CUTTING TEMPERATURE IN HIGH SPEED MILLING OF SILICON CARBIDE USING DIAMOND COATED TOOL

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Abstract- The present research studies the high speed milling process of Silicon Carbide, using diamond coated tool. The effect of machining parameters such as cutting speed, feed rate and depth of cut on the cutting temperature were investigated. The experiments were conducted under dry condition with two flute diamond coated flat end-mill of diameter 2 mm, using different spindle speeds (between 30,000 and 50,000 rpm), different feed rates (between 6 and 60 m/min), and different depth of cuts (between 0.05 and 0.1 mm). Experimental results indicated that all the milling parameters influence the cutting temperature. Cutting temperature increases with the increase of cutting speed at higher depth of cut, but decreases at lower depth of cut. Increasing feed rate will increase cutting temperature at any conditions. Meanwhile, increasing depth of cut will increase cutting temperature at lower feed rate, but decrease cutting temperature at higher level of feed rate. As the conclusion, the combination of high spindle speed with low feed rate and low depth of cut minimizes cutting temperature developed in high speed milling of SiC with diamond coated tool.

Keywords- Cutting Temperature, High speed milling, Silicon Carbide, Diamond Coated Tool.

I. INTRODUCTION

Silicon carbide (SiC) ceramics have been widely used in optical mirror, accelerometer, refractories, electronic components, biomedical, aerospace, and defense industries due to its superior properties. It has excellent characteristics in terms of heat and wear resistance at elevated temperature, chemical inertness, high thermal conductivity, high carrier saturation velocity and high specific stiffness. However, the extreme characteristic of SiC makes it a difficult to machine material. Its high hardness leads to the difficulties of cutting tool selection. Furthermore, its brittle characteristic put SiC under the high risk of crack even in the small chatter of the machining process.

High sped machining by using diamond coated tool has been widely applied to milling process of SiC due to its benefit compare to conventional machining and cutting tool. Apart from the increased productivity or throughput, high speed machining offers the following advantages: increased machining accuracy, better surface finish and reduction in the damaged layer, reduced bur formation, better chip disposal, and possibility of higher stability in cutting due to stability lobes against chatter vibration . At the same time, high hardness characteristic makes the diamond coated cutting tool able to cut hard material like SiC.
In the previous study, the authors found that high speed milling of SiC by using diamond coated endmill result with a very good surface finish . However, it was reported that the high micro-hardness characteristic of SiC increases the cutting temperature during machining process and leads to the high wear rate of the cutting tool [7, 8, 9]. In this study cutting temperature of high speed milling of SiC by using diamond coated endmill was investigated. The experiments were conducted at various spindle speed, feed rate and depth of cut in order to study the relation between milling parameters and cutting temperature.

II. EXPERIMENT AND MEASUREMENT

The cutting condition of high-speed machining depends on the work part and tool materials concerned. In general, when cutting plain carbon steels using sintered carbide tools, the most common combination, cutting speeds over 300 m/min falls into the high speed machining range. For hard materials including titanium alloys, nickel-based alloys and SiC, on the other hand, conventional cutting speeds range from 30 to 100 m/min using sintered carbide tools . By using more precious cutting tools like diamond coated endmill, cutting speed may be increased by several times. The present study deals with high speed machining from this point of view but it is limited by the capability of available equipment.

Table.1The milling parameters

Parameter	Minimum level	Maximum level
Spindle speed (N) [rpm]	30,000	50,000
Feed rate (f) [mm/min]	6	60
Depth of cut (a) [mm]	0.05	0.1

Plan of Experiments. The high speed milling experiments were performed on Silicon Carbide (SiC) material with the size of 20 mm x 20 mm surface area and 15 mm thickness. The milling experiments were carried out using two flute diamond coated flat end-mill of diameter 2 mm, on CNC milling machine at dry condition. The experiments were planned using Response Surface Methodology (RSM) of design of experiments. Three parameters namely, spindle speed (N), feed rate (f) and depth of cut (a) were identified and the range of parameters for the investigation was determined from the past experience and the available resources. The milling parameters used and their levels are presented in Table 1.

During the machining process, the work-piece was hold by a special designed fixture to minimize the chatter on the cutting surface. The fixture was made of aluminium and consisted of a holder and a base. The work-piece was attached onto the holder and clamped in the fixture base as shown in Fig. 1 (b) and (c).

Flattening of SiC was provided prior to any experimental run by using surface grinding process. The process used the 40 mm diameter diamond resin bounded cup wheel at 2000 rpm, 20mm/min feed rate and 0.010 mm depth of cut.

Measurement of Cutting Temperature. In this work, the experiments were conducted on semi-auto DMU 35M Deckel Maho Universal Milling Machine with the following specifications: Spindle speed 20–6300 rev./min. and maximum feed rate: 5000 mm/min. The ultra-precision high speed spindle NSK Planet 850 was attached to the machine spindle to generate high rotational speed of the cutting tool. It is powered by compressed air, speed controlled by an air-line valve system and able to generate up to 90,000 rev/min of spindle rotation. The setup of the high speed spindle on the milling machine is shown in Figure 1 (a) and (b).

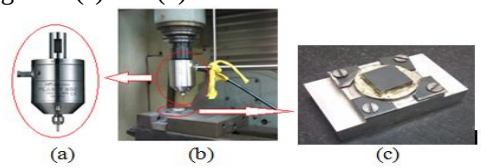


Figure 1: Experimental setup. (a) high spindle speed attachment (b) setup on milling machine (c) work-piece mounted on picture

Table.2Result of the experiment

Trial No.	Spindle speed (N) [rpm]	Feed rate (f) [mm/min]	Depth of cut (a) [mm]	Cutting tempe-rature (T) [°C]
1	40000	28	0.10	129.7
2	40000	28	0.05	53.20
3	50000	60	0.05	46.27
4	40000	28	0.08	96.56
5	40000	28	0.08	96.56
6	40000	28	0.08	96.56
7	40000	28	0.08	96.56
8	50000	35	0.08	76.63
9	30000	36	0.10	100.97
10	40000	48	0.08	226.77
11	40000	28	0.08	147.58
12	50000	10	0.10	61.23
13	40000	28	0.08	96.56
14	30000	6	0.05	154.14
15	30000	21	0.08	167.6

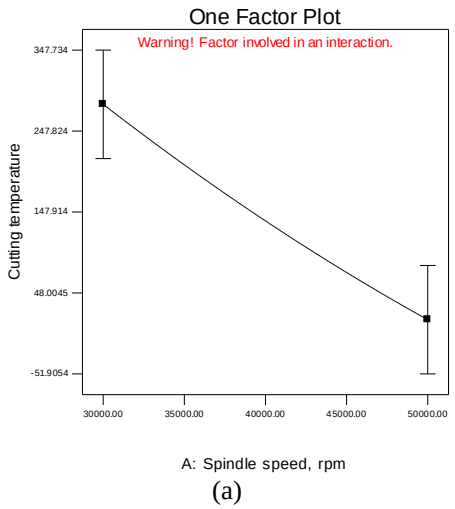
The cutting temperature generated in milling was measured using TP8 thermal imaging camera. It measures the temperature by using noncontact infrared method. The camera is able to measure the range of temperature from -20° to 800° C with sensitivity of 0.08° C and accuracy of ±2° C. The cutting temperature images were transmitted to charge amplifier and stored in Pentium IV computer for further analysis.

III. RESULT AND DISCUSSION

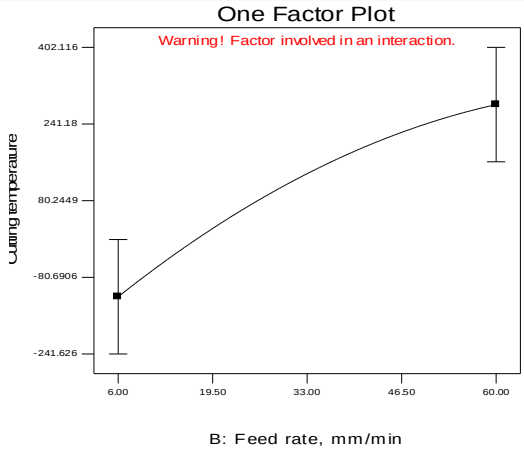
In the present study, RSM was used to develop the empirical relationship between the variables and responses. Due to high cost of cutting tool and work material, the numbers of experiment were minimized. Dealing with the problem, small central composite design of RSM was chosen to develop the design of the experiments. The method generates 15 trials of experiment. The measurements were repeated 5 times for each trial and the average values were taken as the result. The experimental results are presented in Table 2.

Response Surface Analysis. The analysis of variance (ANOVA) was carried out to identify the factors which are having more influence on the high speed milling process. The result of ANOVA shows that the model is significant with F-value of 7.76 and the probability of 0.0181. Values of Prob F less than 0.0500 indicates that the model terms are significant. In this case N, f, and N-a are the significant model terms which influence the cutting temperature in high speed milling of SiC (with the value of Prob F are 0.0061, 0.0061 and 0.0110 respectively).

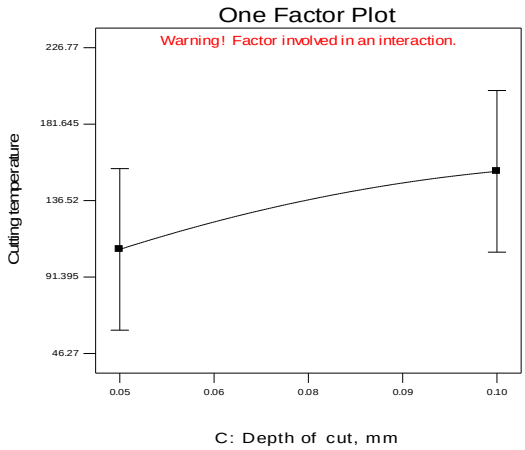
Effect of factors and their interaction. The effects plot for spindle speed, feed rate and depth of cut is presented in Fig. 2. From Fig. 2 (a), it is evident that the cutting temperature developed decreases with increase in spindle speed. Fig. 2 (b) shows that the increase of feed rate increases the cutting temperature. The increase of feed rate increases thecontact area and load on the tool, which in turn



(a)



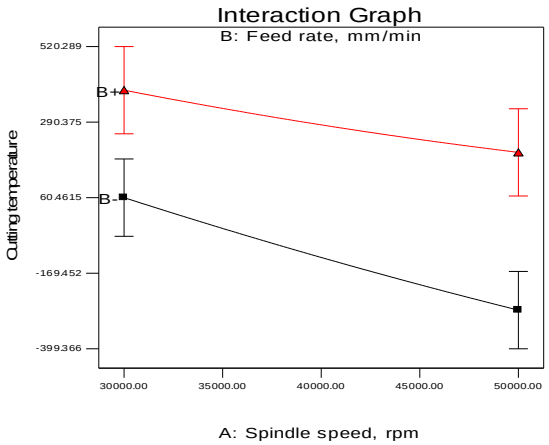
(b)



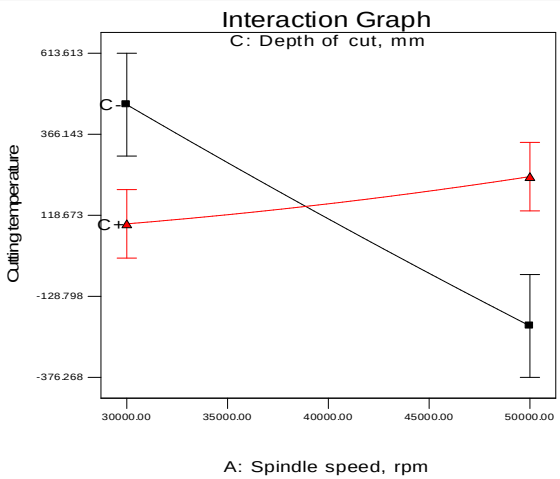
(c)

Figure 2: Effect of milling parameters on cutting temperature: (a) Effect of spindle speed at feed rate 33 mm/min and depth of cut 0.08 mm. (b) Effect of feed at spindle speed 40000 rpm and depth of cut 0.08 mm. (c) Effect of depth of cut at spindle speed 40000 rpm and feed rate 33 mm/min

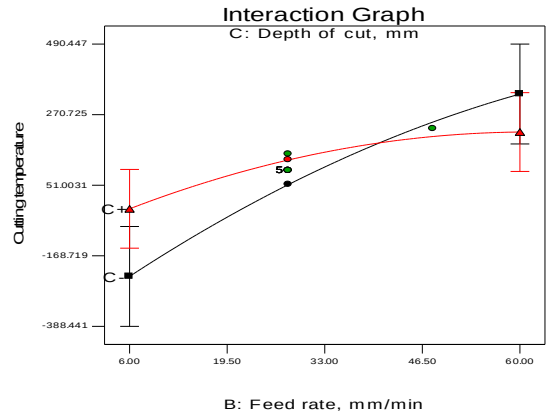
increases the cutting temperature in milling. Fig. 2 (c) indicated that higher depth of cut shows increase cutting temperature in high speed milling of SiC. The increase of depth of cut has increased the contact area with the workpiece while milling which increase the cutting temperature. From the results, it is revealed that the cutting temperature developed in high speed milling of SiC can be minimized with high spindle



(a)



(b)



(c)

Figure 3: The interaction effect between milling parameters: (a) Spindle speed Vs feed rate. (b) Spindle speed Vs depth of cut. (c) Feed rate Vs depth of cut

speed, low feed rate and low depth of cut combination.

The interaction between the parameters also has effect on the high speed milling process of SiC. The interaction plots for the cutting temperature are presented in Fig. 3. From Fig. 3 (a), it is observed that the cutting temperature is decreased with increase of spindle speed at both low and high level of feed rate. Figure 3 (b) indicates that increasing of the spindle speed will decrease the cutting temperature at low level of depth of cut. However at high level of depth of cut increasing of the spindle speed will increase the cutting temperature. Figure 3 (c) shows that the cutting temperature is increase with increase of feed rate. The graph indicated that it increases more at lowdepth of cut. Fig. 3 also indicates that the maximum interaction is observed between spindle speed and depth of cut. Significant interaction is found between feed rate and depth of cut. Meanwhile, spindle speedand feed rate combination does not show proper interactions, in which the lines are almost parallel to each other.

Fig. 4 shows the three dimensional surface plots for cutting temperature developed in high speed milling

of SiC with different cutting conditions. The surface plot can help to visualize the response surface. These are used to establish the desirable response values and operating conditions. The surface plots show how a cutting temperature relates to two factors based on model equation. The surface plots show only two variables, the third variable is kept as constant. For analyzing the cutting temperature, the third variable is kept at constant middle level. Fig. 4 (a) shows the relation between spindle speed and feed rate on cutting temperature. This plot shows how spindle speed and feed rate are related to cutting temperature. This plot reveals that for minimizing the cutting temperature, high spindle speed and low feed rate are preferred.

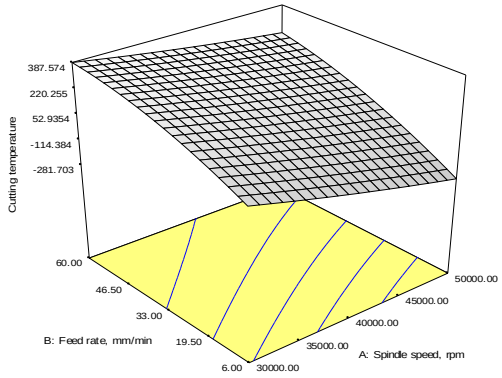
Fig. 4 (b) shows how spindle speed and depth of cut are related to cutting temperature in high speed milling of SiC. This graph indicates that maximum spindle speed and minimum depth of cut are preferred for drilling of SiC. Fig. 4 (c) shows how feed rate and depth of cut have influence the cutting temperature in high speed milling of SiC. The result indicated that for obtaining minimum cutting temperature, 0.05 mm depth of cut and 6 mm/min feed rate are preferred. From Fig. 4, it is asserted that high spindle speed, minimum feed rate and minimum depth of cut are preferred for high speed milling of SiC.

CONCLUSION

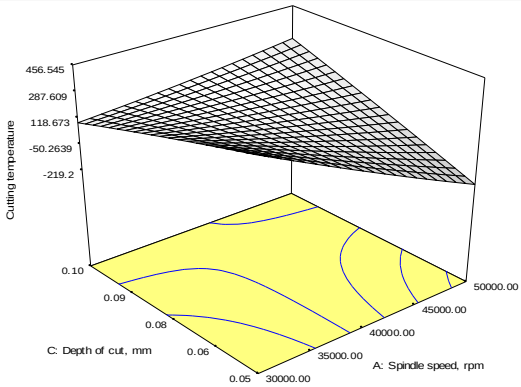
The experiments are planned and conducted by using small central composite design of RSM to predict the influence of cutting parameters on cutting temperature at various cutting conditions in high speed milling of SiC by using diamond coated tool.

Based on the result of the experiment, thefollowing conclusions can be obtained:

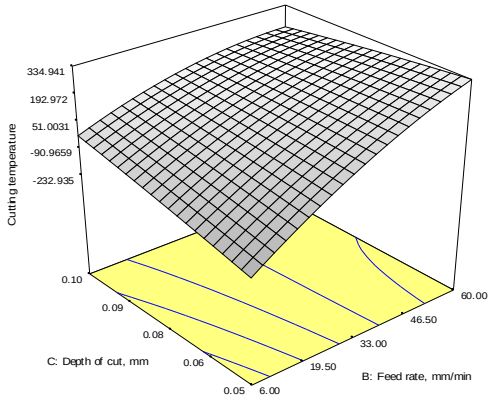
- The result indicates that all the milling parameters influence the cutting temperature in high speed milling of SiC. Among the interactions considered, the interaction between the spindle speed and depth of cut has more influence on the milling process.
- The increase of spindle speed decreases the cutting temperature, whereas the increase of feed rate increases cutting temperature.



(a)



(b)



(c)

Figure 4: Three Dimensions (3D) surface graph: (a) Spindle speed Vs feed rate. (b) Spindle speed Vs depth of cut. (c) Feed rate Vs depth of cut

- From surface plots it is confirmed that the cutting temperature developed is more at low spindle speed and high feed rate combinations and less at high spindle speed and low feed combinations.
- The combination of high spindle speed with low feed rate and low depth of cut minimizes cutting temperature developed in high speed machining of SiC with diamond coated tool.

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