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Flank Wear Modelling in High Speed Hard Milling of AISI D2 Steel

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ABSTRACT
High speed machining has many advantages in reducing time to the market by increasing the material removal rate. However, final surface quality is one of the main challenges for manufacturers in high speed machining due to the increasing of flank wear rate. In high speed machining, the cutting zone is under high pressure associated with high temperature that lead to increasing of the flank wear rate in which affect the final quality of the machined surface. Therefore, one of the main concerns to the manufacturer is to predict the flank wear to estimate and predict the surface roughness as one of the main outputs of the machining processes. The aim of this study is to determine experimentally the optimum cutting parameters: depth of cut, cutting speed (Vc) and feed rate (f) that maintaining low flank wear (Vb). Taguchi method has been applied in this experiment. The Taguchi method has been universally used in engineering analysis. JMP statistical analysis software is used to analyse statically the development of flank wear rate during high speed milling of hardened steel AISI D2 to 60 HRD. The experiment was conducted in the following boundaries: cutting speed 200-400 m/min, feed rate of 0.01-0.05 mm/tooth and depth of cut of 0.1-0.2 mm. Analysis of variance ANOVA was conducted as one of important tool for statistical analysis. The result showed that cutting speed is the most influential input factors with 70.04% contribution on flank wear.

Keywords: AISI D2, High speed hard milling, Taguchi, Flank wear

1 INTRODUCTION

High speed hard milling (HSHM) is an advanced machining processes in industry that merges three advanced machining processes: high speed milling, hard milling, and dry milling [1]. Machining above 45 HRC are considered hard machining and usually ranging from 58 to 68 HRC [2]. On the other hand, high speed machining is not the same for all materials, high speed for one material is not considered a high speed for others. HSHM can reduce manufacturing process cost and reducing time to the market. However, there are many challenges that faces the manufacturer in HSHM. One of the main challenges is the increasing of flank wear extremely fast due to the high pressure and high temperature in the cutting zone. Increasing the flank wear of the cutting tool will lead to damaging the final surface roughness. Therefore, estimating and predicting the flank wear rate before the machining process is an essential issue. Tool wear is defined as the amount of volume loss of tool material on the contact surface due to the friction between the cutting tool and workpiece [3]. It will give significant effect on the finished surface, accuracy, manufacturing cost and tool life. Flank wear occurs on the flank face of the tool. This type of wear is basically between the tool and the workpiece. Kalpakjian and Schmid [4] mentioned it happens because the tool is rubbed along the machined surface. Tool and machined parts dimensions vary due to the change and progress of flank wear, thus flank wear need to be controlled. The maximum range accepted for cutting hard materials is 0.3-0.5mm [5]. Many researchers studied the output responses of HSHM such as surface roughness [6][7], temperature [8] and flank wear [9]. They investigated the effect of cutting speed, feed rate and depth of cut on the final surface roughness using D2 as a work piece hardened to 52-56 HRC, and coated carbide as cutting tool with higher cutting speed 120-240 mm/min. They found that 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. and the cutting speed is the most significant factor

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to the flank wear. One of the advantages in high speed hard machining is the power consumption. According to Zhang [10], the energy consumption in high speed machining is lower because of low cutting forces and high removal rate. Dudzinski [11] stated in his writing, this is an important aspect of advanced manufacturing technology to achieve high productivity and to minimize machining cost as the tool life is longer.

In this research, the investigation of the effect of higher cutting speed up to 400m/min on the flank wear rate of hardened steel AISI D2 that hardened to 60-62 HRC and developing a new statistical model based on experimental work that can give valid results to the manufacturer in the boundaries of the research experiment.

2 Experimental Procedure

This experiment was conducted using high speed milling in machining hardened steel AISI D2 60-62HRC. The experiment was conducted under dry machining to reduce thermal shock and cutting tool breakage. The chemical composition of AISI D2 is given in Table 1. The machine used in conducting the experiment, the type of material, type of inserts used and other experimental set up is summarized in Table 2.

The cutting tool used in conducting the experiment is AlTiN coated carbide (MITSUBISHI VP15TF) and 32 mm diameter tool holder for end milling produced by MITSUBISHI Company. The specific cutting tool has axial rake angle of 5° and radial rake angle of -10°. The thickness of the insert is 3.5 mm, length of 10 mm, 6.35 width and 0.8 mm corner radius. The stated specifications of the insert are provided in Mitsubishi materials manuals shown in table 3. The specifications of insert (Mitsubishi materials manual, 2015). The experiment has been conducted for three levels and three factors. The experiments were conducted using Taguchi's orthogonal array L9 as a design of experiments.is used in Taguchi method. The cutting parameters and cutting levels are shown in Table 4.

Table 1: Chemical composition of AISI D2

Composition	C	Mn	Si	Cr	Ni	Mo	V
Wt. %	1.40 – 1.60	0.6	0.6	11.0 – 13.0	0.3	0.7 – 1.2	1.1

Table 2: Experimental Set Up

Machine	VERTICAL CENTER NEXUS 410A-II
Material	AISI D2
Dimension of material	150mm x 101 mm x 45 mm
Inserts	Mitsubishi VP15TF with AlTiN coating
Cutting condition	Dry

Table 3: Specifications of insert (Mitsubishi materials manual, 2015)

Insert material and grade	ANSI	Tool Dia. (mm)	Axial rake angle (º)	Radial rake angle (º)	Insert thickness (mm)	Insert length (mm)	Insert width (mm)	Corner radius (mm)
Coated carbide VP15TF	AOMT 184808PEERH	32	5	-10	3.5	10	6.35	0.8

Table 4 - Cutting parameters and levels

Parameters	**Unit**	**Levels**		
		1	**2**	**3**
Cutting speed	m/min	200	300	400
Feed rate	mm/tooth	0.01	0.03	0.05
Depth of cut	mm	0.10	0.15	0.20

3 RESULTS AND DISCUSSION

The experimental results from Table 4 were analyzed with analysis of variance (ANOVA), which used for identifying the most affecting the input factors on the performance measures. Figure1 shows images of inserts with wear. The images were captured using Nickon optical microscope with 5X magnification.

Table 3: Orthogonal array L9 of Taguchi experiment design and experimental results

Run	Vc (m/min)	f (mm/tooth)	Depth of cut (mm)	Avg. flank wear (mm)
1	200	0.01	0.1	0.0025
2	200	0.03	0.15	0.0034
3	200	0.05	0.2	0.0069
4	300	0.01	0.15	0.0045
5	300	0.03	0.2	0.0075
6	300	0.05	0.1	0.0063
7	400	0.01	0.2	0.009
8	400	0.03	0.1	0.0126
9	400	0.05	0.15	0.0113

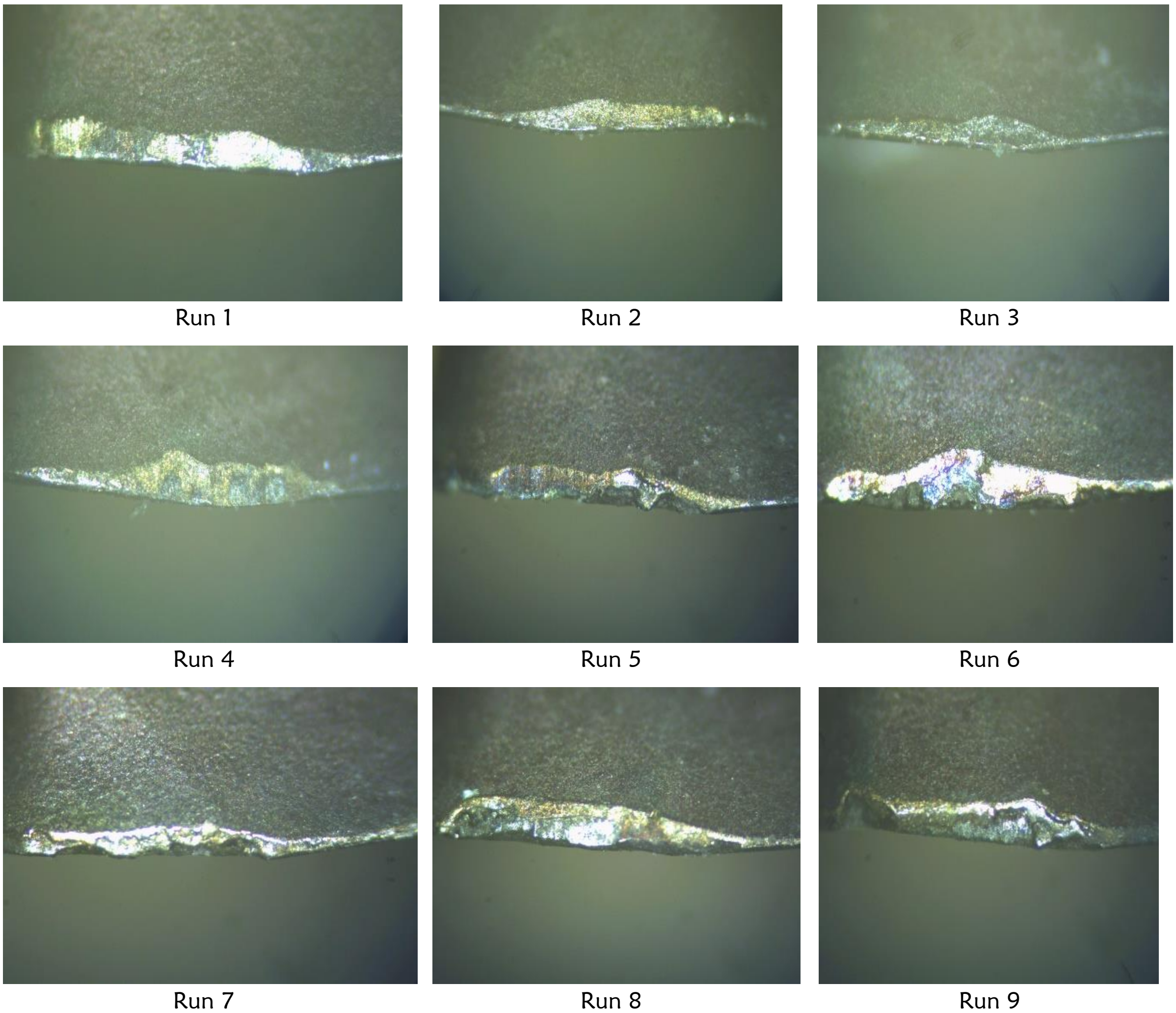

Figure 1: Optical images of weared insert

Table 5 shows the ANOVA result for flank wear analysis. R-Square value for this model is 0.963215. This indicates that the developed model fits and explains 96.32% of the variation in flank wear. The Prob > F value shows that there is only 2.32% chance error in the developed model due to noise. The model developed is said to be significant at 95% confidence level as the value of Prob > F less than 0.05.

F ratio for each cutting parameter is compared to determine the significant cutting parameters. The % contribution indicated that cutting speed affects flank wear the most with 70.04% and followed by the cutting feed with 12.21% of contribution. Depth of cut has 0.39% contribution and it is said to be insignificant. Feed-depth of cut and speed-feed interaction have a small effect on flank wear rate. The effects are small and not significant to the change of flank wear rate. The statistical model was developed using JMP software has generated the modelling equation for flank wear as follow:

$$\begin{aligned} Flank\ wear = {} & -0.0074 + (0.00004 * speed) + (0.0713 * feed) \\ & + (-0.0067 * depth\ of\ cut) + (speed - 300) \\ & * [(feed - 0.03) * (-0.0066)] + (feed - 0.03) * [(depth\ of\ cut - 0.15) \\ & * (2.1965)] \end{aligned}$$

Figure 2 shows the comparison of mean between experimental values and developed model using modelling equation generated by JMP software. Run 3 from Figure 2 has the minimum difference while run 8 has the maximum difference between experimental and developed model values. The variation in flank wear values in due to the presence of noise during machining process such as vibration and random disturbances. The two graphs in Figure 2 show a small deviation between experimental and developed model values.

Table 4: ANOVA for tool wear

Source	DF	Sum of Squares	F Ratio	% Contribution	Remark
Cutting Speed	1	0.00006993	59.909	70.04	Significant
Feed	1	0.00001219	10.4422	12.21	Significant
Depth of Cut	1	0.00000039	0.3335	0.39	Not significant
Speed*Feed	1	0.00000371	3.1795	3.72	Not significant
Speed*Depth of cut	1	0.00001013	8.6796	10.15	Not significant
Error	3	0.0000035			
Total	8	0.00009985			
RSquare = 0.963215		RSquare Adj = 0.901907		Prob > F = 0.0232	

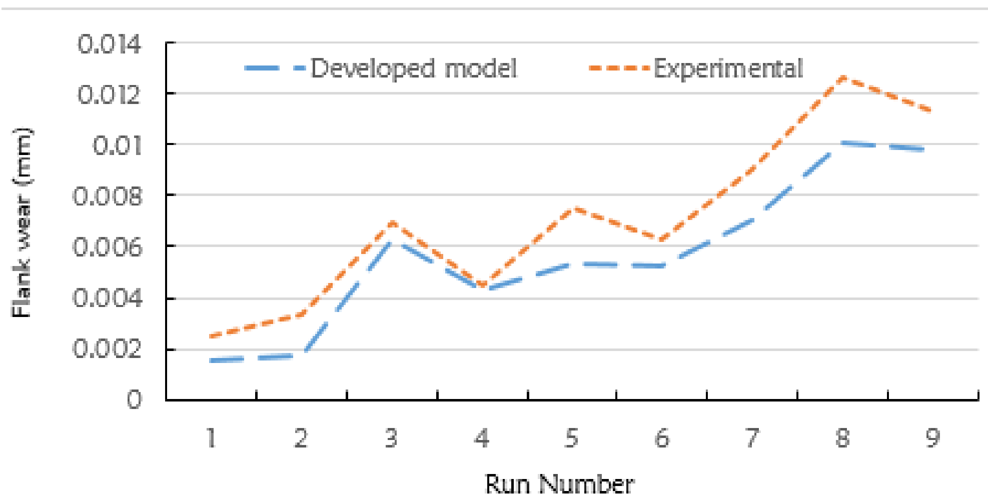

Figure 2: Comparison of mean between developed model and experimental

4 CONCLUSIONS

The results of this study have been analysed and can be concluded by the following:

1. Cutting speed affects flank wear the most. Second influential input factor is cutting feed and effect of depth of cut is said to be insignificant.
2. High speed hard milling is an effective process in reducing the total machining time. However, the flank wear length needs to be monitored and estimated before the machining process to avoid the damage of surface roughness.
3. The new model shows a high accuracy as shown in Figure 1

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