International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 09, September-2018

OPTIMIZATION OF TURNING PARAMETERS OF INCOLOY 825 WHILE MACHINING WITH CVD COATED TUNGSTEN CARBIDE INSERT

Som Dutt[1], Dr.S S Banwait [2]

[1] *ME, 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 considered very hard for machining purpose is surface property and tool wear. The major problem faced by any industry is to obtain the optimal machining input parameters and minimize the surface roughness(Ra) and tool wear(Tw) of a super alloy. In present work impact of cutting conditions (cutting speed V, feed rate f, depth of cut d) on output parameters (i.e. Ra, Tw) has been studied during turning of Incoloy 825 while machining it with CVD Coated Tungsten Carbide Insert. Machining parameters are optimized by RSM based BBD Technique, using the desirability analysis for minimizing the surface roughness(Ra), and tool wear(Tw). The study indicated that the optimal parameters for Multi Response Optimization were found to be at cutting speed(V) 69 m/min, feed rate(f) 0.072rev/min and depth of cut(d) 0.2 mm.

Keywords—Incoloy 825, CVD coated Tungsten Carbide Insert, RSM Technique, Multi Response Optimization.

I. INTRODUCTION

Icoloy 825 which appertain to the family of Nickel based alloys are generally utilized in Marine and aerospace industries[1]. Incoloy 825 have high corrosion resistance properties therefore it is tremendously used as the application in processing of chemicals, processing of nuclear fuel, acid production and equipments for pickling except from its general aerospace industry[2][3]. These alloys are also used in the pollution control systems. These alloys are inexpedient to machine due to their tendency of work hardening and affinity for tool material. These properties lead to reduced tool life during machining, due to which its usage is limited despite excellent mechanical properties[4]. Therefore, the tool used for cutting of these alloys should have higher wear, abrasion and adhesion resistance. Thakur, Gangopadhyay et al. [5] studied on comparative analysis of different characteristics of surface such as analysis of structure, surface roughness(Ra), grain size and micro-hardness with the help of uncoated and CVD coated Tungsten carbide inserts during dry turning of Incoloy 825. Effect of cutting speed and tool coating on surface integrity of Inconel 825 was investigated during dry turning [6]. Thakur, Gangopadhyay et. al[7] investigated the impact of cutting speed on different types of machining characteristics, cutting tool wear during dry turning of Incoloy 825. The comparative study of uncoated and CVD coated Tungsten carbide insert was carried out and different types of chips were obtained at different cutting conditions. The chip thickness ratio was slightly increased while using multilayer coated insert comparatively. SEM and optical microscope were used to get the required results for rake and flank surfaces of insert. During machining of Inconel 825, mainly the tool wear was affected by adhesion, plastic deformation, and diffusion.[8] studied the characteristics of machinability of Incoloy 825 while machining with uncoated, CVD and PVD coated carbide tool. Cutting force was minimum while using PVD coated inserts for all cutting speeds. PVD multilayer coated inserts had remarkable resistance to adhesion. CVD coated carbide performed better than PVD for surface roughness. CVD carbide tools were having greater coefficient of friction comparatively.

After going through the literature, it can be observed that very less study has been done on the machining of Incoloy 825. In this present investigation an exertion has been taken to conduct the turning operation and optimizing the input parameters (i.e. V, f & d) on Incoloy 825. The experiments were performed with variation in parameters using DOE approach. ANOVA analysis was used to obtain mathematical models. Optimization of the results was carried out through desirability approach.

II. EXPERIMENTAL METHODOLOGY

During the experimentation work, different round bars of Incoloy 825 {Ni –(46% max), Fe – (22% min), Cr -(23.5% max), Mo- (3.5% max), Cu –(3% max), Ti –(1.2% max)} having 42mm diameter and 115mm length (refer Fig.1) were machined on conventional Okuma Centre Lathe Machine having driven motor power of 7.5 K Watt. The present work considered 3 levels of Design of Experiment. RSM based BBD Technique was used to develop a Design of Experiment by Design expert 11.1.0 software. Three input variables of cutting speed 27,48 and 69 m/min were selected with feed rate 0.06,0.07 and 0.08 mm/rev & depth 0.2, 0.35 and 0.5 mm. Commercially available CNMG 120408 LM TN 2000 CVD coated (TiN/TiCN/Al2O3) inserts were used with PCLNR 2020K 12 tool holder. Coated inserts of following tool geometry, a) clearance angle = 5°, b) Side rake angle = 6°,c) Inclination angle = 6°,d) Approach angle = 95°, e) Point angle = 80° and f) Nose radius = 0.8 mm (refer Fig.2) were used to conduct the research work. The length of cut was taken constant at 60 mm. Measurement of Ra was done by Mitutoyo SJ 301 Ra Tester and measurement of Tw by Sipkon measurement system.

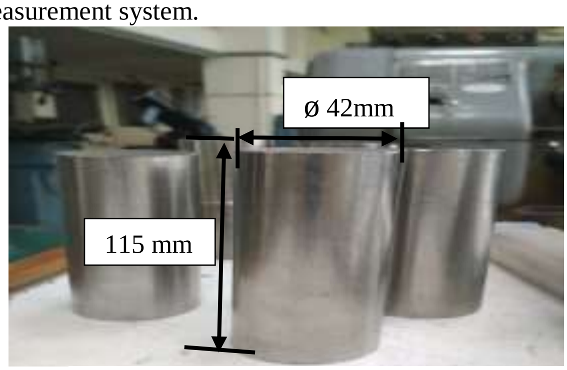


Fig. 1 Dimentions of workpiece

Fig. 2 Coated insert

III. RESULT AND DISCUSSIONS

3.1 EDS of insert

Fig. 3 illustrates that coating of commercially available coated insert (supplied by Widia) was done by TiN, TiCN and $Al_2 O_3$.

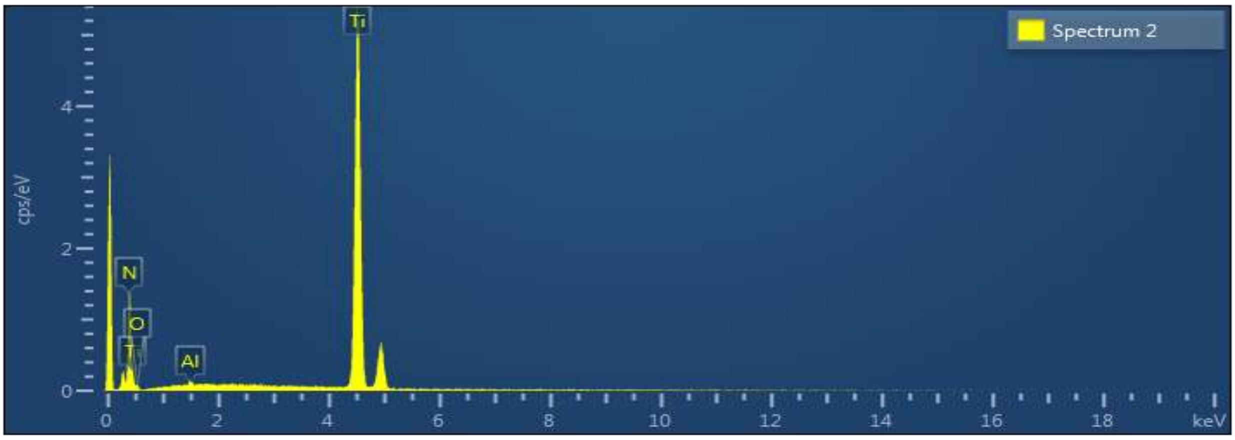


Fig. 3 EDS of Coated insert

3.2 Experimental Results

Experiments were carried out for Coated Tungsten Carbide inserts. 17 experiments were designed by RSM based BBD technique Three levels of each input parameters (i.e. V, f, d) were taken for experimentation & results were calculated as shown in Table I. After conducting the experiments for lathe turning the surface roughness values of workpiece and flank wear value of insert were measured using Mitutoyo surface roughness tester and Sipkon Measurement system. Each run of the experiment contains three trial values for better output of the surface roughness. The average of these three trial values has been taken for the analysis of optimization of input parameters.

TABLE I
EXPERIMENTAL RESULTS

		Factor 1	Factor 2	Factor 3	Response 1	Response 2
Std	Run	A:V	B:f	C:d	Ra	Tw
		m/min	mm/rev	mm	µm	µm
12	1	48	0.08	0.5	0.82	288
4	2	69	0.08	0.35	1.33	280.5
14	3	48	0.07	0.35	0.94	232.5
9	4	48	0.06	0.2	0.66	454
2	5	69	0.06	0.35	1.22	497
5	6	27	0.07	0.2	0.82	321
3	7	27	0.08	0.35	0.64	325

16	8	48	0.07	0.35	0.92	292
15	9	48	0.07	0.35	0.71	289
7	10	27	0.07	0.5	1.36	390
13	11	48	0.07	0.35	0.93	295
1	12	27	0.06	0.35	0.89	283
10	13	48	0.08	0.2	1.26	115
6	14	69	0.07	0.2	0.41	210
11	15	48	0.06	0.5	0.42	279.5
8	16	69	0.07	0.5	0.56	200
17	17	48	0.07	0.35	0.92	327

3.3 Analysis and optimization of Ra and Tw

Analysis and modelling of Ra and Tw was 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 of surface roughness with V, f and d. Multi Response Optimization for minimization of Ra and Tw was performed by desirability analysis.

3.3.1 Analysis of variance

ANOVA analysis was conducted on output responses for determining the experimental results. Significant model was designed after transformation of Data. ANOVA for reduced cubic model was generated. Table II and III shows ANOVA table values of Ra and Tw respectively.

TABLE III
ANOVA TABLE FOR RA

Source	SOS	DOF	MS	F	p	
Model Generated	2.02	12	0.1685	11.45	0.0153	significant
A- V	0.2735	1	0.2735	18.59	0.0125	
B-f	0.0150	1	0.0150	1.02	0.3698	
C-d	0.1632	1	0.1632	11.10	0.0291	
(AB)	0.0424	1	0.0424	2.88	0.1649	
(AC)	0.0101	1	.0101	0.6842	.4546	
(BC)	.0001	1	.0001	0.0065	.9396	
A^2	.0062	1	.0062	0.4199	0.5523	
B^2	0.0221	1	0.0221	1.50	0.2875	
C^2	0.2611	1	0.2611	17.75	0.0136	
AC^2	0.8612	1	0.8612	58.54	0.0016	
B^2C	0.3532	1	0.3532	24.01	0.0080	
BC^2	0.2996	1	0.2996	20.37	0.0107	
Error	.0588	4	.0147			
T	2.08	16				

From Table II, it can be concluded that the F value of model is 11.45 which implies that the model is significant. There is only a 1.53% possibility that an F value of this large could occur due to noise. P values less than .050 shows that all terms associated with model are significant. It can be also be analyzed that R-squared is 97.17 % which is close to 100 %. The value of Adjusted R-squared is 0.8869 represents that 88.69 % variation is explained by the independent variables that actually affects the dependent variables. Adjusted R- Squared is close to R-Squared which represents that only few percent variation is not explained by independent variables which doesn't actually affect the dependent variable. Adequate Precision is used to measures the signal to noise ratio. The ratio should be larger than 4. The ratio is 11.252 which indicates that the signal is adequate.

TABLE IIIII
ANOVA TABLE FOR TW

Source	SOS	DOF	MS	F	p	
Model Generated	1.256E+ 5	11.0	11417.89	11.15	0.0077	significant
A-V	22650.25	1	22650.25	22.12	0.0053	

B-f	7612.56	1	7612.56	7.43	0.0415	
C-d	413.28	1	413.28	0.4035	0.5532	
AB	16705.56	1	16705.56	16.31	0.0099	
AC	1560.25	1	1560.25	1.52	0.2719	
BC	30189.06	1	30189.06	29.48	0.0029	
A^2	3230.69	1	3230.69	3.15	0.1359	
B^2	4197.81	1	4197.81	4.10	0.0988	
C^2	5026.12	1	5026.12	4.91	0.0776	
AB^2	27671.28	1	27671.28	27.02	0.0035	
BC^2	3042.00	1	3042.00	2.97	0.1454	
Residual	5120.73	5	1024.15			
Lack of Fit	457.53	1	457.53	0.3925	0.5650	not significant
Pure Error	4663.20	4	1165.80			
Total	1.307E+05	16				

From Table III, it can be concluded that the F value of model is 11.45 which implies that the model is significant. There is only a .77% possibility that an F value of this large could occur due to noise. P values less than .050 shows that all terms associated with model are significant. Value for lack of fit is 0.39 which is insignificant.

It can be analyzed that R-squared is 96.08% which is close to 100% and navigate that the model explains nearly all the variability of the response data around its mean. The value of Adjusted R-squared is 0.8746 represents that 87.46 % variation is explained by the independent variables that actually affects the dependent variables. Adjusted R- Squared is close to R-Squared which represents that only few percent variation is not explained by independent variables which doesn't actually affect the dependent variable. Adequate Precision is used to measures the signal to noise ratio. The ratio should be larger than 4. The ratio is 14.49 which indicates that the signal is adequate.

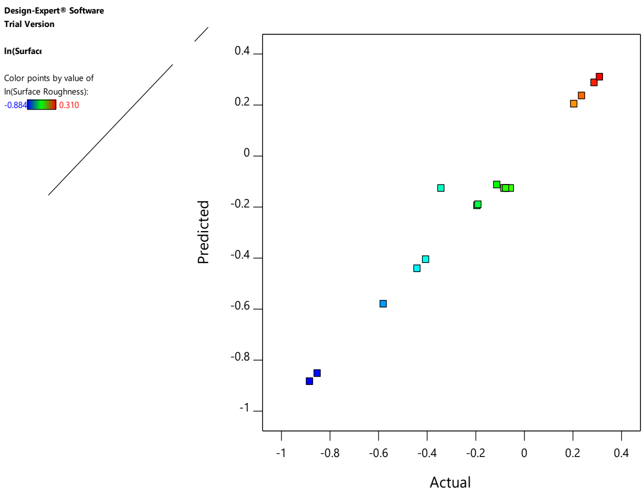
3.3.2 Mathematical Modeling and Regression Analysis

Multiple regression models were developed for Ra and Tw for CVD Coated inserts. The response variable was Tw and Ra and predictors were V, f and d. The mathematical equations for Ra and Tw are given below.

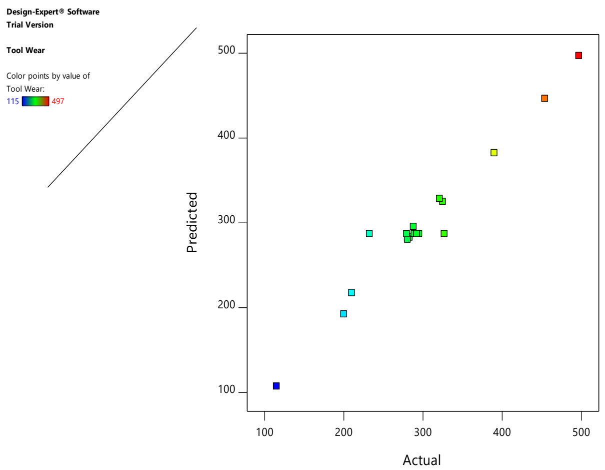
$$\text{Ln (Surface Roughness)} = 44.7467 + (-0.197063 * V) + (-1294.84 * f) + (-90.9832 * d) + (0.495494 * V * f) + (0.966735 * V * d) + (2721.54 * f * d) + (8.87807e\text{-}05 * V^2) + (10530.6 * f^2) + (-63.4321 * d^2) + (-1.40405 * V * d^2) + (-28017.3 * f^2 * d) + (1720.19 * f * d^2) \quad ...(1)$$

$$\text{Tool Wear} = -9445.07 + (291.634 * V + 309249 * f) + (-11117.5 * d) + (-8239.21 * V * f) + (-6.33894 * V * d) + (179250 * f * d) + (0.0642038 * V^2) + \{-2.42883e{+}06 * f^2\} + \{10597.8 * d^2\} + \{56629.2 * V * f^2\} + \{-173333 * f * d^2\} \quad ....(2)$$

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



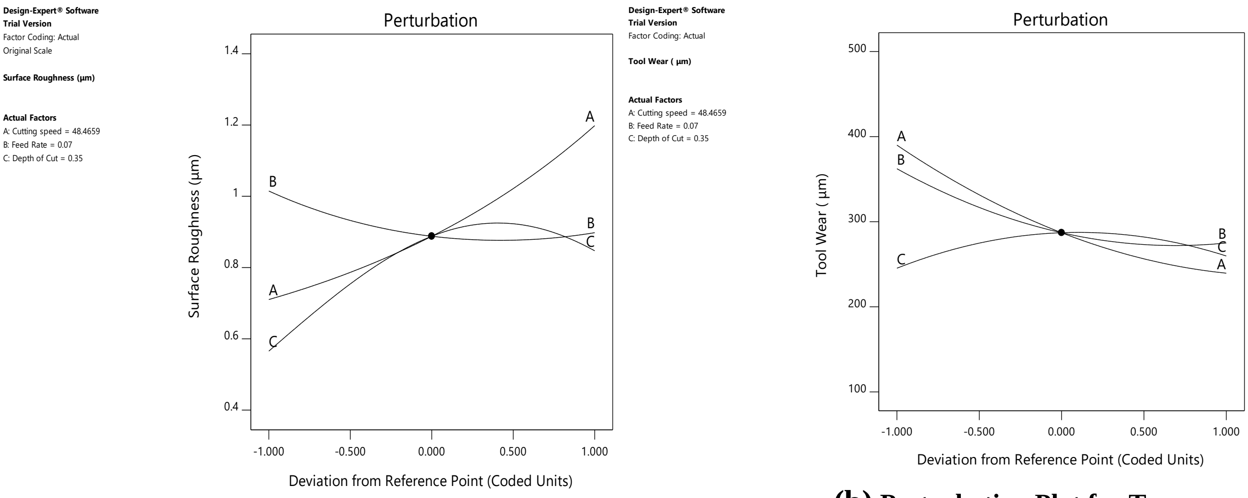
(a) Predicted Vs Actual for Ra



(b) Predicted Vs Actual for Tw

Fig. 4 Diagnosis plots

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



(a) Perturbation Plot for Ra **(b) Perturbation Plot for Tw**

Fig. 5 Perturbation plots

It can be depicted from Fig.5 (a), V and d are the most influential factors for Ra. Fig. 5 (b) illustrates that f and V are most influential factors for Tw.

3.4 Multi Response Optimization

Multi Response optimization was carried out by Design Expert Software 11.1.0. In present investigation there are two response variables and three input parameters. In case of multi response optimization there are consideration of every response simultaneously and optimize the input parameter for optimization of all responses. Numerical Optimization report contains two tables the first summarizing the criteria constraints (refer TABLE IV) used to produce the second table of optimal solutions (refer TABLE V) for the process**.**

TABLE IVV
CONSTRAINTS FOR OPTIMIZATION

No.	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:V	in range	27.6948	69.237	1	1	3
B:f	in range	0.06	0.08	1	1	3
C:d	in range	0.2	0.5	1	1	3
Ra	minimize	-0.883502	0.309932	1	1	3
Tw	minimize	115	497	1	1	3

TABLE V
OPTIMIZED RESULTS

Number	Cutting speed	Feed Rate	Depth of Cut	Surface Roughness	Tool Wear	Desirability	
1	69	0.072	0.200	0.456	178.456	0.875	Selected

The optimum value of cutting parameter for Coated Tungsten Carbide insert for Ra & Tw were found to be at V= 69 m/min, f = 0.072 mm/rev and d=0.20 mm. The combined desirability was 0.87.5 which means that experimental results for coated inserts were closer to the predicted values.

IV **CONCLUSIONS**

The 3 levels rotatable Box- Behnkins Design is employed for developing mathematical models for predicting the Ra parameter and Tw in turning of Incoloy 825. Multi objective optimization was applied for analysing the results of Ra and Tw. Desirability analysis was done to minimize the surface roughness and tool wear. The conclusion drawn from the research work are discussed as follows:

- The Tool Wear was mostly affected by V as well as d. f had very less effect on Tool Wear.
- V and d were the most influential parameters for Ra. f had very less impact on Ra.
- The optimum value of cutting parameter for Coated Tungsten Carbide insert for Ra and Tw were found to be at V= 69 m/min, f= 0.072 mm/rev and d=0.20 mm.
- Better surface finish was found at high cutting speed. The optimized value predicted for surface roughness was 0.456 µm.
- Greater value for Tw was produced at higher cutting speeds and depth of cuts. The optimized value predicted for tool wear was 178.456 µm.

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