The Effect of End Milling Parameters on Surface Roughness when Machining Corrosion Resistance Alloy

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Abstract

The increase of consumer needs for quality metal cutting related products (more precise tolerances and better product surface roughness) has driven the metal cutting industry to continuously improve quality control of metal cutting processes. Within these metal cutting processes, the end-milling process is one of the most fundamental metal removal operations used in the manufacturing industry. The aim of the this study is to develop the surface roughness prediction model for Hastelloy C-22HS with aid of statistical method, using coated carbide cutting tool under various cutting conditions. This material is superior materials for corrosion resistance which commonly used underwater applications such as submarine components and etc. This prediction model was then compared with the results obtained by experimentally. By using Response Surface Method (RSM) of experiment, first and second order models were developed with 95% confidence level. The surface roughness was developed in terms of cutting speed, feed rate and axial depth using RSM and design of experiment. In general, the results obtained from the mathematical model are in good agreement with that obtained from the experiment data's. It was found that the feedrate, cutting speed and axial depth played a major role in determining the surface roughness. On the other hand, the surface roughness increases with a reduction in cutting speed.

Keywords: surface roughness, milling, response surface method, second order model

Introduction

Surface finish influences not only the dimensional accuracy of machined part, but also the mechanical property of the part, especially the fatigue strength. The surface finish describes the geometrical feature of surface which in turn determines the fatigue life and corrosion life [1], [2], [3]. Several methods for inspecting and characterising the surfaces have been developed. Inspection equipment based on both contact and non-contact principles is available. Contact–type instruments, generally employing styluses, are commonly used. Non-contact instruments are usually based on optical interferometry or electron beam principle. A large relief angle may reduce friction between the tool and workpiece, but excess relief angle reduces the support under the cutting edge, thereby causing failure under heavy-duty operation, and may result in inferior surface roughness on machined parts [1].

Recent investigation performed by Alauddin *et al.* [4] has revealed that when the cutting speed is increased, productivity can be maximised meanwhile, surface quality can be improved. According to Hasegawa *et al*. [5], surface finish can be characterised by various parameters such as average roughness (Ra), smoothening depth (Rp), root mean square (Rq) and maximum peak-to-valley height (Rt). The present study uses average roughness (Ra) for the characterisation of surface finish, since it is widely used in industry. By using factors such as cutting speed, feed rate and depth of cut, Hashmi and his coworkers [6],[7] have developed surface roughness models and determined the cutting conditions for 190 BHN steel and Inconel 718. A large relief angle may reduce friction between the tool and workpiece, but excess relief angle reduces the support under the cutting edge, thereby causing failure under heavy-duty operation, and may result in inferior surface roughness on machined parts [8]. However, the variations of both tool angles have important effects on surface roughness. In order to model and analyse the effect of each associated factor and minimise the number of cutting tests, surface roughness models utilising the Response surface methodology [9] and the experimental design are carried out in this investigation. Recent investigations performed by EI-Baradie [10] and Bandyopadhyay [11] have shown that by increasing the cutting speed, the productivity can be maximised and, at the same time, the surface quality can be improved. According to Gorlenko [12] and Thomas [13], surface finish can be characterised by various parameters. Numerous roughness height parameters such as average roughness (Ra), smoothening depth (Rp), root mean square (Rq), and maximum peak-to-valley height (Rt) can be closely correlated. The present study uses average roughness (Ra) for the characterisation of surface roughness, due to the fact that it is widely adopted in the industry for specifying the surface roughness. Mital and Mehta [14] have conducted a survey of the previously developed surface roughness prediction models and factors influencing the surface roughness. They have found that most of the surface roughness prediction models have been developed for steels.

In this paper, the objective is to optimise the cutting conditions such as cutting speed, feed rate, and axial depth for the targeted responses. The idea is to maximise the productivity and life-span of the cutting tool. The factors identified for optimisation are speed, feed rate, and axial depth as they are crucial in determining the productivity. Second order developed to investigate the 2nd order interaction among the variables.

Experimental set-up

The process of finding out the right combination of machine tool, cutting tool and optimum cutting conditions is time-consuming and expensive. From the result of the preliminary experiments carried out with different cutting tools, it is decided to use the design of experiment (DOE) technique to find out a feasible range of cutting condition of the cutting tool. Using the response surface method (RSM) employed in the statistical analysis software “Minitab, ver.14”, it is possible to reduce the time and cost involved in selecting an optimum tool and cutting condition to maximise the material removal rate [9]. Three levels (low, medium and high) are used and the ranges of the levels are obtained from a series of preliminary investigations. The responses identified for maximisation is surface roughness. In Minitab, RSM is used to find a combination of factors which gives the optimal response. RSM is actually a collection of mathematical and statistical technique that is useful for the modeling and analysis of optimisation problems [15], [16]. After the preliminary investigation, the suitable levels of the factors are used in the Minitab software to deduce the design parameters of 90^0 tool holders for Hastelloy C-22HS as shown in Table 1. The lower and higher speed values selected are 100 m/s and 180 m/s, respectively. For the feed, the lower value is 0.1 mm/rev and the higher value is 0.2 mm/rev. For the axial depth, the higher value is 2 mm and the lower value is 1 mm. In the case of radial depth, a value of 3.5 mm is selected for all experiments. Table 2 shows the selected values for the variables.

Table 1: The values selected for the variables.

Factors/Coding of Levels	**low**	**mid**	**high**
Speed, V_c (m/min)	100	140	180
Feed, f (mm/rev)	0.1	0.15	0.2
Axial depth, a_d (mm)	1	1.5	2

Table 2: Design values generate by Minitab.

Experiment Number	**Cutting speed, V_c (m/min)**	**Feed rate, f (mm/rev)**	**Axial depth, a_d (mm)**
1	140	0.1	2
2	140	0.2	1
3	100	0.15	1
4	100	0.15	2
5	140	0.15	1.5
6	100	0.1	1.5
7	180	0.1	1.5
8	180	0.15	2
9	180	0.2	1.5
10	140	0.2	2
11	180	0.15	1
12	140	0.15	1.5
13	140	0.1	1
14	100	0.2	1.5
15	140	0.15	1.5

Workpiece Material

The workpiece material used is Hastelloy C-22HS which is a corrosion-resistant, nickel-chromium-molybdenum alloy which can be heat-treated to obtain strength approximately double that of other C-type alloys. Importantly, the corrosion resistance and the ductility of the alloy remain excellent in high strength condition. In addition to its high uniform corrosion resistance in oxidising as well as reducing environments, the as-heat treated C-22HS alloy possesses high resistance to chloride-induced pitting and crevice corrosion attack.The C-22HS alloy may be also considered for applications which do not require the high strength imparted by the heat treatment. In the annealed condition, C-22HS alloy has even higher corrosion-resistance, particularly to localised corrosive attack. This localised resistance also makes the alloy an attractive candidate as a general-purpose filler metal or weld overlay. The properties of the workpiece material (Hastelloy C-22HS) are shown in Tables 3 and 4.

Table 3: Chemical composition for Hastelloy C-22HS.

Ni	Cr	Mo	Fe	Co	W	Mn	Al	Si	C	B
BAL	21%	17%	2%	1%	1%	0.80%	0.50%	0.08%	0.01%	0.01%

Table 4: Physical properties of Hastelloy C-22HS at room temperature.

Density (g/cm^3)	8.6
Thermal Conductivity (W/m.^{o}C)	11.8
Mean Coefficient of Thermal Expansion (μm/m.^{o}C)	11.6
Thermal Diffusivity (cm^2/s)	0.0334
Specific Heat (J/kg.^{o}C)	412
Young Modulus (GPa)	223

The cutting tool used in this study is a 12º rake positive end milling cutter of 50 mm diameter. The end mill can be equipped with four inserts, in which only one edge can be used for cutting. The tool inserts are made by Kennametal and had an ISO catalogue number of SPHX1205ZCFRGN1W (KC725M). In this study, only one insert per one experiment is mounted on the cutter. The cutting tools implemented in this experiment are shown Figure 1.The composition of the cutting tool is shown in Table5.

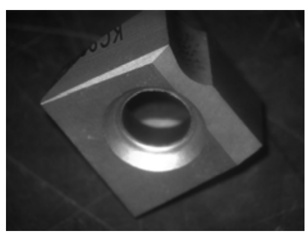

Figure 1: Cutting tool that used in these studies.

Table 5: Composition of the cutting tool

Code name	**Composition (%)**						**Coating**	**Thickness (μm)**
	% Co	% WC	%Cr3C2	%TaC	%TiC	%Nbc		
KC725M	11.5	88	0.5	-	-	-	PVD TiN/TiCN/Al_2O_3	3

Fifteen experiments are carried out on Okuma CNC machining centre MX-45 VA as shown in Figure 2. The water soluble coolant is used in these experiments. Each experiment is stopped after 90 mm cutting length. Tester R200 is used as shown in Figure 2 to measure surface roughness. Each experiment is repeated three times, using a new cutting edge every time in order to obtain accurate readings of the surface roughness.

Figure 2: The Okuma CNC machine used in the present work.

Results and Discussion

After conducting the first pass (one pass is equal to 85 mm length) of the 15 cutting experiments, the surface roughness readings are used to find the parameters appearing in the postulated first-order model. In order to calculate these parameters, the least square method is used with the aid of Minitab. The first and second order quadratic equation for predicting the surface roughness can be expressed as:

$$\text{Surfaceroughness}' = 0.5927 - 0.0045x_1 + 0.98x_2 + 0.27x_3 \quad (1)$$

$$\text{Surfaceroughness}'' = 0.3087 - 0.004x_1 + 1.87x_2 + 0.42x_3 - 1.35x_2^2 - 0.0345x_3^2 - 0.0014x_1x_2 - 0.0001x_1x_3 - 0.2x_2x_3 \quad (2)$$

Generally, the increase in feed rate, axial- and radial depths of cut will cause the surface roughness to increase. On the other hand, the decrease in cutting speed will cause a slight reduction in surface roughness. The feed rate has the most dominant effect on the surface roughness, followed by axial depth and cutting speed. Hence, better surface roughness can be obtained with the combination of high cutting speed, low axial depth and low feed rate. Figures 3 show the surface roughness values obtained by experimentation and the values predicted by the first and second order models. It is clear that the predicted values by second order are very close to those measured. The adequacy of the first-order model is verified using the analysis of variance (ANOVA). At a level of confidence of 95%, the model is checked for its adequacy The ANOVA results and surface plot are given in Table 6 and Figure 4.

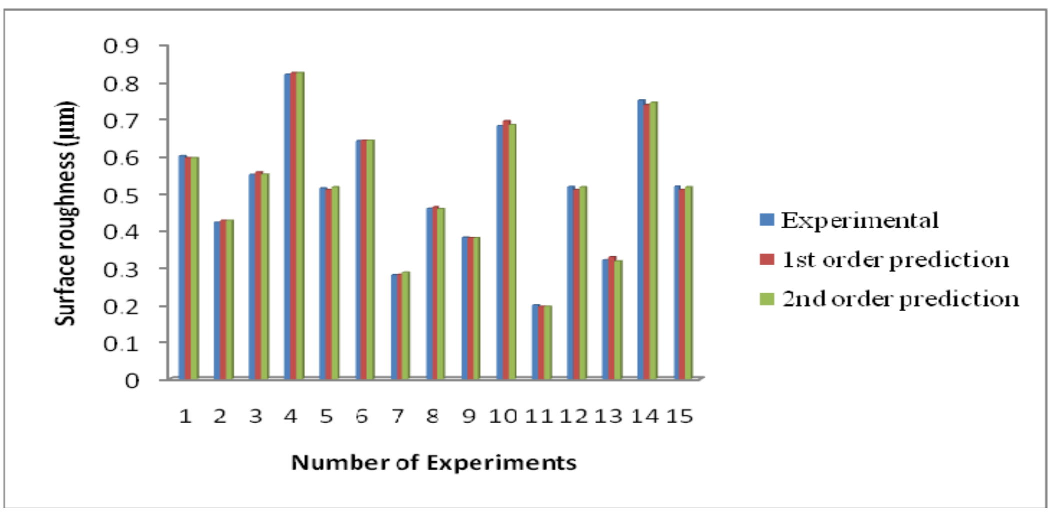

Figure 3: Experiment result and prediction result for surface roughness model

Table 6: ANOVA analysis for (a) first order; (b) second order

Source	**Degree of freedom**	**F-ratio**	**P-value**
Regression	9	1162.72	0
Linear	3	3484.37	0
Square	3	2.49	0.174
Interaction	3	1.28	0.376
Residual Error	5		
Lack-of-Fit	3	8.94	0.102
Pure Error	2		
Total	14		

(a) first order

Source	**Degree of freedom**	**F-ratio**	**P-value**
Regression	3	2545.2	0
Linear	3	2545.2	0
Residual Error	11		
Lack-of-Fit	9	13.1	0.073
Pure Error	2		
Total	14		

(b) second order

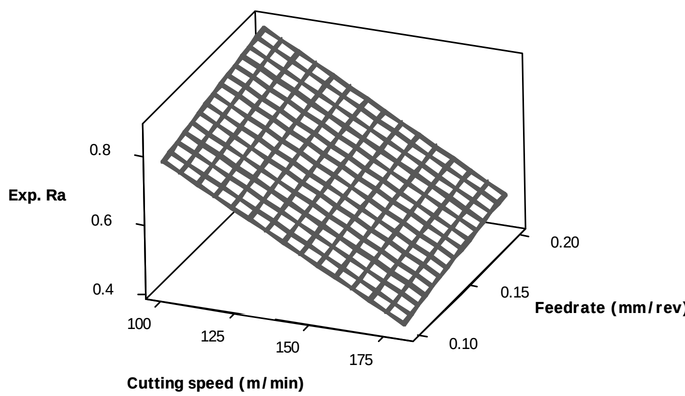

Figure 4: Surface plot for first order

Optimization of the surface roughness value

Ideally, the main goal of the current work is to minimise the cutting force with a correct combination of variables. This goal can be achieved using Minitab. For the Optimization approach employed in Minitab, each response is transformed using a specific desirability function. The weight defines the shape of the desirability function for each response. For each response, a weight can be selected from 0.1 to 10 to emphasise or de-emphasise the target. A weight

- less than one (minimum is 0.1) places less emphasis on the target
- equal to one places equal importance on the target and the bounds
- greater than one (maximum is 10) places more emphasis on the target

The optimum value for surface roughness at tool holder 90^0 with coolant is 0.1474 µm, which corresponds to design variables: cutting speed =180 m/min, feed rate = 0.1 mm/rev and axial depth = 1 mm.

Conclusion

RSM found successful technique to perform trend analysis of surface roughness with respect to various combinations of design variables (cutting speed, feed rate, axial depth and radial depth). The first-and second–order models found to be adequately representing the surface roughness with experimental results. RSM model reveal that feed rate is the most significant design variable to predict the surface roughness response as compared to others. Second-order model found to be no interaction between the variables. With the model equations obtained, a designer can subsequently select the best combination of design variables for achieving optimum surface roughness. This eventually reduces the machining time and save the cutting tools.

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