Finite element analysis of cutting temperature in turning process using Box-Behnken response surface method

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ABSTRACT –The cutting temperature has an effect on the surface quality of the machined parts. Thus, it is important to determine the most influential cutting parameters and to analyze the interactions between the cutting parameters and cutting temperature. Box-Behnken RSM was used for the design of simulation runs. From the results, the most influential cutting parameter is depth of cut and the most influential interaction is the interaction between the cutting speed and depth of cut. The optimization parameters give the minimum cutting temperature of 401.89 °C. Thus, the cutting temperature increases with the increase in depth of cut and a decrease in cutting speed.

1. INTRODUCTION

Aluminium alloy has a superior fatigue strength and has a strength that is equivalent to several kinds of steel, so the aluminium alloy is used for highly stressed components and parts [1]. There are various material removal processes to machine the aluminium alloy, while the most common material removal process to machine the aluminium alloy is the turning process. Turning is an important machining process that removes materials from the surface of the revolving cylinder-shaped workpiece with a single-point cutting tool to get the desired shape [2]. Nowadays, finite element analysis has predominantly become the major tool for simulating the metal machining processes due to substantial cost-saving and gives vision to the process which is not easily measured in experiments [3].

Deform 3D is used to simulate the turning process in order to analyze the effect of the cutting parameters on the cutting temperature. Cutting temperature is the amount of heat generated between the motion of cutting tool and workpiece during the cutting process and it has an important impact on the tool life, surface quality and machining precision [4]. Response surface methodology (RSM) comprises an experimental design to determine an approximate model between the input and output variables and to optimize the responses [5].

In this study, the selected cutting parameters are cutting speed, feed rate, and depth of cut, while the output variable is the cutting temperature. The simulation design used in this study is the Box-Behnken Design. Box-Behnken Design requires less number of runs and the tests at every level of the experimental factors can be analyzed [6]. The first objective of this study is to determine the most affected of the cutting parameters on the output response. The second objective is to investigate the interaction between the cutting parameters and the output responses and third objective is to optimize the cutting parameters setting of the turning process by using Box-Behnken RSM.

2. METHODOLOGY

The Box-Behnken response surface method was used as a statistical tool for the design of simulation runs for this study. Based on the Box-Behnken design matrix, there are 13 simulation runs with one center point that needs to be conducted since this study has three process factors such as cutting speed, feed rate and depth of cut. Meanwhile, the output response of this study is the cutting temperature. Table 1 depicts the value ranges of the cutting parameters.

Table 1 Value ranges of the cutting parameters

Factors	Unit	Level 1	Level 2
Cutting speed	m/min	200	250
Feed rate	mm/rev	0.1	0.25
Depth of cut	mm	0.5	0.6

2.1 FEA Deform 3D simulation setup

The FEA Deform 3D simulation setup began by selecting the turning process as the machining type, and then set up the process parameters and the process condition such as the environment temperature was set to 25 °C. Next, the uncoated carbide triangle turning insert TNMA 432 was selected from the Deform 3D software's library. Further, both of the back rake angle and side rake angle of the tool holder was set to -5 degrees, and the tool mesh generation is by default of 25000. Then the workpiece was set as the simplified model with a length of 10 mm and the workpiece meshing is generating by using the absolute mesh size with a defined size of 25 % of feed. The aluminium alloy 7075 was selected and the number of simulation steps was set to 500 steps. Then it can proceed to the database generation.

3. RESULT AND DISCUSSION

The simulation result for cutting temperature shows that run 5 has the minimum cutting temperature of 447 °C with a combination of cutting speed of 200 mm/min, the feed rate of 0.175 mm/rev and depth of cut of 0.5 mm. The appearance with the cutting tool for minimum cutting temperature in run 5 is shown in Figure 1.

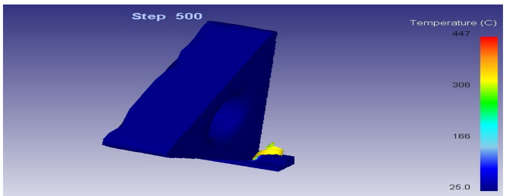

Figure 1 Appearance with the cutting tool

3.1 *Analysis of variance for cutting temperature*

From the ANOVA analysis of the reduced quadratic model for cutting temperature, the most influential cutting parameters on the cutting temperature was the depth of cut. Since it has the lowest "P-value" of 0.133 as compared to the "P-value" of the cutting speed (0.552) and feed rate (0.919) respectively. Furthermore, there is an interaction between the cutting speed and depth of cut which has the most influential on the cutting temperature due to its lowest "P-value" of 0.072. In addition, the Pareto chart of the standardized effects justified the interaction between the cutting speed and depth of cut is the predominant interaction that gives the most effect on the cutting temperature. Since the model term of AC (interaction between cutting speed and depth of cut) is extremely close to the standardized effects of 2.365. Figure 2 shows the Pareto chart of the standardized effects.

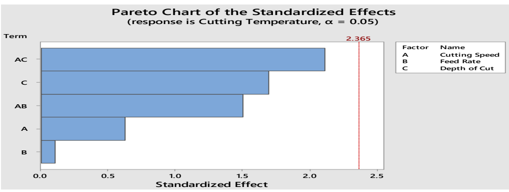

Figure 2 Pareto chart of the standardized effects

Furthermore, the surface plot of the cutting temperature versus depth of cut and cutting speed is depicted in Figure 3. The surface plot of the cutting temperature shows that there is an interaction between the cutting speed and depth of cut, in which the cutting temperature is increasing when there is an increase in depth of cut and a decrease in cutting speed. The decrease in cutting temperature with the increase in cutting speed is supported by Ming et al. [7] stated that the cutting temperature began to decrease when the cutting speed was surpassed the peak critical value.

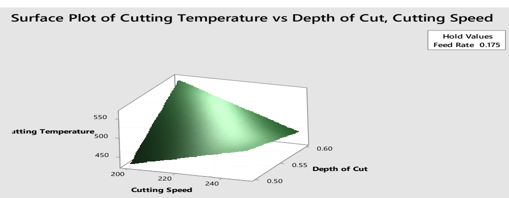

Figure 3 Surface plot of cutting temperature

3.2 *Optimization parameter of cutting temperature*

The optimization parameters of cutting temperature were obtained from Minitab software. From the result shows that the optimization parameters of cutting temperature are the cutting speed is 200 m/min, the feed rate is 0.25 mm/rev and depth of cut is 0.5 mm that gives the minimum cutting temperature value of 401.89 °C. The lowest value of the cutting temperature that was obtained from the simulation is 447 °C, and it shows that the cutting temperature value has reduced from 447 °C to 401.89 °C. This indicates that the cutting temperature has optimized by 11.22 % with the application of the optimization parameters.

4. CONCLUSIONS

In this study, the effect of cutting parameters on the cutting temperature using RSM was studied. From the ANOVA analysis, the most influential cutting parameters on the cutting temperature is the depth of cut, which indicates that the increase in depth of cut would induce an increment in the cutting temperature. Furthermore, there was an interaction between the cutting speed and depth of cut that highest contribution on the cutting temperature, in which the cutting temperature is increasing when there is an increase in depth of cut and a decrease in cutting speed. For the cutting temperature response optimization, the target was set to minimize and the optimization parameters of the cutting temperature are the cutting speed is 200 m/min at low level, the feed rate is 0.25 mm/rev at high level and depth of cut is 0.5 mm at low level that gives the cutting temperature of 401.89 °C.

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