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EXPERIMENTAL INVESTIGATION OF MILLING PARAMETERS OF NIMONIC 75 WHILE MACHINING WITH CRYOGENIC TREATED TITANIUM CARBIDE INSERT

Sanjeev Singh[1], Dr.S SBanwait [2]

[1] *Department of Mechanical Engineering,*
National Institute of Technical Teachers Training and Research, Chandigarh, India,
[2] *Department of Mechanical Engineering,*
National Institute of Technical Teachers Training and Research, Chandigarh, India,

Abstract—The major concern identified with machining of Nickel based alloys which are difficult to machine. A high rate of tool wear and high cutting temperature is occurred during machining. Because of high temperature at cutting zone, the possibility of built up edge formation on cutting tool is occurred that's why the tool wear is increased. The major problem faced by any industry isto obtain the optimal machining input parameters and minimize the cutting temperature and toolwearof a super alloy. In present work impact of cutting conditions (cutting speed V, feed rate f, depthof cut d) on output parameters (i.e. cutting temperature, Tool wear) have been studied during face milling of Nimonic 75 with cryogenic treated titanium Carbide Insert. Machining parameters are optimized by RSMbased BBD Technique, using the desirability analysis for minimizing the cutting temperature, and toolwear. The study indicated that the optimal parameters for Multi Response Optimization were found to be at cutting speed(N) 2499.99 rpm, feed rate (f) 499.9 mm/min and depth of cut (d) 0.3 mm.

Keywords—Nimonic 75, Cryogenic treated titanium Carbide Insert, RSM Technique, Multi ResponseOptimization, CNC milling.

I. INTRODUCTION

Machining is one of the crucial elements in a manufacturing system. In this process high amount of energy is used to shear off the extra work material and convert raw material into finished product. The main aim is to reduce the tool wear or improvement in tool life so that production rate of industry is increased. [1]

There are three basic elements of machining are workpiece, tool and chip [2]. The face milling is one of the most common machining operations and can be performed using a wide range of different tools. Side and face milling cutters can handle long, deep, open solts in a more efficient manner and provide the beststability [3]. A Nimonic 75 is anickel based alloy is widely used in Extreme stress applications such as turbine blade, Industrial furnace structural parts, Heat treatment equipments,nuclear engineering, Aerospace fasteners etc because of its high stress-rupture strength and creep resistance at high temperatures [4]. There are three primary factors in face milling operation are speed, feed and depth of cut.

Shokrani et al. [5] investigated the effects of cryogenic machining on surface integrity in CNC end milling of Ti–6Al–4V titanium alloy. It was observed that surface roughness has been significantly decreased by cryogenic cooling in end milling operations using coated carbide cutters.Microscopic analysis of the machined surfaces indicated while machining with flood and dry cooling, the chip re-deposition and plastic deformation were dominant on all machined samples as compared to machining with cryogenic cooling.

Pereira et al. [6] investigate the effects of CryoMQL technique on the machining of difficult-to-cut materials and also determined the impact of cutting speed on different types ofmachining characteristics, cutting tool wear during turning of AISI 304 using Ti-6Al-4V Tool. The comparative study of titanium carbide insert was carried out with Dry, Wet, MQL and CryoMQL_CO_2machiningtechniques. During machining ofAISI 304 the high rate of tool wear was observed with dry machining because of adhesion, plastic deformation, and diffusion occurred at cutting edge. The remarkable improvement in surface roughness during machining with CryoMQL Techniques. During the machining with CryoMQL techniques because of the proper lubrication the adhesion and diffusion is not occurred at cutting edge and built of edge formation is reduced that's why tool wear reduces. CryoMQL is the better techniques as compared to all other techniques.

After going through the literature, it can be observed that very less study has been done on the machining of Nimonic 75. In this present investigation an exertion has been taken to conduct the milling operation and optimizing the inputparameters (i.e. N, f & d) on Nimonic 75. The experiments were performed with variation in parameters using DOEapproach. ANOVA analysis was used to obtain mathematical models. Optimization of the results was carried out throughdesirability approach.

II. **EXPERIMENTAL METHODOLOGY**

During the experimentation work, a plate of NIMONIC 75 {Ni –(80 % max), Cr -(21 %max),Ti –(0.6 % max) , C- (0.15% max) } having 60 mm length ,50 mm width and 50mm thickness (refer Fig.1) was machined on HURCO vertical CNC milling machine . The present workconsidered 3 levels of Design of Experiment. RSM based BBD Technique was used to develop a Design of Experimentby Design expert 11.1.0 software. Three input variables of cutting speed 2000, 2250, 2500 rpm were selected with feed rate 400, 450 and 500 mm/min & depth 0.3, 0.4 and 0.5 mm. The commercially available APKT 09 TT9080 PVD coated titanium Carbide insertswere usedfor the experimentation purpose. Cryogenic treated titanium carbide inserts of following toolgeometry, a) edge length = 9 mm b) thickness = 3.97 mm,c) cutting edge angle = 90° and d) Nose radius = 0.8 mm (refer Fig.2) were used to conduct the research work. The length of cut was taken constant at 150 mm. Measurement of cutting temperature was done by FLIR E 60 thermal camera and measurement of Tool wear by Sipkon measurement system.

Fig.1 CNC Milling Machine

Fig2 Cryogenic Treated Titanium Carbide Insert

III. RESULT AND DISCUSSIONS

Experimental Results

Experiments were carried out for cryogenic treated Carbide inserts. 17 experiments were designed by RSM based BBD technique. Three levels of each input parameters speed, feed rate and depth of cut were taken for experimentation & results werecalculated as shown in Table I. After conducting the experiments for face milling, the cutting temperature and flank wear value of insert were measured using thermal camera and Sipkon Measurement system. Each run of the experiment contains three trial values for better output of the cutting temperature.

The average of these three trial values has been taken for the analysis of optimization of input parameters.

TABLE I
EXPERIMENTAL RESULTS

Run	**A:Cutting Speed (N)**	**B:Feed (f)**	**C:Depth Of Cut (d)**	**Temperature**	**Tool Wear**
	rpm	mm/min	Mm	°C	Mm
1	2500	450	0.3	107	90.5
2	2000	500	0.4	142	126
3	2000	450	0.5	126	204.5
4	2500	400	0.4	116	184
5	2250	450	0.4	128	135.5
6	2250	450	0.4	125	133
7	2250	400	0.5	172	167
8	2250	450	0.4	129	139
9	2250	500	0.3	114	129.5
10	2250	450	0.4	127	132
11	2250	400	0.3	118	147.5
12	2500	450	0.5	237	250
13	2250	450	0.4	125	130
14	2500	500	0.4	137	187
15	2000	400	0.4	173	173.5
16	2250	500	0.5	130	136
17	2000	450	0.3	110	149

Analysis and optimization of cutting temperature (^{0}C) and Tool wear (T_W)

Analysis and modelling of cutting temperature (^{0}C)and Tool wear (T_W) were performed by Design Expert 11.1.0 software. Diagnosis plots were made in order to validate regression models. Graphs were drawn in order to find variation in cutting temperature and tool wear with cutting speed (N), feed(f)and depth of cut(d). Multi Response Optimization for minimization of cutting temperature (^{0} C)and tool wear(T_W) was performed by desirability analysis.

Analysis of variance

ANOVA analysis was conducted on output responses for determining the experimental results. Significant model wasdesigned after transformation of Data. ANOVA for reduced cubic model was generated. Table II and III shows ANOVA table values ofcutting temperature and tool wear respectively.

Table II
ANOVA for Cutting Temperature

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	16171.85	11	1470.17	270.15	< 0.0001	Significant
A-cutting speed	961.00	1	961.00	176.59	< 0.0001	
B-Feed	25.00	1	25.00	4.59	0.0850	
C-depth of cut	1225.00	1	1225.00	225.10	< 0.0001	
AB	676.00	1	676.00	124.22	0.0001	
AC	3249.00	1	3249.00	597.01	< 0.0001	
BC	361.00	1	361.00	66.33	0.0005	
A^2	763.51	1	763.51	140.30	< 0.0001	
C^2	103.35	1	103.35	18.99	0.0073	
A^2C	722.00	1	722.00	132.67	< 0.0001	
AC^2	3612.50	1	3612.50	663.81	< 0.0001	
BC^2	162.00	1	162.00	29.77	0.0028	
Residual	27.21	5	5.44			
Lack of Fit	14.41	1	14.41	4.50	0.1011	not significant
Pure Error	12.80	4	3.20			
Cor Total	16199.06	16				

The model F-value of 270.15 implies the model is significant. There is chance of only a 0.01% that F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. Adequate Precision measures the signal to noise ratio and its ratio greater than 4 is desirable. The ratio of 66.328 indicates an adequate signal. This model can be used to navigate the experimental range.

TABLE III
ANOVA for Tool Wear

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	22100.09	10	2210.01	166.86	< 0.0001	significant
A-cutting speed	1278.06	1	1278.06	96.50	< 0.0001	
B-Feed	1092.78	1	1092.78	82.51	< 0.0001	
C-depth of cut	169.00	1	169.00	12.76	0.0118	
AB	637.56	1	637.56	48.14	0.0004	
AC	2704.00	1	2704.00	204.16	< 0.0001	
BC	42.25	1	42.25	3.19	0.1243	
A^2	4123.26	1	4123.26	311.31	< 0.0001	
C^2	314.09	1	314.09	23.71	0.0028	
A^2C	4465.13	1	4465.13	337.12	< 0.0001	
AC^2	892.53	1	892.53	67.39	0.0002	
Residual	79.47	6	13.24			
Lack of Fit	31.27	2	15.63	1.30	0.3679	not significant
Pure Error	48.20	4	12.05			
Cor Total	22179.56	16				

From Table III, it can be concluded that themodel F-value of 166.86 indicates the model is significant. There is chance of only 0.01% that F-value this large could occur due to noise. The predicted R^2 of 0.8959 is in reasonable agreement with the adjusted R^2 of 0.9904; i.e. the difference is less than 0.2. AdequatePrecisiondetermines the signal to noise ratio. The ratio of 54.484 indicates an adequate signal.The experimental range can use this model for navigation.

Mathematical Modeling and Regression Analysis

Multiple regression models were developed for cutting temperature and tool wear for cryogenic treated inserts. The response variable was tool wear and cutting temperature and predictors were cutting speed (N), feed (f) and depth of cut (d). The mathematical equations for cutting temperature (^{0}C) and tool wear ($T_{W)}$ are given below.

Cutting Temperature = -7855.02632 +6.23779 (Cutting Speed) -4.51000 (Feed)
+37579.21053(Depth of Cut) +0.001040 (Cutting Speed* Feed)
-26.14000 (Cutting speed *Depth of Cut) +12.50000(Feed* Depth of Cut)
-0.001001 (Cutting Speed^2) -29655.26316 (Depth of Cut^2)
+0.0030 (Cutting Speed^2* Depth of Cut) +17.0 (Cutting Speed^2 * Depth of Cut^2)
-18.0000 (Feed* Depth of Cut^2) ------------------------- (1)

Tool wear = -7702.812+ 9.2070 (Cutting Speed) -2.24625 (Feed) + 20390.0 (Depth of Cut)
+ 0.001010 (Cutting Speed * Feed) -26.22000 (Cutting Speed * Depth of Cut)
-0.650000 (Feed* Depth of Cut) -0.002524 (Cutting Speed^2)
+19875.00000(Depth of Cut^2) + 0.007560 (Cutting Speed^2* Depth of Cut)
– 8.45000 (Cutting Speed *Depth of Cut^2) ------------------------------ (2)

The equation (1) & (2) in terms of actual factors can be used to make predictions about the response for given levelsof each factor.

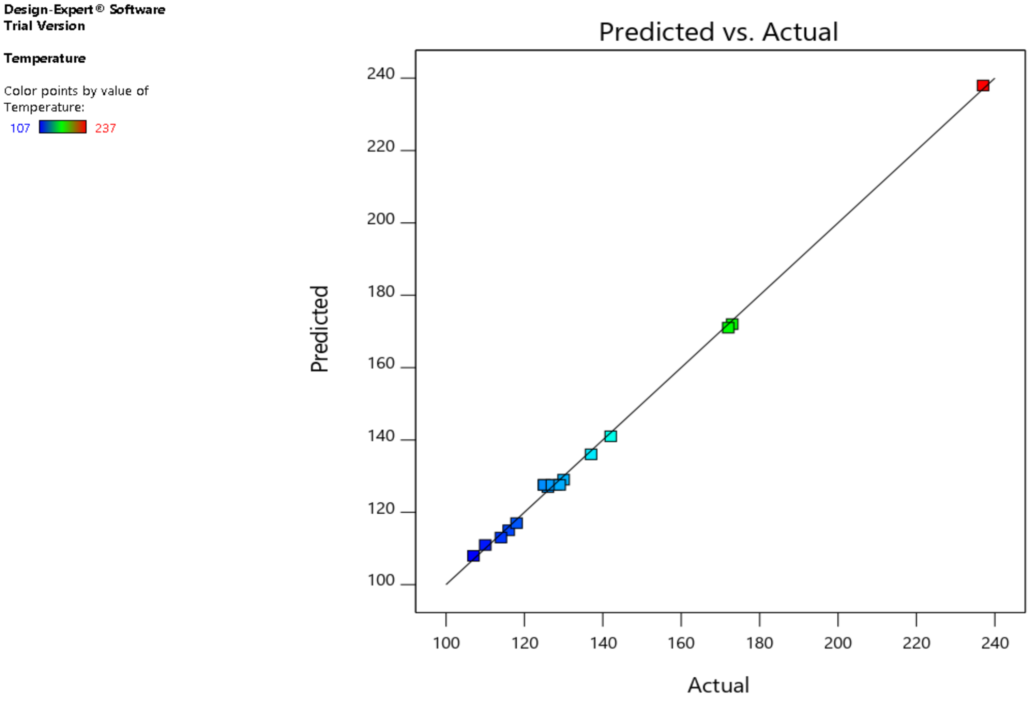

Fig. 3 Predicted vs. Actual Values of Cutting Temperature

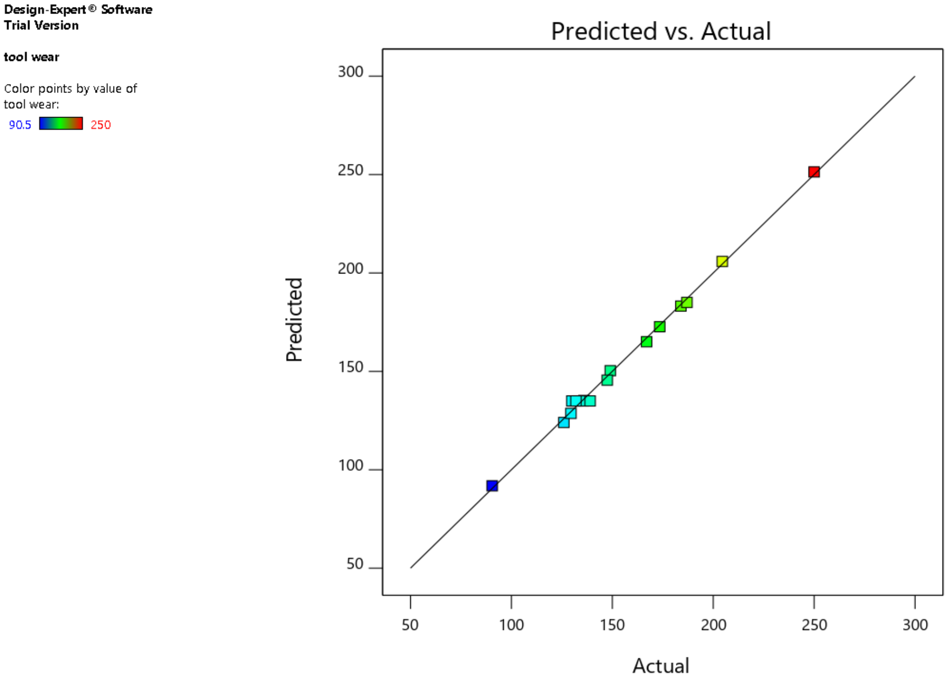

Fig. 4Predicated vs. Actual values of Tool Wear

Fig.3 and fig.4 depict that approximately all points are lying closer to predicted value which means that residual error are very less and model is accurate.

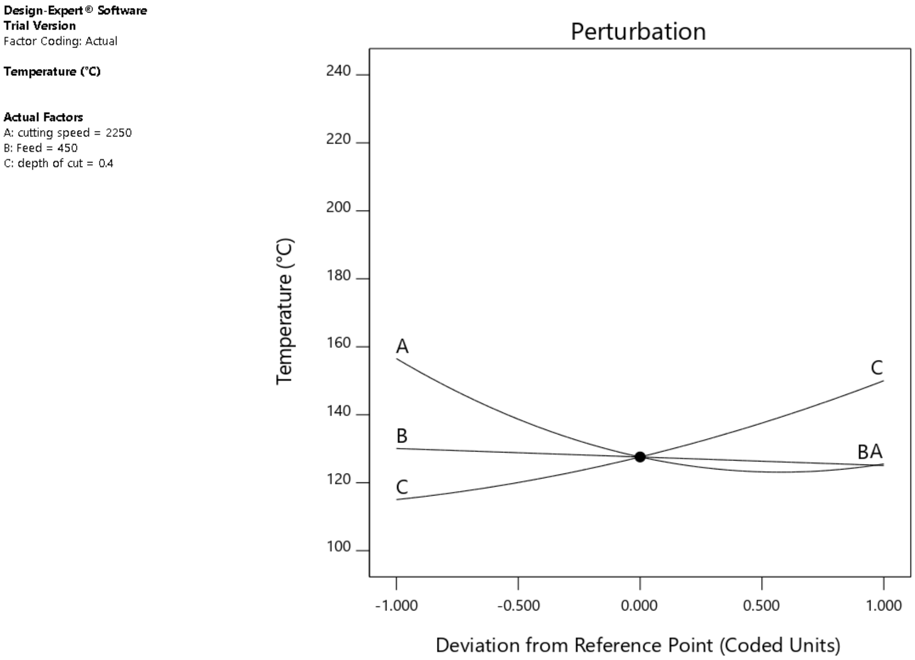

Fig. 5 Perturbation Plot of Cutting Temperature Values

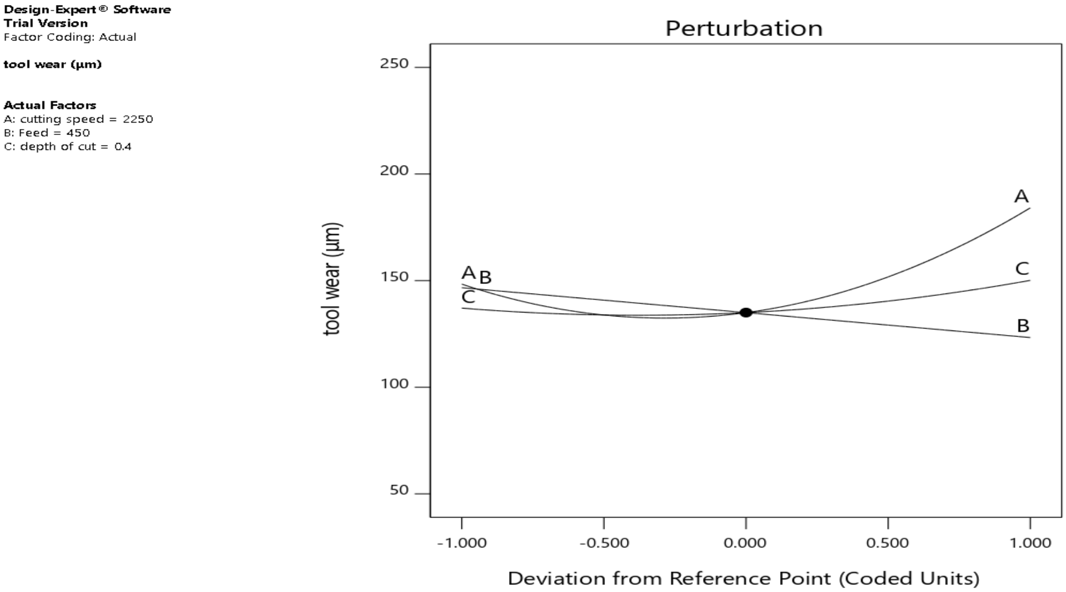

Fig. 6 Perturbation Plots of Tool Wear

It can be depicted from Fig.5, the main influencing parameters which affect the cutting temperature is depth of cut. It is observed from figure 6 that the main parameters which influenced the tool wear arecutting speed and depth of cut.

Multi Response Optimization

Multi Response optimization was carried out by Design Expert Software 11.1.0. In present investigation there are tworesponse variables and three input parameters. In case of multi response optimization there are consideration of everyresponse simultaneously and optimize the input parameter for optimization of all responses. Numerical

Optimizationreport contains two tables the first summarizing the criteria constraints (refer TABLE IV) used to produce the secondtable of optimal solutions (refer TABLE V) for the process.

TABLE IV
CONSTRAINTS FOR OPTIMIZATION

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:cutting speed	is in range	2000	2500	1	1	3
B:Feed	is in range	400	500	1	1	3
C:depth of cut	is in range	0.3	0.5	1	1	3
Temperature	minimize	107	237	1	1	3
tool wear	minimize	90.5	250	1	1	3

TABLE V
OPTIMIZED RESULTS

Number	Cutting Speed	Feed	Depth Of Cut	Temperature	Tool Wear	Desirability
1	2499.998	499.995	0.300	118.973	96.063	0.892

The optimum value of cutting parameter for Cryogenic treated Carbide insert for cutting temperature & Tool wear were found to be at N=2499.99 rpm, f = 499.9 mm/min and d=0.30 mm. The combined desirability was 0.892 which means that experimental results for cryogenic treated s were closer to the predicted values.

IV **CONCLUSIONS**

The3 levels rotatable Box- Behnkins Design is employed for developing mathematical models for predicting the cutting temperature parameter and tool wear in face milling of Nimonic 75. Multi objective optimization was applied for analysing the results of cutting temperatureand tool wear. Desirability analysis was done to minimize the cutting temperature and tool wear. The conclusion drawn from the research work is discussed as follows:

(1) The main parameter which influenced the Cutting temperature isdepth of cut whereas no significant effect of feed rate and cutting speed on cutting temperature.

(2) The Tool Wear was mostly affected by cutting speed as well as depth of cut while feed rate has a very little effect on tool wear.

(3) The optimum value of cutting parameter for cryogenic treated Carbide insert for cutting temperature and tool wear were found to be at N= 2499.99 rpm, f= 499.99 mm/min and d=0.30 mm.

(4) Lower value of cutting temperature is obtained at high feed rate and low depth of cut. The optimized value predicted for cutting temperature was 118.973 ^{0}C.

(5) High rate of tool wear produced at high cutting speeds and depth of cuts. The optimized value predicted for toolwear was 96.03µm.

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