm (W x L x H) is finished by using wet machining to prevent the material changing during material preparation and to eliminate any effect on the surface of work piece, each new layer was face-milled. The material workpiece block of High Thermal Conductivity Steel-150 (HTCS-150), which reportedly up to 66 W/mK [7], the physical and mechanical properties of the HTCS-150 material under 300K test temperature is shown in Table 1 with 56HRC, the hardness for each workpiece were checked before machining to avoid material hardness variation. All of experiment was carried out in the dry condition, where is no liquid cooling will apply during the machining process. Tool wear was measured using Tool Maker Microscope, the method used to measure the wear on cutting tool is illustrated in figure 2. In all tests, measurements were performed after completing 1000 passes for each running equal 60 meter long. The measurements were made on the cutting tool insert which is contacted on workpiece surface directly.

Figure 1 : Insert Holder 20 mm diameter and the carbide end mill insert 20 mm diameter

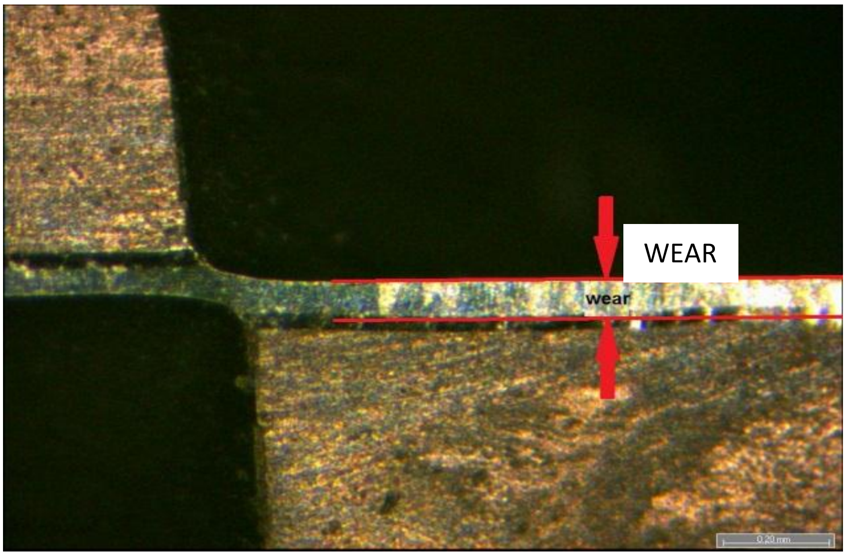

Figure 2: Tool wear mesurement method using tool maker microscope

Table 1 : Physical and Mechanical properties of HTCS-150 tool steel under 300K test temperature[8]

Physical and Mechanical Properties	Measurement Value	Unit
Density	7.97 x 10^3	Kg/m^3
Elastic Modulus	216 x 10^3	MPa
Mechanical Resistance	1305	MPa
Yield Strength 0.2%	1233	MPa
V-Notched Charpy resilience	18	J
Unnotched Charpy resilience	331	J
Abrasive Wear resistance	178	Rovalma-coefficient 2

In this study, cutting experiments are planned using by response Surface Methodology (RSM), where the box-Behken approach was undertaken with total of 17 runs of the experiment where 5 form 17 runs are repeated at the same parameters. These 17 runs consist of 8 corner points locate at the vertices of the cube and center point repeated five times [9], these repetitions are important to determine the bias during experiment. Cutting experiments are conducted considering three independent cutting configurations: feed rate (fz), cutting speed (Vc), and depth of cut (ap). The width of cut (ap) was kept constant at 0.01mm throughout this experiment. The detail parameter set is shown in Table 2. Experiments were performed in a random order with Table 3 showing the full test matrix of the RSM design.

Table 2 : Cutting test parameter

CONDITION	Cutting speed, Vc (m/min)	Feed rate, fz (mm/tooth)	Depth of cut, (mm)
DESCRIPTION	484-553	0.31-0.36	0.1-0.5

Table 3: Cutting condition and experiment result

Std Order of Experiment	Cutting Speed, Vc (m/min)	Feed rate, fz (mm/tooth)	Depth of Cut, ap (mm)	Tool Wear (mm)
1	484	0.31	0.3	0.047
2	553	0.31	0.3	0.043
3	484	0.36	0.3	0.040
4	553	0.36	0.3	0.030
5	484	0.33	0.1	0.046
6	553	0.33	0.1	0.033
7	484	0.33	0.5	0.048
8	553	0.33	0.5	0.044
9	518	0.31	0.1	0.046
10	518	0.36	0.1	0.034
11	518	0.31	0.5	0.053
12	518	0.36	0.5	0.040
13	518	0.33	0.3	0.048
14	518	0.33	0.3	0.052
15	518	0.33	0.3	0.051
16	518	0.33	0.3	0.049
17	518	0.33	0.3	0.050

3. Result and Discussion

The outcome of the experiment will be detailed in graph and table view to offer the other researcher with a clearer view. The outcome will be analyzed using Design Expert software. Table 3 shows the result of tool wear obtained from 17 runs of different cutting parameter. The some of the experimental results can achieve low tool wear. From the experiment, the lowest tool wear was 0.033 mm and the highest 0.057 mm after completing 10000 passes and the other machining, machining process in figure 3 shows the progression of tool wear cutting time under test where 120 minutes (60000 pass) machining time was chosen as a criterion for standard tool live in this experiment. In general, tool wear for 120 minute time machining in range 0.120 mm until 0.180 mm, with the Run 3 (Vc=553 m/min, ft=0. 33 mm/tooth, DOC=0. 10 mm) showing the lowest wear (0.120mm) and corresponding Run 11 (Vc=484 m/min, ft=0. 33 mm/tooth, DOC=0. 50 mm) giving the highest wear value equal to 0.182 mm, it is shown that Run 11 is the lowest tool life comparing to Run 3, this result was supported by past researcher where the higher the parameter led to be shorter tool life due to greater tool wear [10].

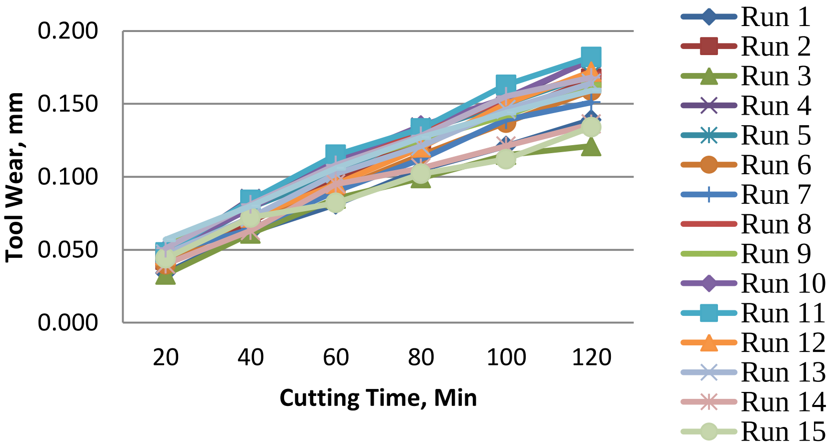

Figure 3: Tool wear versus cutting time

The analysis of variance (ANOVA) in Table 4 shows the parameters that plays a major role in Tool wear. Based on ANOVA generated by Design Expert software, the Quadratic model was found to be significant with P-value is below 0.0001 and the F-value is 40.26 where there is only below 0.01 % chance that a Model F-Value this large could occur due to noise, in this model A, B, C, A^2, B^2 and AC are significant model terms. The cutting parameters those P-Value less than 5% (95% confidence interval) are significant. In this case, radial depth of cut and feed rate were found significant controlling surface roughness whirls cutting speed does not appear to correspond to tool wear. By sorting the F-value, a ratio between group variability over within group variability, the most dominant factors were feed rate followed by the radial depth of cut. From the model, the desired R2 is close to 1, its show how well the least square model equation. The R2 value of 0.9810 is in a reasonable agreement with the adjusted R2 of 0.9567.

Table 4: ANOVA for Quadratic model

Source	**Sum of** Squares	df	**Mean** Square	**F** Value	**p-value** Prob> F	
Model	7.376×10^{-4}	9	8.196×10^{-5}	40.26	<0.0001	significant
Cutting Speed, A	1.201×10^{-4}	1	1.201×10^{-4}	59.01	0.0001	
Feed Rate, B	2.531×10^{-4}	1	2.531×10^{-4}	124.34	<0.0001	
Depth of Cut, C	8.450×10^{-5}	1	8.450×10^{-5}	41.51	0.0004	
A^2	1.161×10^{-4}	1	1.161×10^{-4}	57.01	0.0001	
B^2	9.500×10^{-5}	1	9.500×10^{-5}	46.67	0.0002	
C^2	1.684×10^{-5}	1	1.684×10^{-5}	8.27	0.0238	
AB	9.000×10^{-6}	1	9.000×10^{-6}	4.42	0.0736	
AC	2.025×10^{-5}	1	2.025×10^{-5}	9.95	0.0161	
BC	2.500×10^{-7}	1	2.500×10^{-7}	0.12	0.7363	
Residual	1.425×10^{-5}	7	2.036×10^{-6}			
Lack of Fit	4.250×10^{-6}	3	1.417×10^{-6}	0.57	0.6657	Not significant
Pure Error	1.000×10^{-5}	4	2.500×10^{-5}			
Cor Total	7.519×10^{-4}	16				
R-Squared	0.9810					
Adj R-Squared	0.9567					

The Quadratic equation describes the effect cutting parameter on the tool life. The prediction model of tool life can be denoted as:

$$\text{Tool Wear} = -2.12088 + 4.94650 \times 10^{-3}\,Vc + 5.78374\,fz - 0.10608\,ap - 4.41084 \times 10^{-6}\,Vc^2 - 7.6\,fz^2 - 0.05\,ap^2 - 1.73913 \times 10^{-3}\,Vc\,fz + 3.26087 \times 10^{-4}\,Vc\,ap - 0.05\,fz\,ap \quad (1)$$

A mathematical relationship for tool life, Tool wear (mm) as a function of the cutting speed, Vc, (m/min), Feed rate (mm/tooth) and depth of cut, d, (mm). The comparison between calculated and collected experimental data is detailed in Figure 4. The average error obtained was 5%. It indicates the model was moderately fit within the predetermined parameter range. According to Hill, 1999, the experimental error below 10% deviation for the predicted uncertainty in the model parameters is acceptable [6].

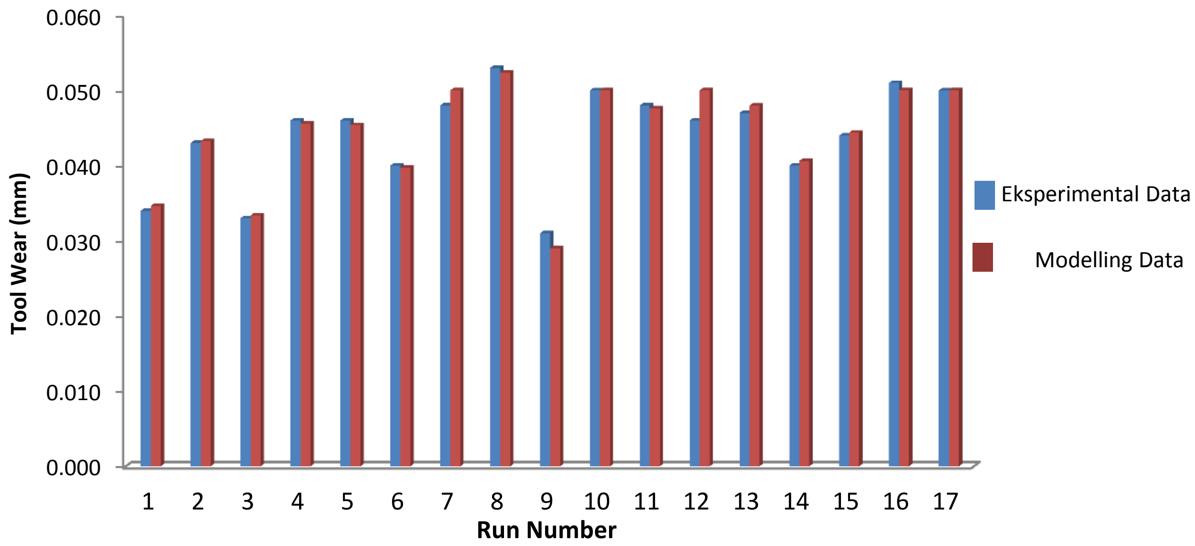

Figure 4: Comparison between the experimental and model result of tool wear with the average error of 5%

Validation with 3 random combination was made. The comparison the experiment result which is close to predicted with the value, the average error percentage is 7.0%. It is shown that the Quadratic equation for the tool life model can be used to predict the tool wear.

4. Conclusion

The Box-Behnken tool as a part of the response surface methodology was applied to evaluate the factors affecting the tool wear Mitsubishi Carbide inserts end mill during end milling. This paper presents the finding of the influence of cutting speed, feed rate and depth of cut on tool wear by using insert carbide attach at the CNC MAZAK 5-axis milling machine. The competence of the model has been evaluated by ANOVA, which designates significant at 98%. The following conclusion can be conferred from this study:

- This experiment demonstrated that tool wear as low as 0.033 mm of end milling can be achieved after 1000 passes equal to 60 meters long.
- This study shows the Quadratic model with feed rate to mitigate the effect of cutting speed and depth of cut found are affected significantly the tool wear. An increase in cutting speed, feed rate and depth of cut were descrease the tool life.
- The Quadratic model tool wear prediction is valid within the cutting speed of 484-553 m/min, feed rate of 0.31-0.36 mm/tooth and depth of cut of 0.1-0.5 mm. The average error between predicted model and actual experiment was 5%.
- The lowest tool wear can be achieved when cutting at Vc = 552.26 m/min, fz = 0.36 mm/tooth, ap = 0.15 mm for 60 meters long.
- The response surface plot is good tool to estimate the region of maximum tool life.

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