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Statistical model to determine surface roughness when milling hastelloy C-22HS

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Abstract

The aim of this study is to develop the surface roughness prediction models, with the aid of statistical methods, for hastelloy C-22HS when machined by PVD and CVD coated carbide cutting tools under various cutting conditions. These prediction models were then compared with the results obtained experimentally. By using response surface method (RSM), first order models were developed with 95 % confidence level. The surface roughness models were developed in terms of cutting speed, feed rate and axial depth using RSM as a tool of design of experiment. In general, the results obtained from the mathematical models were in good agreement with those obtained from the machining experiments. It was found that the feed rate, 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. PVD coated cutting tool performs better than CVD when machining hastelloy C-22HS. It was observed that most of the chips from the PVD cutting tool were in the form of discontinuous chip while CVD cutting tool produced continuous chips.

Keywords: Surface roughness; Milling; Response surface method; CVD; PVD

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1. Introduction

Over the years, the nickel- chromium-molybdenum/tungsten alloys have been proven to be among the most reliable and cost effective materials for aggressive seawater application and excellent resistance to localized corrosive attack (pitting, crevice corrosion). Hastelloy nickel alloy of C-type is one example of these alloys. As these alloys are used in critical applications, the quality of their surface finish plays vital factors. Hence, this paper focuses on studying the surface roughness parameters of these alloys after being machined by carbide tools.

Surface processes carried out by using different manufacturing methods are directly or indirectly affected by machining parameters. Poor selection of machining parameters causes cutting tools to wear and break quickly as well as economical losses such as damaged workpiece and poor surface quality [1].

Boothroyd [2] and Baradie [3] investigated the effect of speed, feed and depth of cut on steel and grey cast iron, and then emphasized the use of RSM in developing a surface roughness prediction model.

Fuh and Wu [4] proposed a prediction model using Taguchi method and the response surface method (RSM). By using factors such as cutting speed, feed and depth of cut, Alauddin et al. [5] developed surface roughness models and determined the cutting conditions for 190 BHN steel and inconel 718. They found that the variations of tool angles had important effects on the surface roughness. In order to model and analyze the effect of each variable and minimize the cutting tests, surface roughness models utilizing

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response surface methodology and the experimental design were carried out in this investigation.

2. Box – Behnken design

Box-Behnken design as a type of RSM is normally used when performing non-sequential experiments. That is performing the experiment only once. These designs allow efficient estimation of the first and second order coefficients. Because Box-Behnken design has fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken design does not have axial points, thus can be sure that all design points fall within the safe ranges of operating parameters. Box-Behnken design also ensures that all factors are never set at their high levels simultaneously [6-8].

After some preliminary investigation, the suitable levels of the factors were used for machining tests (Table 1). In this study, three variables have been selected, which are cutting speed, feed rate and axial depth. For the radial depth, 3.5 mm has been selected for all experiments.

Table 1. Level of independent variable.

Levels	Low	Medium	High
Coding	-1	0	1
Speed v [m/min]	100	140	180
Feed f [mm/rev]	0.1	0.15	0.2
Axial depth d_a [mm]	1	1.5	2

Fig. 1. Portable surface roughness tester.

3. Experiment setup

The 15 experiments were carried out on Okuma CNC machining centre MX-45 VA with 90^0 holders and using a standard water soluble coolant. Each experiment was stopped after 85 mm cutting length. For the surface roughness measurement a portable surface roughness tester was used as shown in Fig. 1. Each experiment was repeated three times using a new cutting edge to obtain reliable readings of the surface roughness. A cutting pass was conducted in such a way that a shoulder of 3.5 mm width was produced for the three values of axial depth of cut (1, 1.5 and 2 mm).

The workpiece material used in these experiments was selected to represent the major group of workpiece materials used in industry under the type of HASTELLOY C type. The chemical composition and physical properties are given in Tables 2 and 3, respectively.

The cutting tools used in this study are a 12° rake positive inserts mounted on an end milling cutter of 50 mm diameter. The end mill can be equipped with four inserts whose only one edge can be used for cutting. The tool inserts were made by Kennametal and had an ISO catalogue number of PHX1205ZCFRGN1W (KC520M) and SPHX1205-ZCFRGN1W (KC915M). KC520M is coated with TiAlN (PVD) and KC915M is coated with TiN/MT-TiCN/TiCN/AL2O3. In this study, only one inserts per one experiment was mounted on the cutter. The cutting inserts used in this experiment are shown in Fig. 2.

Table 2. 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 3. Physical properties of hastelloy C-22HS at room temperature.

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

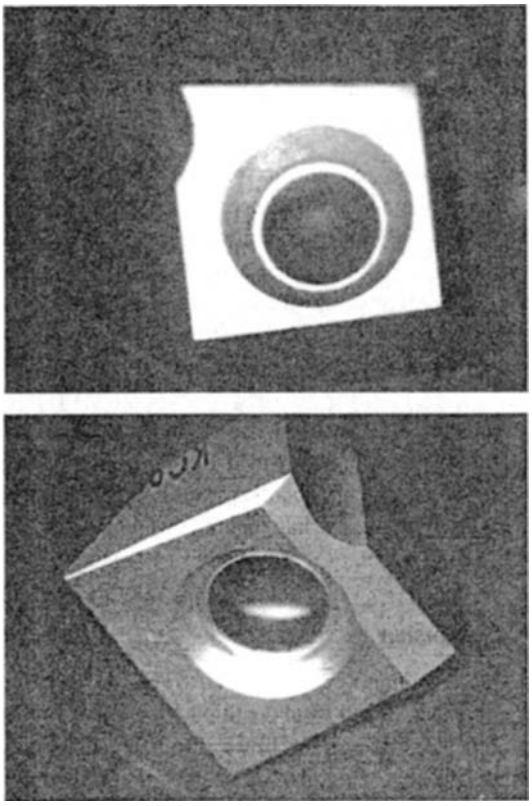


Fig. 2. Cutting inserts.

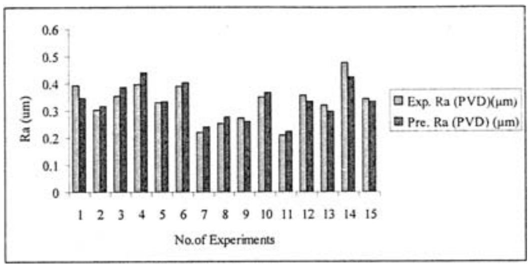


Fig. 3. Experimental and first order prediction results for surface roughness (PVD cutting tools).

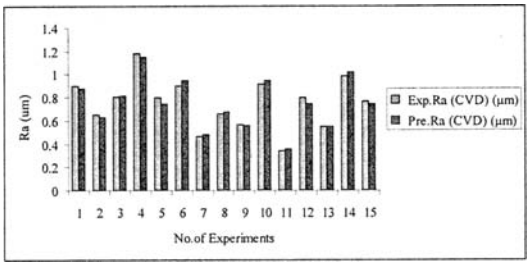


Fig. 4. Experimental and first order prediction results for surface roughness (CVD cutting tools).

4. Development of first order surface roughness model

The proposed linear model relationship between the machining responses and machining independent variables can be represented by the following:

$$y' = mCuttingspeed + nFeedrate + pAxialdepth + C \qquad (1)$$

where y' is the response, C, m, n, and p are the constants. Eq. (1) can be written in the following form:

$$y' = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad (2)$$

where y' is the response, x_0 = 1(dummy variables), x_1= cutting speed, x_2= feed rate, and x_3= axial depth. β_0 = C and β_1, β_2, and β_3, are the model parameters.

The first order linear equation for predicting the surface roughness for PVD and CVD coatings is expressed as:

$$y = 0.5119 - 0.0021x_1 + 0.1975x_2 + 0.0525x_3 \text{ (PVD)} \qquad (3)$$

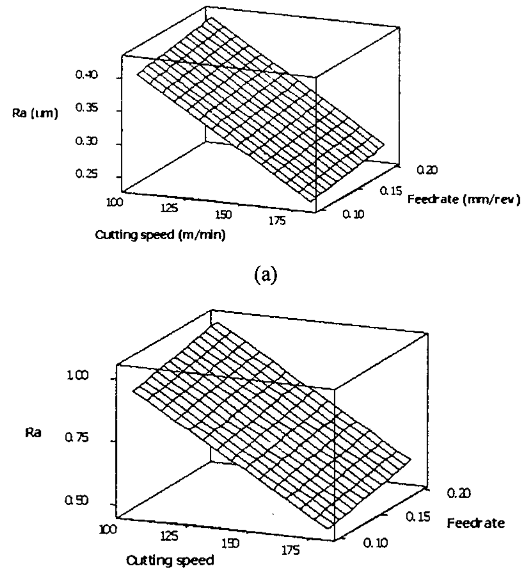
$$y = 0.9595 - 0.0058x_1 + 0.78x_2 + 0.3245x_3 \text{ (CVD)} \qquad (4)$$

Generally, the increase in feed rate, axial depths of cut will cause the surface roughness to become larger. On the other hand, the decrease in cutting speed will slightly cause a reduction in surface roughness. Hence, a better surface roughness is obtained with the combination of high cutting speed, low axial depth and feed. From the experimental results it was found that the PVD coated cutting tool produced finer surface roughness compared to the CVD cutting tool.

Figs. 3 and 4 show the surface roughness values obtained by experimentation and the values predicted by the first order model. It is clear that the predicted values are very close to the experimental readings.

The adequacy of the first order model for both cutting tools was verified using the analysis of variance (ANOVA). At a level of confidence of 95%, the model was checked for its adequacy. The models are adequate and could fit since the P values of the lack-of-fit are not significant for both models.

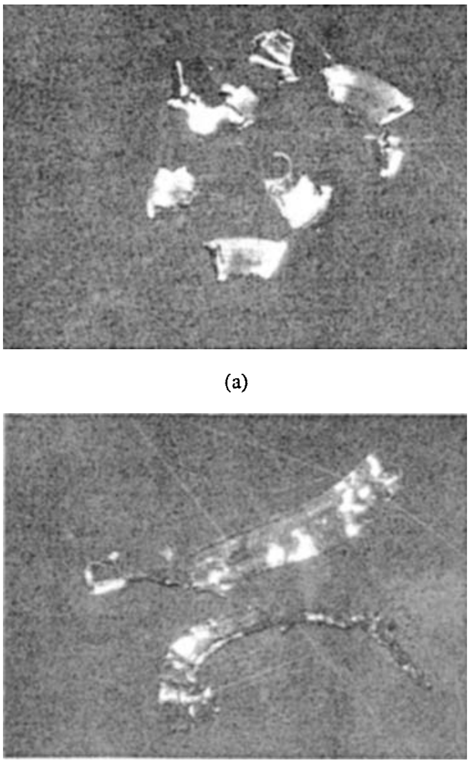
The developed linear models (Eqs. 3 and 4) were used to plot contours of the surface roughness. Fig. 5 shows the surface roughness contours at middle value of the axial depth. It is clear that low in cutting speed



(a)

(b)

Fig. 5. Surface roughness contours in the cutting speed-feedrate plane at 1.5 mm axial depth: (a) PVD and (b) CVD coatings.



(a)

(b)

Fig. 6. (a) Discontinuous chips (PVD inserts) and (b) continuous chips (CVD inserts).

and high feed rate and axial depth will cause dramatic increase of the surface roughness.

4. Chip analysis

Chip shape (continuous and discontinuous) depends on the combined effects of the workpiece and insert material properties, cutting speed, feed rate and cutting tool geometry. The chip type is a good indicator of the quality of the machined surface. The comprehension of chip formation plays an important role in milling process optimization, surface integrity (roughness, residual stress and surface texture) and thus part performance [9].The chips collected during the experiments are shown in Fig. 6. It is observed that most of the chip obtained from PVD cutting tool was discontinuous while continuous chips for the CVD cutting tool.

5. Conclusion

In the milling operation of HASTELLOY, cutting speed, feedrate and axial depth play the major role in producing good surface finish. From the first order models, one can easily notice that the response y (surface roughness) is affected significantly by the feed rate followed by axial depth of cut and then by cutting speed. Generally, reduction in the feed rate, axial depth and increase in the cutting speed will result in lower surface roughness. PVD produced finer surface finish compared with the CVD. PVD cutting tools produced discontinuous chips while CVD cutting tool produced continuous chips. From the experimental results, the PVD coated cutting tool performs better than CVD coated cutting tool when machining hastelloy C-22HS. Response surface method is very useful since with few simulations, a lot of informations can be derived such as the relationship between the variables (cutting speed, feedrate and axial depth) and the response (surface roughness).

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