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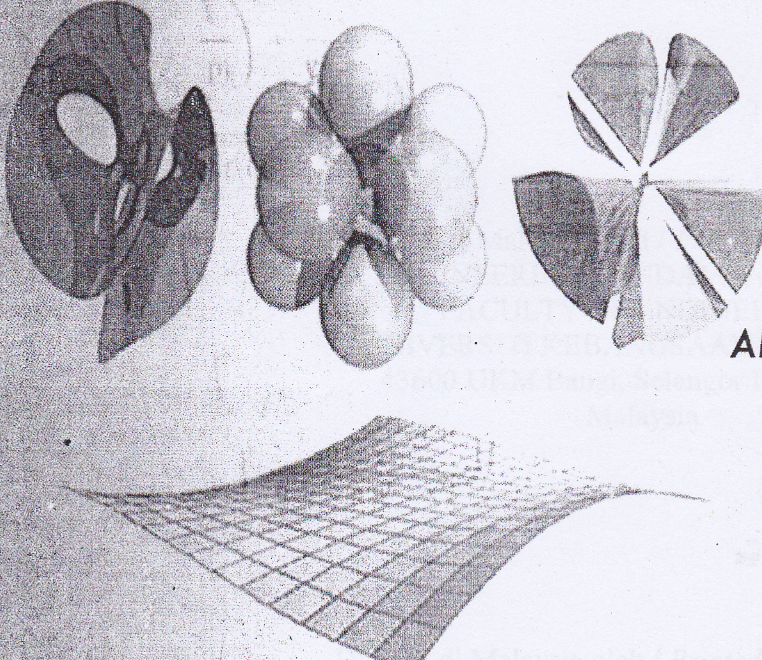

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Judul	: Tool Life Assessment Using Fractional Factorial Method in Turning of Titanium Alloy With CBN Cutting Tool
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TOOL LIFE ASSESSMENT USING FRACTIONAL FACTORIAL METHOD IN TURNING OF TITANIUM ALLOY WITH CBN CUTTING TOOL

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ABSTRACT

Tool life is the one of the most important parameters in the machining research area. Most researchers have dealt the effect of cutting variables on tool life by the one-variable-at-a-time method. This approach needs a separate set of tests for each combination of cutting condition and cutting tool. The approach required large amount of cost and cannot consider the combined effect of cutting conditions on response. This research developed tool life model which take account the combined effect of cutting variables using design of experiment including cutting speed, feed rate, and depth of cut. The effects of cutting variables are investigated by the application of fractional factorial design method. The first-order of tool life mathematical model are formulated to predict tool life with a power form equation using cutting parameters. The cutting tests are conducted with Cubic Boron Nitride (CBN) as cutting tool when turning of titanium in dry condition.

Keyword: machinability, tool life, cutting condition, fractional factorial, predicted equation

INTRODUCTION

Machinability data of titanium is usually obtained from the experimental work. The material is machined by varying only one cutting variable at a time while holding the other variables constant and known as one-variable-at-a-time (OVAT). This method is time consuming and requiring in large cost. The condition become much worse when the combination of work piece and cutting tool materials are expensive.

The most experimenters have been using statistical design of experiment (DOE) despite of using one-factor-at-a-time to save cost and time. Statistical design of experiment is the process of planning the experiments so that the appropriate data should be collected which may be analyzed by statistical methods resulting in valid and objective conclusions (Montgomery 1991). Design of experiment can result the data uniformity and reduce the total number of experiment.

The objective of the study is to establish the tool life model of CBN cutting when turning Titanium 6Al-4V (Ti-6Al-4V). It is necessary to employ theoretical models that it is feasible to make prediction in function of operation conditions such as spindle speed, feed rate, cutting depth, tool geometry and so on. The study also investigates some significant factors that affect the CBN tool life.

EXPERIMENTAL METHOD

Design of Experiment

The application of design of experiment is able to reduce the experiment expenses. There are some methods in the design of experiment including full factorial, fractional factorial, screening design, Taguchi method and variables search. Among these methods, full and fractional factorial designs are most widely used in manufacturing companies are at two-levels and three-levels.

A full factorial designed experiment consists of all possible combinations of levels for all factors. The total number of experiments for studying k factors at 2-levels is 2^k. The 2^k full factorial design is particularly useful in the early stages of experimental work, especially when the number of process parameters or design parameters (or factors) is less than or equal to 4.

If the experimenters can reasonably assume that certain higher-order interactions (third-order and higher) are not important, then information on the main effects and two-order interactions can be obtained by running only a fraction of the full factorial experiment. A type of orthogonal array design that allows experimenters to study main effects and desired interaction effects in a minimum number of trials or experimental runs is called a fractional factorial design. These fractional factorial designs are the most widely and commonly used types of design in industry. These designs are generally represented in the form $2^{(k-p)}$, where k is the number of factors and $1/2^p$ represents the fraction of the full factorial 2^k.

This study uses the fractional factorial as design of experiment method. It takes into account the simultaneous variation of variables including speed, feed, depth of cut and CBN content. The tool life, surface roughness and cutting force are considered as a response. The relationship between the machining responses and machining independent variables can be represented as following:

$$T = C(V^w f^x d^y) \qquad (1)$$

where T is the tool life in minutes, V, f, and d are the cutting speeds (m/min), feed rates (mm/rev), and depths of cut (mm) respectively, C, w, x, y are constants. This equation is obtained from Taylor equation in predicting the tool life. The equation can be written in the logarithmic form as follows:

$$lnT = lnC + w\ ln\ V + y\ ln f + x\ ln\ d \qquad (2)$$

This equation actually represents a regression model of the two-factorial experiment,

$$y = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 \quad (3)$$

where y is the measured tool life to a logarithmic scale, $x_0 = 1$ (dummy variable), $x_1 = \ln V$, $x_2 = \ln f$, $x_3 = \ln d$,, $b_0 = \ln C$, and b_1 ,b_2 and b_3 are the model parameters. In the present study, the parameters of Equation (3) will be estimated by using a computer package. To develop the first-order model, 2^{4-1} fractional factorial design will be used. A design consisting of 8 experiments was conducted.

TABLE 1 Level designation of different process variables

Level	V (m/min)	F (mm/rev)	D (mm)	CBN content
-1 (Low)	180	0.05	0.1	Low
1 (High)	280	0.25	0.5	High

Workpiece Material

A 150 mm diameter x 300 mm long bar of Ti-6Al-4V was used for the trials. Chemical composition and physical properties of Ti-6Al-4V are shown in Table 2 and 3.

TABLE 2 Chemical compositions of Ti-6Al-4V

C	Fe	N	O	H	Al	V	Sn
-	0.21 6	0.002 4	0.16 0	0.003 3	6.28	4.27	-

TABLE 3 Physical properties of Ti-6Al-4V

Characteristics	Ti-6Al-4V
Melting point (K)	1813 – 1923
Density (x10^3 kg/m^3)	4.42
Young's modulus (MPa)	113,190
Modulus of rigidity (MPa)	44,100
Poisson's ratio	0.3 – 0.33
Specific heat (KJ/(kg.K)	0.56
Thermal conductivity (W/(m.K)	7.54

Machine and cutting inserts

The machining trials were carried out on a Cincinnati Avenger 200T CNC lathe. A MCLNR 2020K09 tool holder was used to provide an 85° cutting edge angle and 5°-rake angles. The cutting tools used were Kennametal grade KD081 and

KD120 designated CNGA 120408S1020, in order to investigate the influence of CBN content. All of the experiments were conducted in dry condition. Depending on the cutting condition and wear rate, machining was stopped at various interval of time varying from 5 sec to 1 min to record the wear of the insert. Flank wear was considered as the criteria of tool wear and the wear was measured with a Mitutoyo microscope. The machining was stopped when an average flank wear greater than 0.30 mm or fracturing happened.

RESULTS AND DISCUSSIONS

Table 4 shows the experimental conditions together with the measured tool life values. These results are inputted to Design Expert 6.0.10 and half-normal probability plot is obtained (Figure 1). The figure shows all of the factors and the interaction (cutting depth-CBN content) should have the effect to cutting tool life. The increasing of these factors will decrease the tool life. The feed rate has the strongest effect to the tool life and followed by cutting speed, depth of cut and CBN content.

TABLE 4 Experimental conditions and results

Run	F actors				Tool life (sec)
	Cutting speed (V m/min)	Feed rate (f mm/rev)	Cutting depth (d mm)	CBN content	
	A	B	C	D	
1	180	0.05	0.10	Low	1200
2	280	0.05	0.10	High	630
3	180	0.25	0.10	High	640
4	280	0.25	0.10	Low	60
5	180	0.05	0.50	High	1200
6	280	0.05	0.50	Low	150
7	180	0.25	0.50	Low	60
8	280	0.25	0.50	High	36

Thereafter, analysis of variance (ANOVA) was applied to calculate the main effects of cutting speed (*V*), feed rate (*f*), depth of cut (d) and CBN content together with their two-level interaction effects on tool life. The ANOVA output and the calculated *F* ratios are shown in Table 5 for each significant effect. The 5 percent level was used for testing the significance of the main effects and the interaction. Table 5 shows that all of the factors and the interaction of depth of cut-CBN content are significant.

The *R*-squared statistic indicates that the first-order model explains 99.85 % of the variability in tool life (T). The calculation also indicate that the model have an adequate signal to noise ratio. The normal probability plots of the residuals and the plots of the residuals versus the predicted response for tool life are shown in Figures 2 and 3, respectively. A check on the plots in Figures 2 and 3 revealed that the residuals generally fall on a straight line implying that the errors are distributed normally. This implies that the models proposed are adequate and there is no reason to suspect any violation of the independence or constant variance assumption. It means that the proposed model using fractional factorial design is suitable for running the experiment.

TABLE 5 ANOVA for Selected Factorial Model [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.739E6	5	3.478E5	263.05	0.0038	significant
A	6.183E5	1	6.183E5	467.68	0.0021	
B	7.104E5	1	7.104E5	537.39	0.0019	
C	1.469E5	1	1.469E5	111.11	0.0089	
D	1.958E5	1	1.958E5	148.09	0.0067	
CD	1.290E5	1	1.290E5	97.60	0.0101	
Residual	2644.0	2	1322.0			
Cor Total	1.741E6	7				

Figure 5 shows plot of cutting depth-CBN content interaction on tool life. In this study is found that the higher CBN content will prolong the tool life. It is according to Ezugwu (2005) statement the increasing of CBN content will reduce notch wear. The change of cutting depth is more significant at low CBN content than at high CBN content.

The proposed predicting equation model

The first-order equation model is obtained using ANOVA. Design Expert software have separated the tool life model into two models are the tool life model at low CBN content and the tool life model at high CBN content. For the low CBN content, the first order model as following:

$$\ln T_{CBN} = \ln 2487.05 - 5.56 \ln V - 2980 \ln f - 1312.5 \ln d \qquad (4)$$

Whereas for the high CBN content is:

$$\ln T_{CBN} = \ln 2365.05 - 5.56 \ln V - 2980 \ln f - 42.5 \ln d \qquad (5)$$

The both of equations will construct the tool life response curves as in Figure 6 below.

CONCLUSION

In this work, it has been shown that partial factorial design of experiments can be applied for modeling the tool life when turning Titanium 6Al-4V with CBN cutting tool. The design is very helpful in the running of expensive cutting tool-material combinations. The work showed that the cutting depth is the most significant factor to tool life, followed by cutting speed and feed rate. The lower depth of cut is more significant to tool life at the cutting speed range of 180 –280 m/min. It showed that there is no contribution of CBN content to tool life

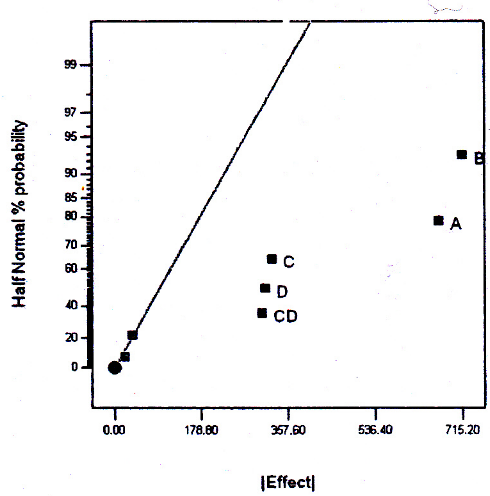

FIGURE 1 Half-normal probability plot of results

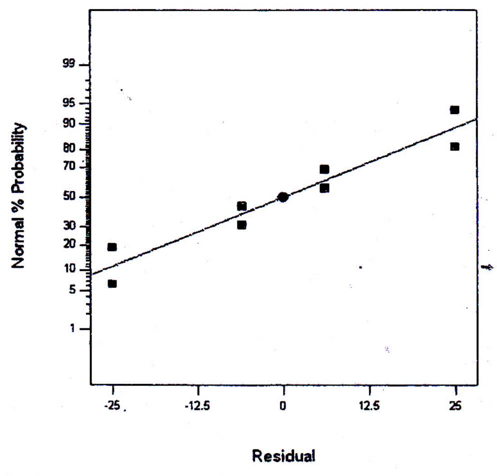

FIGURE 2 Normal plots of residuals for tool life data

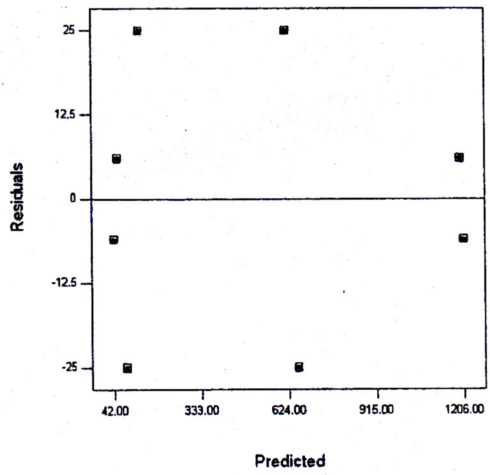

FIGURE 3 Plot of residuals and predicted responses

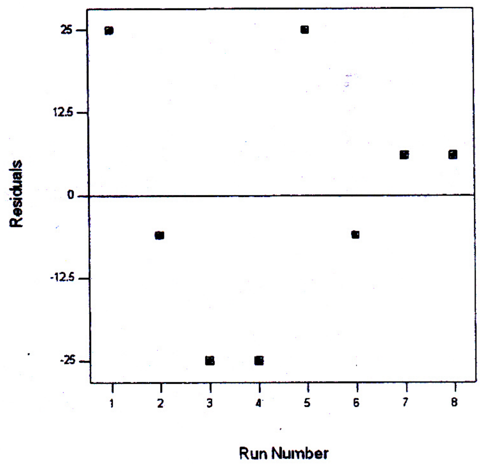

FIGURE 4 Plot residuals and run number

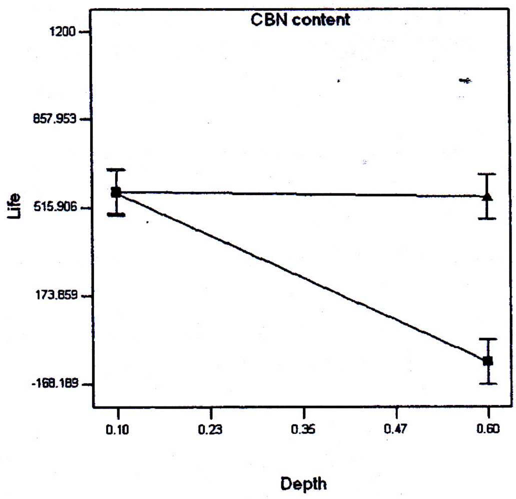

FIGURE 5 Plot interaction between depth of cut and CBN content

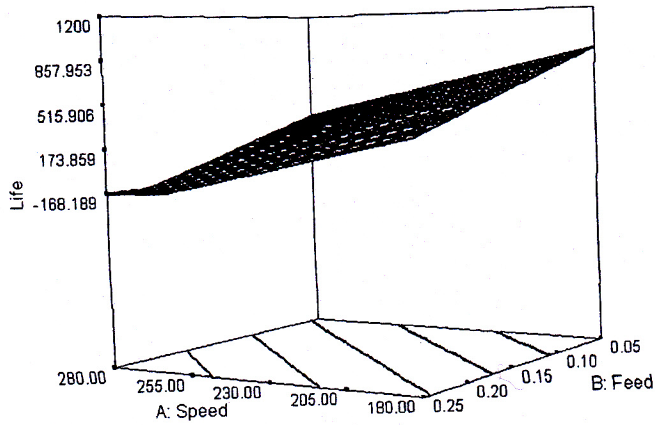

FIGURE 6 3D plot of tool life response

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