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MODELLING OF TOOL LIFE WHEN MILLING NICKEL BASE ALLOYS WITH TWO DIFFERENT COATED CARBIDE INSERTS

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ABSTRACT

This paper discusses the development of the first-order model for predicting the tool life in end-milling operation of Hastelloy C-22HS nickel base superalloy when employing two differently coated carbide cutting tools. The first-order equations of tool life are developed using response surface methodology (RSM). The cutting variables used in this study are the cutting speed, feed rate, and axial depth of cut. The analysis of the obtained models is supported using a statistical software package. From this study, it is found that the models are able to predict values of tool life close to those readings recorded experimentally with a 95%-confidence interval. The tool life first order equations show that feed rate is the most dominant factor, followed by axial depth of cut, and then cutting speed. In addition, the study indicates that inserts coated with a single TiAlN layer outperform the other type of inserts, which are with multiple-layered coating.

1 INTRODUCTION

The C-22HS alloy, which is high in strength, is derived from the formation of strengthening particles, Ni_2 (Mo,Cr), which are formed after two-step age-hardening heat treatment. C-22HS alloy may be considered for applications which do not require the property of high strength imparted by heat treatment process. In the annealed condition, C-22HS alloy has even higher corrosion-resistance, particularly with regard to localised corrosive attack. This localised attack resistance also makes the alloy an attractive candidate as a general-purpose filler metal or weld overlay [1].

Wu [2] has been pioneering the application of RSM in tool life testing. The number of experiments required to develop a surface roughness equation can be reduced as compared to that of the traditional one-variable-at-a-time approach. Based on RSM and factorial designs, first- and second-order models have been developed in this project. Only 12 tests are required to develop the first-order model, whereas 24 tests are needed for the second-order model. Reen [3] has pointed out that for accurate rating of machinability, three factors, namely, tool life, surface finish, and power consumed during cutting, must be considered. Similar opinions have been contributed by Shaw [4].

2 DESIGN OF EXPERIMENT

After the preliminary investigation, the suitable levels of the factors are used in a statistical software package to produce test combinations for machining 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 as a fixed parameter for all experiments. Table 2 shows the experimental combinations of the selected values for the variables. In order to develop the first-order model, a total of 15 experiments are carried out. All the experiments repeated 3 times to get more accurate readings.

Table 1: The values selected for the variables.

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

3 WORKPIECE AND CUTTING TOOL MATERIALS

The properties of the workpiece material (Hastelloy C-22HS) are shown in Tables 3 and 4. The cutting tool used in this study is a 12° 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 have an ISO catalogue number of SPHX1205ZCFRGN1W (KC520M and KC 930). In this study, only one insert per one experiment is mounted on the cutter. The composition of the cutting tool is shown in Table 5.

Table 2: Design values obtained from the Minitab

Run No.	Cutting speed (m/min)	Feed rate (mm/rev)	Axial depth (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

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 %	0.8 %	0.5 %	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

4 MACHINING TESTS

The 15 experiments are carried out on Okuma CNC machining centre MX-45 VA. A 90°-tool holder is used in the experiments. Each experiment is stopped after 90 mm cutting length. The series of experimentations was repeated three times using a new cutting edge every time to obtain accurate readings of the tool life and reduce experiment error. For the tool life, the cutting tool will be stopped if its flank wear reach more than 0.3 mm. After each run, the cutting tools were analysis under a microscope with an image analyser to measure the tool flank wear.

Table 5: Composition of the cutting tool

Code	Composition (%)				Coating	Thickness (µm)
	% Co	% WC	$\%Cr_3C_2$	%Nbc		
KC520M	6	93.5	0.5	-	PVD TiAlN	3.5
KC930	6	91.5	0.5	2.0	CVD TiN/MT-TiCN/TiCN/AL_2O_3	3

5 RESULTS AND DISCUSSION

5.1 Tool life prediction model for PVD and CVD cutting tools

After conducting the cutting experiments using the two groups of inserts (PVD and CVD coating), the tool life 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 a statistical software. The first-order linear equation used to predict the cutting force is expressed as:

$$y' = 1.9788 - 0.0036x_1 - 2.85x_2 - 0.475x_3 \quad \text{(for PVD-coated cutting tool)}$$

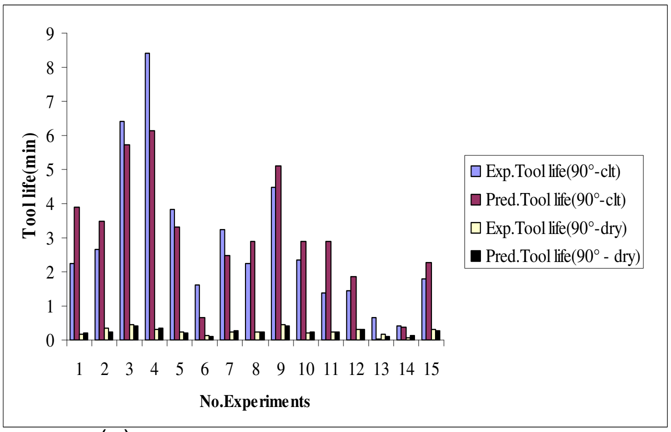
$$y' = 16.0247 - 0.033x_1 - 18.2x_2 - 3.86x_3 \quad \text{(for CVD-coated Cutting tool)}$$

The equations show that tool life decreases with the increasing cutting speed, feed rate, radial depth and axial depth. Generally, the feed rate has the most dominant effect on the tool life, followed by the axial depth and cutting speed. Hence, longer tool life can be attained with the combination of low cutting speed and low feed rate. According to Alauddin *et al.* [5] the effect of feed rate is more pronounced than the effect of speed, on tool life. Alauddin *et al.* [6] have found that an increase in speed, feed rate, and axial depth of cut will decrease the tool life.

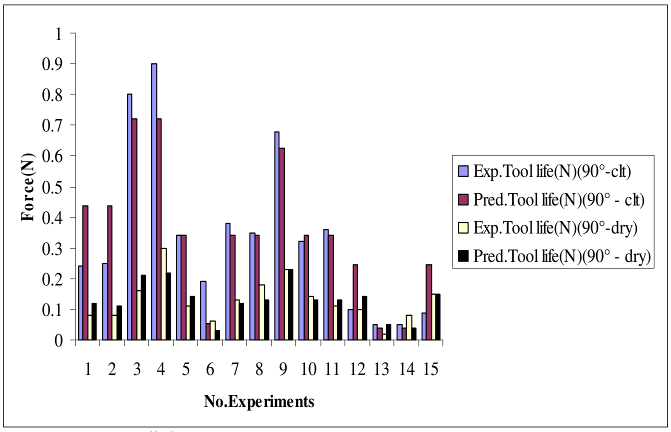
The study also included eperiments with the use of a coolant (dry cutting). However, the tool life span of the cutting tools was found to be very short. Thereore, it was concluded that the dry cutting is not suitable for machining Hastelloy C-22HS with the current parameters. Due to the fact that it is not suitable to be used, the statistical analysis of dry cutting is not performed.

Figures 1 (a) and 1 (b) show the measured tool life and the predicted one based on the first-order models for both dry and wet cutting. It is clear that the predicted values are very close to the experimental readings.

The adequacy of the first-order model is verified using ANOVA. At a level of confidence of 95%, the model is checked for its adequacy. As shown in Table 6, the model is adequate owing to the fact that the P values of lack-of-fit are not significant. This implies that the model could fit and it is adequate.



(a)



(b)

Figure 1: Experiment results and prediction result for first order tool life model: (a) PVD –coated cutting tool coolant and dry (b) CVD –coated cutting tool coolant and dry

Table 6: Variance analysis for first order cutting tool life model: (a) PVD –coated cutting tool coolants and (b) CVD –coated cutting tool coolants

Source	**DF**	**F**	**P**
Regression	3	11.88	0.001
Linear	3	11.88	0.001
Residual Error	11		
Lack-of-Fit	9	5.9	0.153
Pure Error	2		
Total	14		

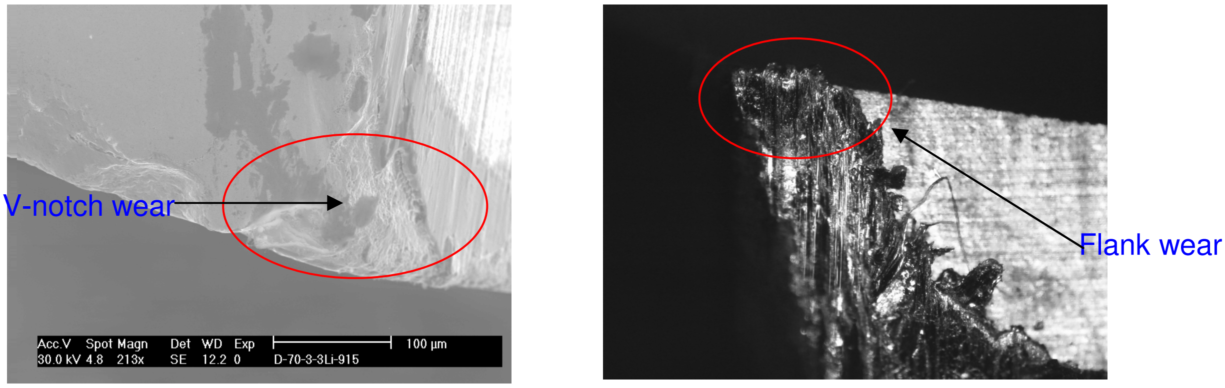
(a)

Source	**DF**	**F**	**P**
Regression	3	14.39	0
Linear	3	14.39	0
Residual Error	11		
Lack-of-Fit	9	3.3	0.142
Pure Error	2		
Total	14		

(b)

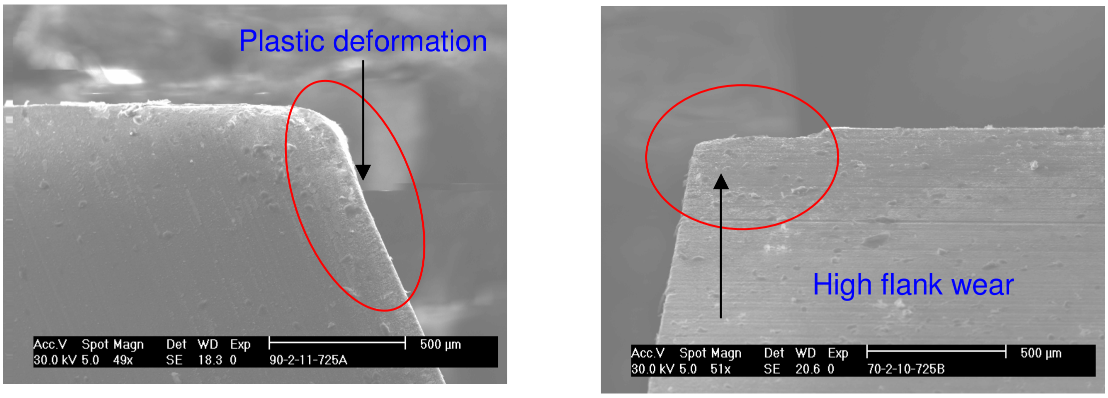
The failure mechanism, called notching, appears as a severe notch-shaped abrasive wear pattern that is localised at the depth-of-cut line, as illustrated in the Figure 2 (a) (Cutting speed 100 m/min, feed rate 0.1 mm /rev, axial depth 0.7 mm, CVD coated cutting tool – coolant). Notching generally occurs during the machining of high temperature alloys and work-hardened materials, where scale material resided on the surface of the workpiece is very hard and causes accelerated abrasive wear on the insert at the depth-of-cut line. Abrasive flank wear is caused by the abrading action of the workpiece against the cutting edge of the insert. Although this abrasive action is normal in the machining process, it causes a wear land to appear on the flank of the cutting tool, as shown in Figure 2.

Plastic deformation occurs when the carbide at the cutting edge is softened by intense heating happened during machining operations. The softened carbide is deformed from its original shape by the cutting forces, as shown in Figure 3 (a) (Cutting speed 140 m/min, feed rate 0.2 mm/rev, axial depth 1 mm, PVD coated cutting tool – coolant). For Figure 3 (b), the cutting tool damages due to high flank wear.



(a) (b)

Figure 2: (a) V-notch wear and (b) Abrasive flank wear



(a) (b)

Figure 2: (a) Plastic deformation and (b) High flank wear

6 CONCLUSION

n the current work, the first order mathematical models have been developed to predict cutting parameters for Hastelloy C-22HS using coated carbide cutting tools (PVD and CVD), and two different cutting environments. The results have been compared by those measured experimentally Tool life increase with the increasing of feed rate, axial depth and cutting speed. The PVD-coated cutting tools perform better than the CVD-coated cutting tools in terms of tool life. The life span for the PVD- coated cutting tools is longer than CVD – coated cutting tools.

ACKNOWLEDGMENT

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