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Optimization of Cutting parameters for cutting force on Turning of Niobium alloy C-103 by using Response Surface Methodology

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Abstract

Industries around the world continually strive for lower cost solutions with reduced lead time in order to maintain their competitiveness. Traditionally, most Niobium based alloys parts are hard machining. Machinability consideration of Niobium based alloy C-103 in turning operations has been carried out using ceramic inserts under dry conditions. Niobium alloy C-103 is a difficult to machine material because of its low thermal diffusive property and high strength at high temperature. This paper describes the selecting of a cutting speed and feed rate from the charts that depends on cutting force model for turning niobium alloy C-103 utilizing response surface methodology. The model found to be accurate based on the variance analysis and the predicted value is closer with the experimental results. The Analysis shows that depth of cut is the most evident factor for cutting force (Fz).

Key words: Cutting speed, feed, depth of cut, Response surface methodology, cutting force, Machining.

1. Introduction

To get the sufficient model that related the cutting force and the cutting parameters (cutting speed, feed rate, and depth of cut), different tests for each and every combination of cutting tools and work piece material needed. In this paper several of cutting speed, feed rate, depth of cut have been taken into account and predict the cutting force. Then the cutting speed can be selecting of cutting Parameters from Prediction Model of cutting force for turning Niobium alloy C-103 using Response Surface Methodology.

In this work, experimental results were used for modeling using response surface methodology (RSM) (Montgomery, D.C., 1984). The RSM is practical, economical and relatively easy for use and it was used by lot of researchers for modeling machining process (EI Baradie, M.A., 1993, Hasegawa, M., A. Seireg and R.A. Lindberg, 1976, 4. Sundaram, R.M. and B.K. Lambert, 1981). (Mead and Pike, 1975) and (Hill and Hunter, 1966) reviewed the earliest work on response surface methodology. Response surface methodology (RSM) is a combination of experimental and regression analysis and statistical inferences. The concept of response surface Methodology involves a dependent variable "y‟ called the response variable and several independent variables x_1, x_2…….x_k (Hicks, C.R., 1993). If all of these variable are assumed to be measurable, the response can be expressed as

$$Y = f(x_1;\ x_2;\ldots;x_k) \qquad (1)$$

Optimizing the response variable y, it is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. The response or the dependent variable is assumed to be a random variable.

2. Experimental work

2.1 CNC Lathe Machine

Retrofitted VDF Computer Numerical Control (CNC) turning machine supported with spindle drive motor 12kw and 6000 rpm maximum speed, distance between centers 100 cm, feed 0.04 to 205 mm as shown in fig.1.

Fig.1. CNC Lathe Machine

2.2. Force Measuring Instrument

A kistler four-component dynamometer was used to measure the cutting force components. This dynamometer can be used for measuring a torque and the three orthogonal components of a force. The dynamometer has a great rigidity and consequently a high natural frequency. Its high resolution enables the smallest dynamic changes in large forces and torques to be measured, as shown in fig. 2.

Fig.2. Kistler four component dynamometer

2.3. Work material

Niobium alloy C-103 is a precipitation hardening, creep resisting Nickel-chromium-cobalt-molybdenum alloy developed by Rolls Royce. It is supplied in high temperature annealed condition and can service up to 950 degree centigrade.

Chemical Composition

	Hf(%)	Zr(%)	Tantalum	Nickel(%)	Carbon(%)	Oxygen(%)	Niobium
C-103	10	0.7	0.5	0.001	0.001	0.003	balance

Table.1.Chemical composition of Niobium alloy C-103

2.4. Cutting Tool

Multi-layered PVD coated cemented tungsten carbide inserts were used for the turning tests. These inserts were manufactured by WIDIA. The coated carbide grade was TN6025, which is designed for light and medium turning operations of high temperature alloys. TN6025 inserts are Nano-multilayered TiAlN coated insert, having very high wear resistance and good toughness.

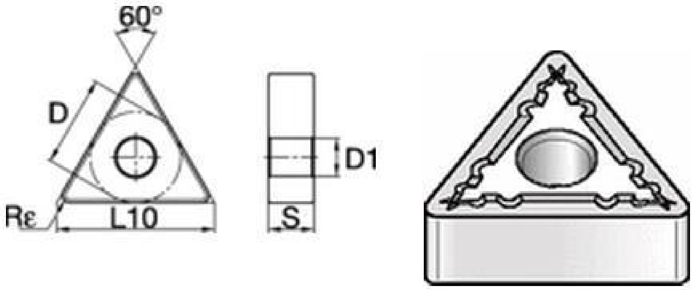

Fig. 3. Cutting Insert

ISO catalog number	ANSI catalog number	D		L10		S		Rε		D1	
		mm	in	mm	in	mm	in	mm	in	mm	in
TNMG160408	TNMG332	9,53	3/8	16,50	.650	4,76	3/16	0,8	.031	3,81	.150

Table: 2. Insert Dimensions

2.5. Tool Holder

A double clamp-type tool holder to provide rigidity was used with all its dimensions. It is fixed with the fixture that is fitted on the dynamometer and overhang is kept as low as possible to increase the rigidity of the setup. Figure:4 gives the actual picture of tool holder fitted with insert and various small clamping parts of DTGNL 2020 K16 tool holder

Fig. 4.Tool Holder

2.6. Design of Experiments

Commercial statistical analysis software Design Expert (Dx8) was employed for design of experiment. In Dx8 RSM is used to find a combination of factors which gives the optimal response. Response Surface Methodology is actually a collection of mathematical and statistical technique that is useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response (Montgomery, D.C., 1984, Andre I, Khuri and John A. Cornell). There are essentially two main types of design experiments which are based on response surface analysis as follows

1. Box-Wilson Central Composite Design(CCD)
2. Box-Behnken Design(BBD)

Both of these methodologies require a quadratic relationship between the experimental factor and the responses. In this research work the CCD has been chosen.

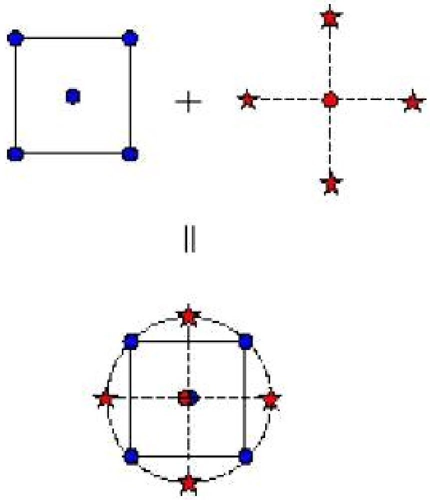

Fig. 5. Generation of a Central Composite Design for Two Factors

CCD designs start with a factorial or fractional factorial design (with center points) and add "star" points to estimate curvature as shown in fig. 5..

There are three varieties of central composite designs, classified on the basis of the position of the star points. A central composite design always contains twice as many star points as there are factors in the design. The star points represent new extreme values (low and high) for each factor in the design.

The level of independent variables and coding identifications used in this are presented in Table below.

Code	-1(low level)	0(Center level)	+1(High level)
Cutting Speed(m/min)	80	85	90
Feed(mm/rev)	0.08	0.14	0.2
Depth of cut(mm)	0.3	0.45	0.6

Table.3. Level of independent variables and coding Identification

3. Results and Discussion

3.1 Effect of Process Variables on Cutting Force (Fz)

Source	Sum of Squares	df	Mean Square	F value	p-value Prob>F	
Block	36026.64	1	36026.84			
Model	1.669E+005	4	41729.11	8.91	0.0009	significant
A-Speed	549.08	1	5499.08	0.12	0.7371	
B-Feed	663.10	1	663.10	0.14	0.7123	
C-DOC	1.208E+005	1	1.208E+005	25.80	0.0002	
C	44588.51	1	44588.51	9.52	0.0081	
Residual	65566.48	14	4683.32			
Lack of Fit	55840.57	10	5584.06	2.30	0.2196	not significant
Pure Error	9725.91	4	2431.48			
Cor Total	2.685E+005	19				

Table . 4. ANOVA table for Response Surface Reduced Quadratic Model for cutting force

3.2. Statistical Inferences

- The Model F-value of 8.91 implies that the model is significant. There is only a 0.09% chance that a "Model F-Value" this large could occur due to noise.
- Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case C, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

The "Lack of Fit F-value" of 2.30 implies the Lack of Fit is not significant relative to the pure error. There is a 21.96% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

- The various R^2 statistics (i.e. R^2, adjusted R^2 (R^2adj) and predicted R^2 (R^2pred)) of the cutting force are as follows. The value of R^2 = 0.7180 for surface roughness indicates that 71.80% of the total variations are explained by the model.
- The adjusted R^2 is a statistic that is adjusted for the “size” of the model; that is, the number of factors (terms). The value of the R^2adj = 0.6374 indicates that 63.74% of the total variability is explained by the model after considering the significant factors.
- “C.V.” stands for the coefficient of variation of the model and it is the error expressed as a percentage of the mean ((S.D./Mean)×100). Lower value of the coefficient of variation (C.V. =31.61) indicates improved precision and reliability of the conducted experiments.
- "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Here ratio of 7.572 indicates an adequate signal. This model can be used to navigate the design space.

Mathematical Model Generated After Regression Analysis

The regression coefficients of the second order equation are obtained by using the experimental data. The regression equation for the cutting force as a function of three input process variables was developed using experimental data and is given below. Final equation in terms of actual factors after eliminating insignificant terms:

$$Fz = 905.78462 - 1.48200*v - 125.13298*f - 3406.29867*d + 4598.99853*d^2.$$

3.3 Response Curves Generated

The perturbation curve after pooled ANOVA shows that the cutting speed and cutting feed are less effecting on cutting force and the depth of cut is most effecting parameter on cutting force.

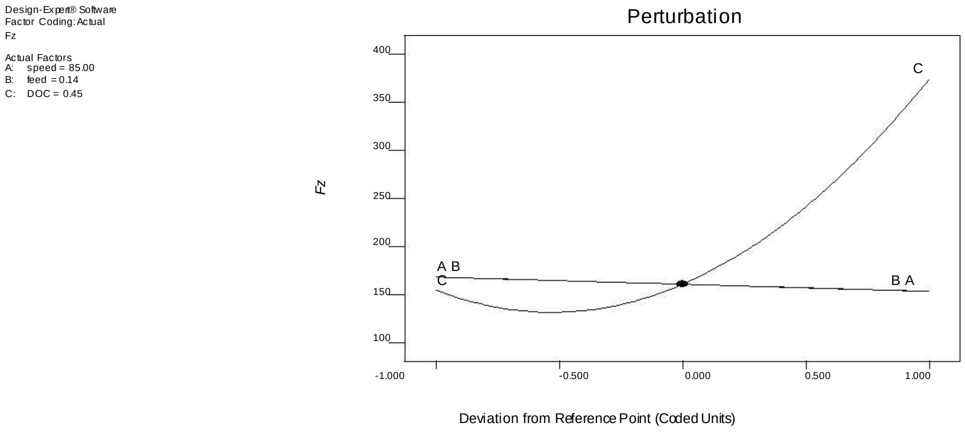

Fig.6. Perturbation curve after pooled anova

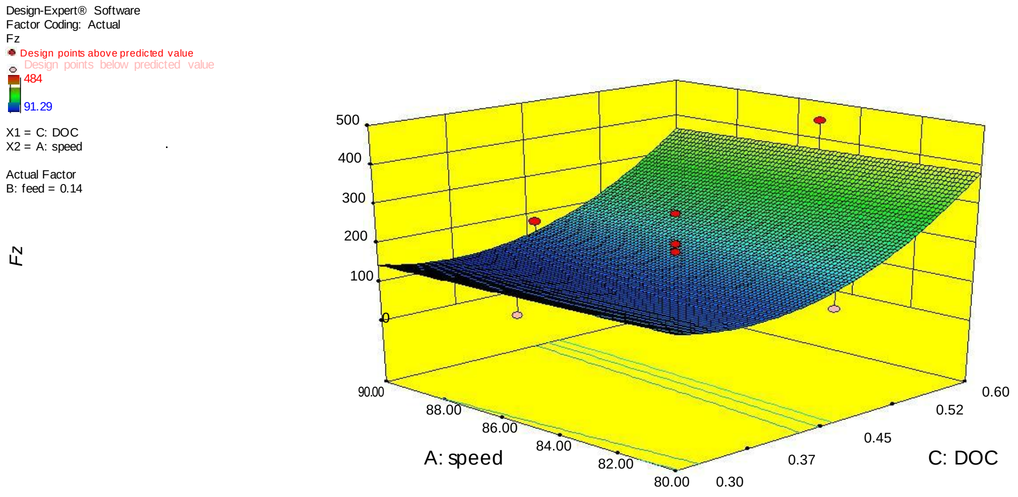

Fig. 7. Response surface for cutting force with cutting speed and Depth of cut

The above 3D surface graph is used to read the optimum parameters (cutting speed and depth of cut) for minimum cutting force. Cutting force is increasing by increasing depth of cut and it is decreasing by decreasing cutting speed. The Red points at the center of graph indicate the optimum speed and depth of cut for cutting force.

4. Conclusion and Recommendations

(1) The cutting force fitted to the Quadratic model in the given range of parameters.

(2) The highest influence on cutting force is exerted by the depth of cut. Cutting force increase with increase in the depth of cut.

(3) The optimum cutting parameters to minimize the cutting force are cutting speed =84.32 m/min, feed = 0.15 mm/rev & depth of cut = 0.37mm.

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