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INVESTIGATION OF CUTTING CONDITIONS WITH DRY CUTTING AND APPLICATIONS OF CUTTING FLUID FOR BALL-END MILLING PROCESS

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***Abstract**: In order to reduce the use of cutting fluid and the environmental hazard, this paper presents the investigation of the machinability of ball-end milling process with the dry cutting, the wet cutting, and the mist cutting for aluminum. The relations of the surface roughness, the cutting force, and the cutting parameters are proposed based on the experimental results to obtain the proper cutting condition. The in-process cutting force is utilized to monitor the relations of the surface roughness and the cutting parameters. The surface roughness and the cutting force models have been proved by utilizing the analysis of variance at 95% confident level. The proper cutting condition can be determined easily referring to the use of cutting fluid, and the minimum surface roughness and cutting force of the surface plot by using the Response Surface Analysis with the Box-Behnken design.*
***Key words:** dry cutting, wet cutting, mist cutting, surface roughness, response surface analysis*

1. INTRODUCTION

In order to reduce the waste in the cutting processes, there has been a continuing worldwide trend to minimize or eliminate the use of cutting fluids (Thepsonthi et al., 2009). It is therefore desirable to know the effects of the wet cutting, the mist cutting, and the dry cutting on the cutting parameters such as the surface roughness.

The aluminium such as Al 6063 is most popularly used for the mechanical parts. The ball-end milling process is one of the important cutting processes, which is used to cut those materials in order to obtain the surface roughness as required.

The Box-Behnken design with the Response Surface Analysis (RSA) is the one method to use in an empirical study of the relationship and the optimization, where several independent variables influence a response. Several researches of regression equation-based modelling in metal cutting process are reported in literature (Horng et al., 2008; Indrajit & Pradip, 2006). It is normally used to find the optimal solution in machining proccss (Kadirgama et al., 2007).

It is already known that the cutting force can be used to examine and analyze the surface roughness. The in-process monitoring of cutting forces is hence proposed to investigate the cutting condition with the dry cutting, the wet cutting, and the mist cutting.

The aim of this research is to investigate the cutting conditions with the dry cutting, the wet cutting, and the mist cutting to obtain the proper cutting conditions for the aluminium with the ball end milling based on the criteria of the minimum surface roughness of the machined parts, the minimum cutting force, and the minimum use of cutting fluid. The relations of the surface, the cutting force, and the cutting parameters are developed by utilizing the Response Surface Analysis (RSA).

2. EXPERIMENTAL PROCEDURES

2.1 Experimental setup

The cutting experiments are carried out with the dry cutting, the wet cutting, and the mist cutting to obtain the suitable cutting condition. The cutting tests are performed by using the coated carbide ball end mills (TiAlN) with the diameter of 6 mm, two cutting edges, 30° helix angle. The 5-axis CNC machining center is employed for the cutting tests. The workpiece is aluminium (Al 6063). The values of cutting parameters are selected from the recommended values in the cutting tool manual. A dynamometer is installed on the table of the machine to measure the in-process cutting forces.

2.2 Experimental design

The following procedures are adopted for the cutting tests. Firstly, the Box-Behnken design with the RSA is utilized to obtain the suitable relation between response *Y*, which are the surface roughness and the cutting force, and a set of cutting parameters {n, f, d} based on the experimental data for the dry cutting, the wet cutting, and the mist cutting. The analysis of variance (ANOVA) is utilized to prove the effect of the cutting parameters at the 95% confident interval.

Secondly, the proper cutting condition is determined referring to the criteria mentioned above. The relation between the response and the independent input variables can be expressed in the following equation:

$$Y = F(n, f, d) \quad (1)$$

where *Y* is the response and *F* is the response surface function in the terms of cutting parameters which are the spindle speed (*n*), the feed rate (*f*), and the depth of cut (*d*), respectively.

The approximation of *Y* is proposed by using the fitted second-order polynomial regression model (Montgomery, 2006) as shown in the below equation:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum\sum_{i<j} \beta_{ij} x_i x_j + \epsilon \quad (2)$$

where β_0 is the constant, β_i, β_{ii}, and β_{ij} represent the coefficients of linear, quadratic and cross product terms, respectively. The $X_{i,j=1,2,3}$ represent the coded factors that correspond to the cutting parameters. The values of β coefficients used in the above model can be obtained by using the Box-Behnken design.

The Box-Behnken design consists of 15 runs for three variables as shown in Fig. 1, and provides three levels which are low, center, and high for each independent variable as shown in Tab. 1.

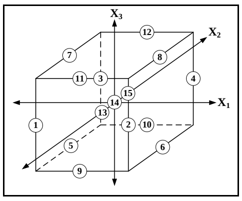

Fig. 1. The Box-Behnken design

Parameters	Unit	Levels		
		-1	*0*	*+1*
Spindle speed (*n*)	rpm	1,000	2,000	3,000
Feed rate (*f*)	mm/rev	0.01	0.02	0.03
Depth of cut (*d*)	mm	0.5	1.0	1.5

Tab. 1.Factors and levels for response surface analysis

3. RESULTS AND DISCUSSIONS

According to the experimentally obtained results, the second-order response model representing the surface roughness (Ra) and the cutting force (Tangential force: Fx) in the mist cutting can be expressed by the following equations:

$$Ra = 0.182679 + (-1.24\text{e} - 5)S + 1.45F + (-0.146443)D + 0.0578714D^2 \quad (3)$$

$$Fx = -0.575 + (-0.00139096)S + 121.875F + 6.05558D + (2.29115e - 7)S^2 + (-1.72154)D^2 + 57.5FD \quad (4)$$

The above models show the sensitivity of the multiple regressions of the surface roughness and the cutting force to the cutting conditions. The coefficient of each parameter means to the responsibility of those parameters to the models, while the sign of the coefficient means to how it affects to the surface roughness and the cutting force. The experimentally obtained surface roughness and the cutting force models are valid at the high significance (P-value = 0.000) of 95% confident level.

The experimentally obtained contour plot of the surface roughness in the mist cutting is shown in Figs. 2. Figure 2 indicates that the surface roughness will be low if the feed rate is selected at the low level and the depth of cut is set at low level for the mist cutting.

The response optimization is performed to check the optimum cutting condition for the minimum surface roughness as shown in Fig. 3. The surface roughness decreases while the feed rate decreases. The minimum surface roughness can be obtained at the center level of the spindle speed, at the low level of the feed rate, and the high level of the depth of cut, respectively. An increase in the feed rate results in the increment of the surface roughness which corresponds to the theoretical surface roughness.

Referring to the criteria of the minimum surface roughness, the minimum cutting force, and the minimum use of cutting fluid, the suitable cutting condition obtained is the mist cutting at the spindle speed of 3,000 rpm, the depth of cut of 1.25 mm, and the feed rate of 0.01 mm/rev.

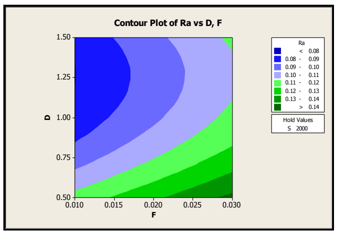

Fig. 2. Example of the experimentally obtained contour plot of surface roughness in the mist cutting

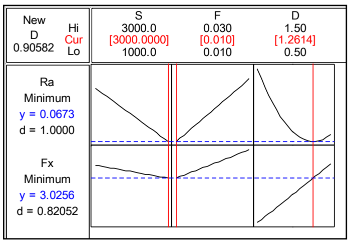

Fig. 3. The optimization chart for minimum surface roughness for cutting aluminum in the mist cutting

4. VERIFICATION OF THE MODELS

The new cutting tests are conducted in order to verify the optimum cutting condition and the models of the surface roughness prediction and the cutting force.

Figure 4 shows that the experimentally actual surface roughness is close to the predicted surface roughness obtained from equation (3). It is understood that the developed surface roughness model can be effectively used to predict the surface roughness under various cutting conditions.

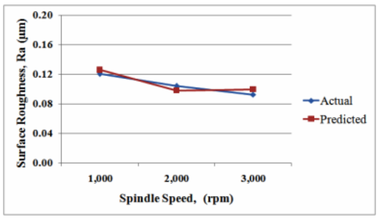

Fig. 4. Illustration of the acutal surface roughness and the predicted surface roughness for the mist cutting

However, the limitation of the proposed models is that the preliminary tests are required to fit the models of the surface roughness and the cutting force when the work materials and the cutting conditions are changed.

5. CONCLUSIONS

The in-process monitoring is proposed to measure the cutting force by employing the tool dynamometer in order to analyze the surface roughness under various cutting conditions during the cutting.

The reponse surface analysis wih the Box-behnken design is utilized to develop the prediction of the surface roughness and cutting force models represented by the second-order response functions. The experimentally obtained model clearly shows that the feed rate is the most significant factor on the surface roughness, followed by the depth of cut. It has been proved that the developed surface roughness prediction model can be effectively used to predict the surface roughness with the 95% confident level.

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