Flank wear analysing of high speed end milling for hardened steel D2 using Taguchi Method

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Abstract. One of the main challenges for any manufacturer is how to decrease the machining cost without affecting the final quality of the product. One of the new advanced machining processes in industry is the high speed hard end milling process that merges three advanced machining processes: high speed milling, hard milling and dry milling. However, one of the most important challenges in this process is to control the flank wear rate. Therefore a analyzing the flank wear rate during machining should be investigated in order to determine the best cutting levels that will not affect the final quality of the product. In this research Taguchi method has been used to investigate the effect of cutting speed, feed rate and depth of cut and determine the best level s to minimize the flank wear rate up to total length of 0.3mm based on the ISO standard to maintain the finishing requirements.

1. Introduction

High speed hard end milling is an advanced technology that merging three advanced machining processes: high speed milling, hard milling and dry milling. This advanced process increases the productivity and better final quality compare with the conventional machining. There are several researcher had done a researched on the consequence of cutting parameters on flank wear rate and tool life [1-4]. Ezuwanizam [5] claimed the optimal cutting parameters for cutting speed, feed rate and depth of cut in optimize the tool life of carbide insert coated with TiN in milling aluminum 6061. Xuan-Truong and Minh-Duc [6] had explained the effect of cutting parameters on flank wear through the transformation of natural logarithm. They found that cutting speed has given major significant effect on flank wear and surface roughness is mostly influenced by feed rate. While for depth of cut, they conclude that it only gives a minor effect for both surface roughness and flank wear especially at low cutting speed and feed rate. However, in this research taguchi method will be used to analyse and investigate the three independent factors: cutting speed (Vc), feed rate (f) and depth of cut on the flank wear rate (Vb$_r$) up to flank wear length equal to 0.3 mm.

2. Taguchi method

Taguchi method is a tool of finding the best combination of an input (cutting parameters, cutting condition, work piece and cutting tool material properties) for producing a high quality of product and services. Malvade and Nipanikar [7] mentioned that Taguchi methods more focus on developing the design for manufacturing process for creating high quality product compared to statistical process control which tries to control the factors that affect the product quality. Taguchi's orthogonal array (OA) is a step where provides less number of experiment run with high balanced combination of inputs. While Taguchi signal-to-noise ratios (S/N) is statistical measurement for the performance of the experiment for desired output. Signal is a mean ratio while noise is a standard deviation. S/N ratios can be divided into three categories which is Nominal-is-Best (NB), Lower-the-Better (LB) and Higher-the-better (HB) and tits depending on the quality of the product or process being optimize. Highest S/N means the optimal parameters combination [8].

3. Experiment procedure

The experiment was conducted using the high-speed end milling modeled NEXUS 410A-II with vertical centre. The carbide inserts are attached to a 30 mm diameter of end milling cutter holder, While for the work piece, hard steel material which is D2 are chosen as the work material of this experiment as shown in the figure 13. Work material used is hardened steel D2 with dimension of 200 mm x 100 mm x 50 mm hardened to 52-56 HRC. For this experiment, a fresh carbide inserts will be used for each run of the experiment. The result and analysis of using Taguchi method using JMP statistical analysis software in analyzing and identify the optimizing the machining parameters in high speed end milling. Table 1 shows the experiment design using L9.

Table 1. Range of cutting parameters of the experiment.

Cutting parameters	Min.	Max.
Cutting speed(m/min)	120	240
Feed rate (mm/tooth)	0.05	0.15
Depth of cut (mm)	0.10	0.20

4. Statistical analysis

The ANOVA and S/N ratio were developed using JMP statistical analysis. Finally, JMP also used for finding the optimum cutting parameter combination in order to get the lower surface roughness and flank wear. Signal-to-noise ratio is a method used to measure the performance of the experiment. Signal means the desirable effect to the response or mean while noise is an undesirable effect or standard deviation to the response characteristics. The smaller-the-better output used in this analysis since the lower flank wear and surface roughness are desirable. The equation for calculating the smaller-the-better output as follow:

$$\text{S/N} = -10\log_{10}\left[\frac{i}{n}\left(\sum_{i=1}^{a} y_i^2\right)\right]$$

$$y_i = \text{measured experiment result in ith}$$
$$n = \text{the number of measurement in each run.}$$

Table 2 summarizes the results of flank wear.

Table 2. Summarize result for analyzing process**.**

V_c (m/min)	f (mm/tooth)	DoC (mm)	Flank Wear Rate, (mm/min)
120	0.05	0.1	0.0027
120	0.1	0.15	0.0027
120	0.15	0.2	0.0031
180	0.05	0.15	0.0047
180	0.1	0.2	0.0056
180	0.15	0.1	0.0061
240	0.05	0.2	0.0077
240	0.1	0.1	0.0039
240	0.15	0.15	0.0095

Tables 3 and 4 show the statistical details necessary for determining whether a significant relation exist between the variables.

Table 3. Analysis of variance table.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	113.01009	28.2525	12.6611
Error	4	8.92579	2.2314	Prob > F
C. Total	8	121.93587		0.0153*

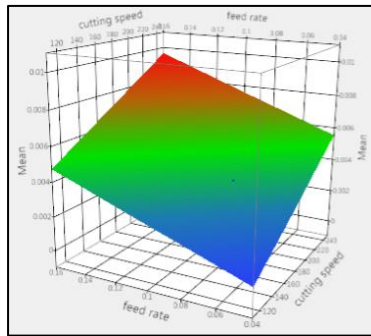**Table 4.** Summary of fit model.

RSquare	0.926799
RSquare Adj	0.853599

Based on the results in tables 3-4, the Rsquare are in reasonable agreement with the RSquare Adjusted and Values of 'Prob > F' less than 0.05 and significant for both models. The signal to noise ratio has been developed as shown in Figure 1.
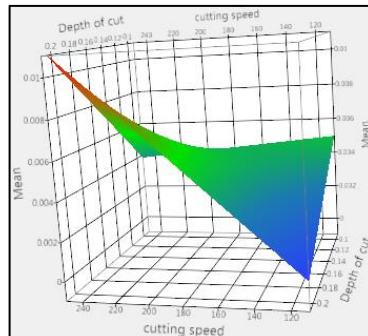

Figure 1. S/N ratio for flank wear.

The best cutting parameters for minimizing the noise factors were cutting speed of 120 m/min, feed rate of 0.10 mm/tooth and depth of cut of 0.10 mm. According to the slope of the graph, it shows that cutting speed gives most significant effect to the flank wear mean rate. This situation may happen
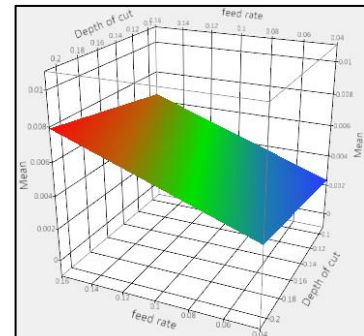
because of the machining environment. As the flank wear increase due to the noise effect of vibration and temperature. In order to investigate the effect of cutting parameters combination of high speed end milling on flank wear rate of insert carbide, 3D contour plot were generated using JMP software. Figure 2a, 2b and 2c below shows the interaction between cutting parameters and flank wear mean rate of the insert carbide.

Figure 2a. Effect of cutting speed and feed rate on flank wear mean.
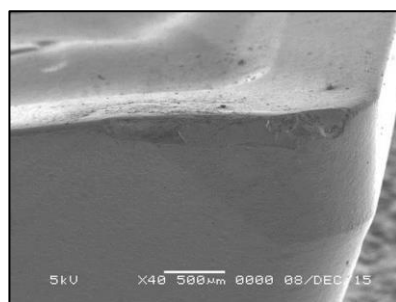
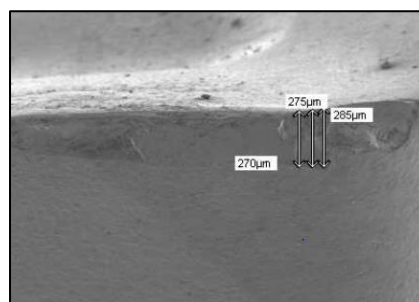**Figure 2b.** Effect of cutting speed and DOC on flank wear rate.

Figure 2c. Effect of feed rate and DOC on flank wear rate.

4.1. Scanning Electron Microscope (SEM) Image

Scanning Electron Microscope (SEM) is one of the electron microscope used for capturing the image of the small sample for example the flank wear of the insert. The insert was placed inside the SEM and the flank wear surface of the insert was analyzed as shows in the figure below. The image in figure 3a was taken using 40x magnification and figure 3b is the close up view for taking the measurement of the flank wear. The SEM image was captured in order to explain on how the flank wear measurement being taken using Hisomet II tool maker microscope. The flank wear reading was taken by measuring the average width of the wear on the insert. Figures 3a and 3b show the measurement for the flank wear of the insert by using SEM machine.
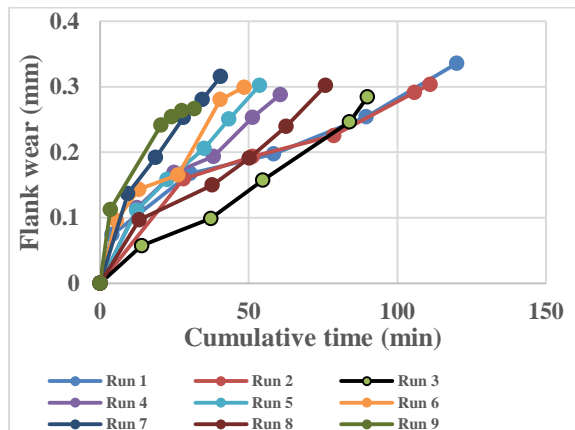

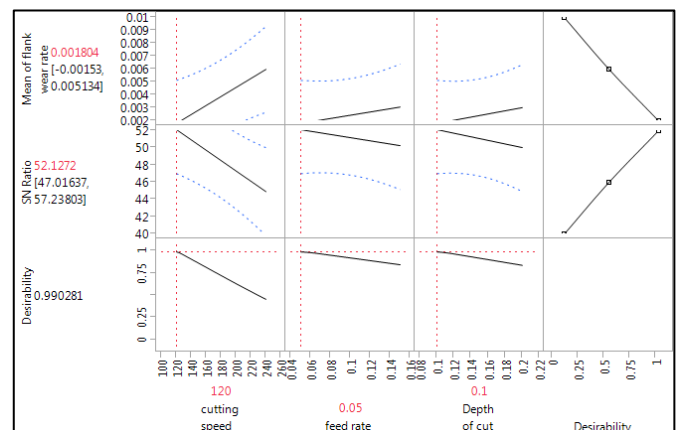**Figure 3a.** Flank wear image captured by SEM.

Figure 3b. Closed up of flank wear image for measurement.

Figure 4 show the graph relationship between flank wear of the insert and the machining time was constructed in order to determine the tool life of the insert as the machining time gradually increase. For determining the best tool life, the feed rate and depth of cut need to be optimized and the cutting speed need to be reduce. The relationship between the flank wear length and the machining time for different runs has been concluded on figure. Finally the desirability function graph is shown in Figure 5.

Figure 4. The relationship between flank wear and machining time.

Figure 5. Optimization result for minimizing flank wear and maximizing S/N ratio.

5.   Summary

The experimental process was successfully done and the data was collected through High Speed End Milling process. The data were analyzed using JMP statistical software. The statistical analysis shows a high correlation between the cutting parameters combination and the output responses. The new model for flank wear rate have been developed in terms of cutting speed, Vc (m/min), feed rate, f (mm/tooth) and depth of cut, DOC (mm). The desirability function was implemented to minimize the flank wear rate and maximize the signal noise ratio. It was found that with desirability 0f 98%, the cutting speed 120 mm/min, feed rate of 0.05 mm/tooth and 0.01 mm of depth of cut as shown in the Figure 5.

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