Applied Mechanics and Materials Vols. 117-119 (2012) pp 1561-1565
Online available since 2011/Oct/24 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.117-119.1561

Optimization of Cutting Parameters on Turning Process Based on Surface Roughness using Response Surface Methodology

Muhammad Yusuf[a], M.K.A. Ariffin[b], N. Ismail[c] and S. Sulaiman[d]

Department of Mechanical and Manufacturing Engineering

Universiti Putra Malaysia 43400 Serdang, Selangor D.E. Malaysia

[a]m_yusoef@yahoo.com, [b]khairol@eng.upm.edu.my, [c]napsiah@eng.upm.edu.my, [d]suddin@eng.upm.edu.my

Keywords: turning process, parameters process, surface roughness, design of experiment

Abstract. This paper describes effect of cutting parameters on surface roughness for turning of aluminium alloy 7050 using carbide cutting tool with dry cutting condition. The model is developed based on cutting speed, feed rate and depth of cut as the parameters of cutting process. The selection of cutting process was based on the design of experiments Response Surface Methodology (RSM). The objective of this research is finding the optimum cutting parameters based on surface roughness. The relation between cutting parameters and surface roughness were discussed.

Introduction

In turning operation, the surface integrity is an important requirement for many turned parts. Thus, the evaluation of machine tool and the choice of cutting parameters become very important to control the required surface quality. The cutting parameters such as cutting speed, feet rate, depth of cut, tool geometry, workpiece material and coolant conditions will highly affect the turning performance. It is necessary to select the most appropriate parameters in order to improve cutting efficiency, low cost process and produce high quality products. The optimization techniques of cutting parameters through experimental methods and mathematical and statistical models can be achieved to improve higher efficiency of turning process.

The characteristics of turning process such as surface roughness, uses of cutting tool, cutting force and energy consumption can be determined only by experiment. In order to improve uses of cutting tool, process design of performance of machine a series of experiments have to be conducted which are very costly and time consuming. Therefore, a proper design of experiment (DOE) data acquisition and statistical model construction along with its verification are of prime concern by researchers.

The application DOE has been employed by the researchers for modeling and analyzing of the process effect [1, 2, 3, 4, 5]. The main objective of this study is to optimize the parameter of turning process based on surface integrity, which included surface roughness and uses of cutting tool for aluminium alloy 7050 using Response Surface Methodology (RSM). This work identifies influence of cutting parameters, which included cutting speed *(v)*, feed rate (*f*) and depth of cut (a_p) on response factor of surface roughness (R_a) using uncoated carbide cutting tools in dry cutting condition.

Experiment set up

The material used for experiment is aluminum alloy 7050. The test sample was 150 mm length and 25 mm diameter, it is machined under dry cutting condition. The machined of length was set up to 120 mm on each the test sample. The machining was done on Harrison conventional lathe machine**,** maximum spindle speed achievable on this machine is 2200 rpm and spindle power 5.5 KW. The Taegutec VCGT 160408 FL K10 cutting tool insert uncoated carbide was used in the experimental with tool holder MTJNR. The surface roughness was measured using portable MarSurf PS1 to measure of average surface roughness (*Ra*). Cutting speed (*v*), feed rate (*f*) and depth of cut (a_p) were selected as the cutting parameters to analyze their effect on surface roughness (R_a). The design of cutting parameters models was based on design of experiment response surface methodology use of

Minitab Software. Fifteen cutting parameters models represent Box-Behnken design to determine effect of cutting parameter factors on responses [6]. The factors and levels each parameter was set as shown in Table 1.

Design of Experiment

Design of experiment (DOE) is powerful analysis tool for modeling and analyzing of the process effect. The application design of experiment is able to reduce the experiment expenses. The design of experiment method is an effective approach to optimize the various cutting parameters on machining processes. There are some methods in the design of experiment including factorial design, response surface design, mixture design and taguchi method used in experiment studies.

The response surface methodology (RSM) was employed for modeling and analyzing the influence of cutting parameters on the surface roughness and uses of cutting tool, three principal cutting parameters, including cutting speed (v), feed rate (f) and depth of cut (a_p) were specified as cutting parameters. In the turning process, these cutting parameters were selected as the independent input variables. The surface roughness and uses of cutting tool were assumed to be affected by the above three principal cutting parameters as the output responses. The quantitative form of relationship between the output response and independent input variables can be represented as the following:

$$Y = F\left(v\ f\ a_p\right) \tag{1}$$

where Y is the desired response, and F is the response function or response surface. The approximation of Y has been proposed by fitting second-order polynomial regression model, which is called quadratic model of the following form:

$$Y = a_0 + \sum_{i=1}^{3} a_i\ X_i + \sum_{i=1}^{3} a_{ii} X_i^{\ 2} + \sum_{i<1}^{3} a_{ij} X_i X_j \tag{2}$$

where a_0 is a constant and a_i, a_{ii} and a_{ij} are the coefficients of linear, quadratic and cross product term, respectively. The X_i reveals the coded variables corresponding to studied cutting parameters ($v, f,$ and a_p).

The necessary data required for developing the response models have been collected by the experimental design. In this study, the collection of experimental data base on Box-Behnken design (BBD). The levels and cutting parameters were selected as shown in Table 1.

Experiment Result and Discussion

The experimental results of surface roughness (*Ra)* along with design matrix based on BBD are tabulated in Table 2. The coefficients of regression analysis for surface roughness (*Ra*) are shown in Table 3 along with their *P*-value of parameters, higher order and interactions.

The *P*-value of regression analysis of surface roughness (*Ra*) in Table 3 indicates that linear, square, interactions of cutting speed and depth of cut and interactions of cutting speed and feet rate are not less than 0.05 (use $\alpha = 0.05$, or 95% confidence), therefore, there is not significant effect on surface roughness (*Ra*). However, linear and square of feed rate and interaction of cutting speed and depth cut are most significant. The other important coefficient, R^2, which is called determination coefficients in the resulting ANOVA table, the higher of R^2 is better to determine the coefficient of regression equation.

The approximation of surface roughness (*Ra*) by the regression model equation is presented as follow:

$$\begin{aligned} Ra = -0.326847 + 0.0112854v - 1.15056f + 0.963750a_p + 6.28125\mathrm{E}-05v^2 + \\ + 21.5278f^2 + 0.0965000a_p^2 - 0.0286667v\,f - 0.0145250v\,a_p - \\ - 1.26000f\,a_p \end{aligned} \tag{3}$$

The above model obtained can be used to predict the surface roughness (*Ra*) within the limits of factors studied. The differences between experimental results and predicted responses are illustrated in Fig. 1.

The statistical significances of the fitted quadratic model for the surface roughness (*Ra*) were evaluated by the *F*-test ANOVA, the results are listed in Table 4. When the *P*-values of term of models are less than 0.05, this concludes that the terms in the model have a significant effect on the responses. The *P*-values of *Ra* models linear, square and interaction effects of cutting speed and depth of cut are significant. The lack-of-fit test is not significant for the effect, thus the model is adequate in 95% confident limit.

Table 1. Parameters process and their levels

Factor	Unit	Levels Low	Levels Medium	Levels High
Code levels		-1	0	+1
Cutting speed (v)	m min^{-1}	40	60	80
Feed rate (f)	mm rev^{-1}	0.05	0.125	0.2
Depth of cut (a_p)	mm	0.5	10	1.5

Table 2. Experimental results with design matrix

Test model	Factors v (m min^{-1})	Factors f (mm rev^{-1})	Factors a_p (mm)	Response *Ra* (μm)
1	-1	-1	0	0.625
2	1	-1	0	0.628
3	-1	1	0	2.719
4	1	1	0	2.378
5	-1	0	-1	0.963
6	1	0	-1	1.193
7	-1	0	1	1.352
8	1	0	1	1.001
9	0	-1	-1	0.542
10	0	1	-1	2.789
11	0	-1	1	0.573
12	0	1	1	2.442
13	0	0	0	1.070
14	0	0	0	1.037
15	0	0	0	1.127

Table 3. Regression coefficient of *Ra*

Term	Coefficient	*P value*
Constant	-0.326847	<0.000
v	0.0112854	0.173
f	-1.15056	<0.000
a_p	0.963750	0.698
v^2	6.28125E-05	0.656
f^2	21.5278	<0.000
a_p^2	0.0965000	0.669
v f	-0.0286667	0.153
v a_p	-0.0145250	0.036
f a_p	-1.26000	0.124
Standard deviation (*S*)		0.102153
Predicted residual error of sum of square (PRESS)		0.777813
R^2		99.42 %
R^2 Predicted		91.37 %
R^2 adjusted		98.38 %

Table 4. Analysis of Variance for *Ra*

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	8.96540	8.96540	0.99616	95.46	<0.000
Linear	3	7.94831	7.94831	2.64944	253.89	<0.000
Square	3	0.86739	0.86739	0.28913	27.71	<0.002
Interaction	3	0.14970	0.14970	0.04990	4.78	0.062
Residual Error	5	0.05218	0.05218	0.01044		
Lack-of-Fit	3	0.04803	0.04803	0.01601	7.72	0.117
Pure Error	2	0.00415	0.00415	0.00207		
Total	14	9.01757				

In order to investigate the influence of cutting parameters on the surface roughness (*Ra*), the three dimensional response surfaces are drawn in Fig. 2. The surface roughness (*Ra*) generally increases with increase of the feed rate (*f*). However, the surface roughness appears to be decreasing with increasing depth of cut (a_p) at the scope of middle feet rate 0.25 mm rev^{-1}. The low surface roughness is at lower cutting speed, feed rate and depth of cut ranges.

Numerical optimization technique of RSM has been employed on response of surface roughness (*Ra*). The objective of optimization was to minimize the value of surface roughness (*Ra*) while keeping the cutting parameters within range. The goal was to minimize the surface roughness, the higher value and target has been fixed at 2.789 and 0.542 µm, respectively. The parameter setting for achieving a surface roughness as low as 0.3631 µm has been predicted as cutting speed 40 m min^{-1}, feed rate 0.1 mm rev^{-1} and depth of cut 0.5 mm. The desirability (*d*) of optimization has been calculated as 1.0, it be concluded that the parameters are within working range. The optimization plot for surface roughness is shown in Fig. 3.

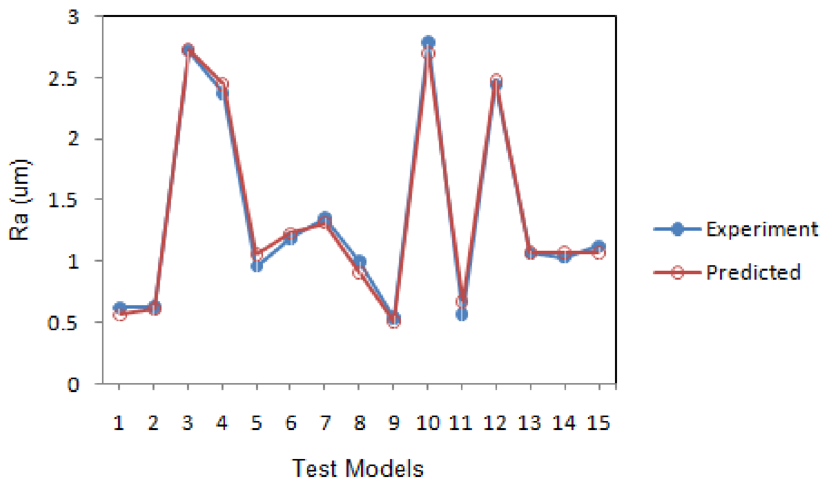

Fig. 1. The comparison between experimental and predicted value for *Ra*

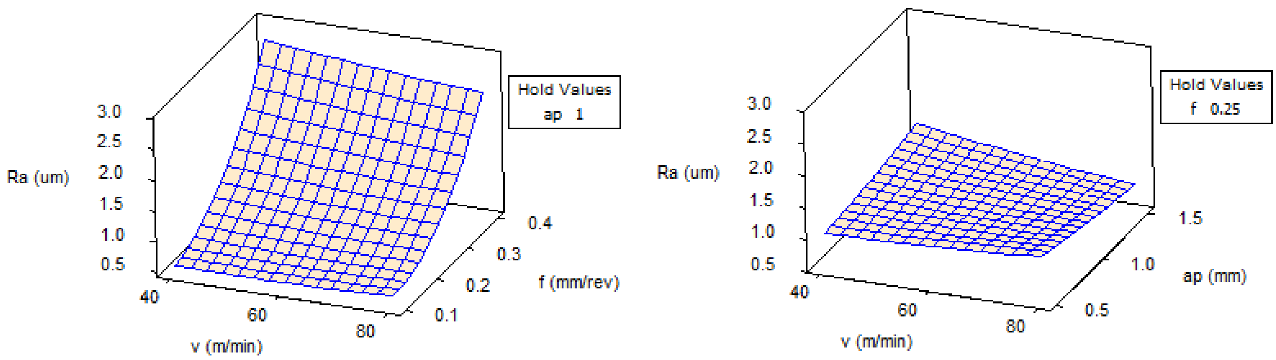

Fig. 2. The influence of cutting parameters on surface roughness (*Ra*)

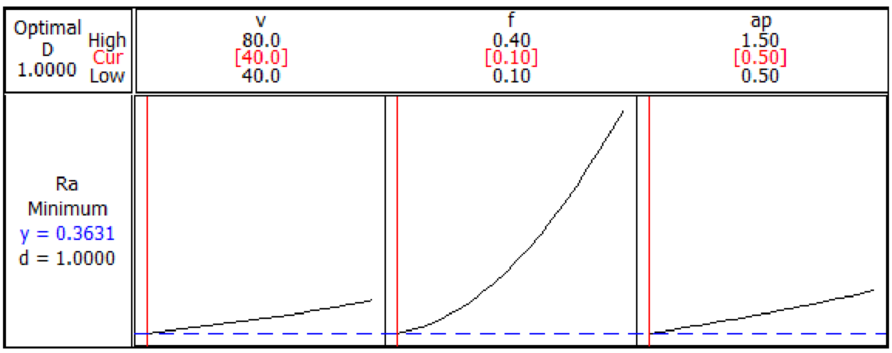

Fig.3. Optimum results for minimum surface roughness

Summary

In this paper, the response surface methodology has been applied to develop and optimize mathematical models of the surface roughness (*Ra*) and uses of cutting tool and to investigate the influence of cutting parameters on response factors during turning of aluminum alloy 7050. The following conclusion of research as follow:

- The proposed regression model for surface roughness are found to be adequate in 95% confident limit and can be used to predict the characteristics within the experimental range. Feed rate and interactions of cutting speed and dept of cut are found to be more significant effect on surface roughness (*Ra*) when compared to other parameters.
- The surface roughness increase with increase of feed rate and cutting speed. The low surface roughness was found at lower cutting speed, feed rate and depth of cut ranges.
- The optimal turning parameters combination is obtained using desirability function. The minimum surface roughness of 0. 363 µm can be achieved when use of cutting conditions such as cutting speed 40 m min^{-1}, feed rate 0.1 mm rev^{-1} and depth of cut 0.5 mm.

Acknowledgements

This work was financially supported by Research University Grant Scheme (RUGS: 9199811) Universiti Putra Malaysia.

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Materials and Computational Mechanics
10.4028/www.scientific.net/AMM.117-119

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