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OPTIMIZATION OF CUTTING TEMPERATURE AND MRR DURING CNC MILLING OF INCOLOY 800 USING DOE TECHNIQUE

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Abstract- The process high cutting frictional forces lead to rise in temperature at workpiece and tool interface which may affect the dimensional and surface quality of the product. Optimum machining parameters can reduce tool workpiece interference temperature and maximise material removal rate (MRR) at minimum machining cost. In this paper, the machining parameters i.e. cutting speed (V_c), depth of cut (d) and feed rate (f) has been optimized to reduce cutting temperature (T) and maximise MRR using Design of experiments (DOE). The optimization of the cutting temperature and MRR has been done simultaneously by multi response optimization technique and also a mathematical relation between response parameters and input process variables has been developed. The optimized process parameters obtained from machining through RSM were V_c is 2454.95 rpm, f is 437.05 mm/min and d is 0.20 mm, corresponding T and MRR were 126.04 ˚C and 1.40 cm^3/min respectively.

Keywords— Incoloy 800, Titanium Coated Cryogenic Treated Tungsten Carbide Insert, RSM, Multi Response Optimization, Milling.

I. INTRODUCTION

Surface finish is a major extent of the mechanical idea of a thing and a parameter that basically impacts producing cost. Surface unpleasantness (Ra), cutting force (Fc), and Tool wear (Tw) are normally used to evaluate machinability. A basic bit of machining process is wearing up of hardware [1, 2]. Surface harshness is a for the most part experienced issue in machined surfaces that has pulled in the thought of researchers for better surface quality [3]. It is portrayed as the irregularities of surface abnormalities, which is the consequence of basic action of the creation procedure. Along these, surface unpleasantness fundamentally influences thing quality [4].

The primary part of the processing procedure is cutting device and device breakage is a chief wellspring of unscheduled work stoppage in modern destinations utilizing processing. Gathering of hardware harm after some time regularly results in instrument breakage, and has unfortunate time misfortune and capital impacts [5]. The three key components in any basic machining process are Vc, d and f. The yield cutting parameters in machining activity are the capacity of info cutting procedure parameters [6-8].

The relationship between's at least one yield factors and a lot of info factors can be considered by utilizing reaction surface approach. These methodologies are frequently utilized in the wake of perceiving the sensible factors and the point of this procedure is to establish the factor setting that advances the reaction parameter esteems. There is no fixed factorial or partial structure in the Box-Behnken plan (BBD) [9-12]. The structure focuses in Box-Behnken configuration are not exactly focal composite plans, in this manner they have less number of preliminaries with a similar number of components and along these lines more affordable.

II. LITERATURE REVIEW

In anticipating the performance of any machining process the surface roughness and tool wear are paramount factors. It is important to comprehend the current trend in this area for making and optimizing the tool wear (T_w) and surface roughness (R_a) model.

Palanisamy and Selvaraj [13] intended to locate the ideal reactions for machining of Incoloy 800H. The tests were directed in CNC turning place for the planned parameters (L_{27} OA) in dry condition. The chose machining parameters were Vc, f and d. Ra and MRR were the yield reactions. To achieve nature of the turned parts, Ra was limited and MRR was augmented by means of Taguchi strategy. The consolidated impacts of info factors over the reactions were researched utilizing OA notwithstanding ANOVA.

Erdik and Şen [14] concentrated on two unique models, in particular, relapse scientific and counterfeit neural system models for foreseeing instrument wear. Flank wear was taken as the reaction variable estimated amid processing, while at the same time cutting rate, feed and profundity of cut were taken as info parameters. The Design of Experiments (DOE) method was produced for three elements at five dimensions to lead tests. Trials have been led for estimating device wear dependent on the DOE system in an all inclusive processing machine on AISI 1020 steel utilizing a carbide shaper.

Rashid and Lani [15] created two models first scientific model utilizing numerous relapse and other was counterfeit neural system. Axle speed, feed rate, and profundity of cut were picked as indicators so as to anticipate surface harshness. 27 tests were controlled by utilizing FANUC CNC Milling α-T14E. Investigation of changes demonstrates that the most huge parameter is feed rate pursued by axle speed and in conclusion profundity of cut. Anticipated surface harshness was gotten by utilizing the two techniques, normal rate mistake was determined aimed to find the optimal responses for machining of Incoloy 800H. The experiments were conducted in CNC turning centre for the designed parameters (L_{27}OA) in dry environment. The selected machining parameters were Vc, f & d. R_a and MRR were the output responses. To attain quality of the turned components, Ra was minimized and MRR was maximized via Taguchi method. The combined effects of input variables over the responses were investigated using OA in addition to ANOVA.

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III. EXPERIMENTAL METHODOLOGY

The intention of the present work is to optimize the cutting Temperature (T) and MRR value for Incoloy 800 steel using RSM. During the experimentation work, Incoloy 800 workpiece {Fe –(min 39.5%) , C – (0.10%), Ni - (35%), Cr- (19-23%), Al –(0.15-0.60%) and Ti – (0.60)} having dimensions (length 50 mm, height 50 mm and width 50 mm) was machined on HURCO vertical CNC milling machine (NITTTR, Chd) with spindle motor power 11 kW using face milling cutter of 20 mm diameter.

The present work were considered three levels of design of experiment. RSM based BBD Technique was used to improve the design of experiments by Design Expert Software. Three input variables of cutting speed 2000, 2250 and 2500 m/min were selected with feed rate 350, 425 and 500 mm/min and depth of cut of 0.2, 0.4 and 0.6 mm. Commercially available TPKN2204PDR coated tungsten carbide inserts of given tool geometry (Shape – Rhombic, Included angle = 50°, Cutting edge = 2) were used to conduct the research work.

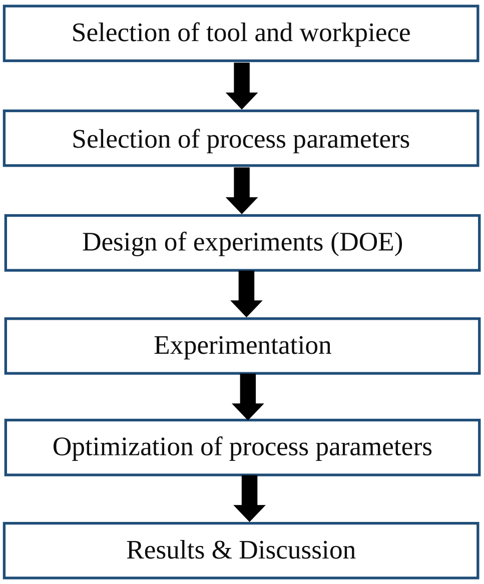


Figure 1: Methodology used for the optimization of MRR and Cutting Temperature

The framework of methodology adopted for the present work is shown in Figure 1. ANOVA was employed to study the performance characteristics of milling operation.

IV. RESULTS AND DISCUSSION

The experiments were performed with variation in different process parameters using design of experiment approach and results were evaluated using response surface methodology. 27 experiments were designed by RSM based BBD technique. For each input parameter (*i.e.* V_c, f and d) three levels were taken for experimentation and results were calculated as shown in Table 1. Each run of the experiment contains three trial values for better output of the MRR and Cutting Temperature. For the analysis of optimization of input parameters average of these three trial values has been taken

Table 1. Experimental design matrix

	Factors			Responses	
Run	Cutting Speed:A	Feed:B	Depth of Cut:C	Temperature	MRR
	(rpm)	(mm/rev)	(mm)	(°C)	(cm^3/min)
1	2000	425	0.2	97	0.58
2	2250	350	0.6	142	1.97
3	2500	500	0.4	160	2.1
4	2250	500	0.2	123	0.74
5	2000	500	0.4	99	0.87
6	2250	500	0.6	187	2.1
7	2250	425	0.4	118	1.7
8	2500	425	0.2	134	1.62
9	2500	350	0.4	163	1.87
10	2250	350	0.2	124	0.71
11	2500	425	0.6	221	2.6
12	2250	425	0.4	122	1.81
13	2250	425	0.4	120	1.6
14	2250	425	0.4	117	1.42
15	2250	425	0.6	192	1.98
16	2000	350	0.4	130	0.98
17	2250	425	0.4	116	1.46

1. Optimization of Cutting Temperature and MRR

The models were generated from the response parameter values in order to find the obtained models are productive or not. So, F-ratio test and ANOVA analysis has been performed. It was observed that the model generated for all the response parameters were significant.

(a) Analysis of Temperature and MRR

The square root transformation was used for cutting Temperature, therefore RSM suggests the desirability of the model is cubic as shown in Table 2. The power transformation was used for MRR model, therefore RSM suggests the desirability of the model is cubic as shown in Table 3.

Table 2. Model significance of Temperature using ANOVA

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	18894.56	12	1574.55	271.47	< 0.0001	significant
A	216.15	1	216.15	37.27	0.0036	
B	289	1	289	49.83	0.0021	
C	3982.16	1	3982.16	686.58	< 0.0001	
AB	196	1	196	33.79	0.0044	
AC	21.9	1	21.9	3.78	0.1239	
BC	529	1	529	91.21	0.0007	
A^2	790.44	1	790.44	136.28	0.0003	
B^2	0.0034	1	0.0034	0.0006	0.9819	
C^2	2079.17	1	2079.17	358.48	< 0.0001	

F-value of 129.44 indicates the model is significant. Only a 0.01% probability that F-value this large could occur due to noise.

Table 3. Model significance of MRR using ANOVA

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.09	8	0.3858	35.54	< 0.0001	significant
A	0.8028	1	0.8028	73.94	< 0.0001	
B	0.0013	1	0.0013	0.12	0.7376	
C	1.46	1	1.46	134.1	< 0.0001	
AB	0.0138	1	0.0138	1.27	0.292	
AC	0.068	1	0.068	6.26	0.0368	
BC	0.0001	1	0.0001	0.011	0.9166	
B^2	0.0996	1	0.0996	9.18	0.0163	
C^2	0.0523	1	0.0523	4.81	0.0595	

F-value of 35.54 indicates the model is significant. Only a 0.01% probability that F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant.

(b) Mathematical Modelling and Regression Analysis

The results obtained by ANOVA model were formulated as a regression analysis equation for Temperature and MRR by RSM and given in equation 1 and equation 2 respectively.

$$(\text{Temperature}) = [612.33 - 0.25\,A + 4.35\,B - 2593.59\,C + 0.0053\,AB + 0.089AC + 16.31\,BC + 0.00031\,A^2 - 0.0053\,B^2 - 2126.66\,C^2 - (6.73E{+}06)\,AB^2 - 0.024\,B^2C + 6.50\,BC^2] \quad \ldots\ldots\ldots\ldots..\ (1)$$

$$\ln(MRR) = -9.22265 + 0.001462\,A + 0.565453\,B + 11.8744\,C + (3.13411E - 06)\,AB - 0.003342\,AC + 0.000375\,BC - 0.000028\,B^2 - 2.85527\,C^2 \quad \ldots\ldots\ldots\ldots(2)$$

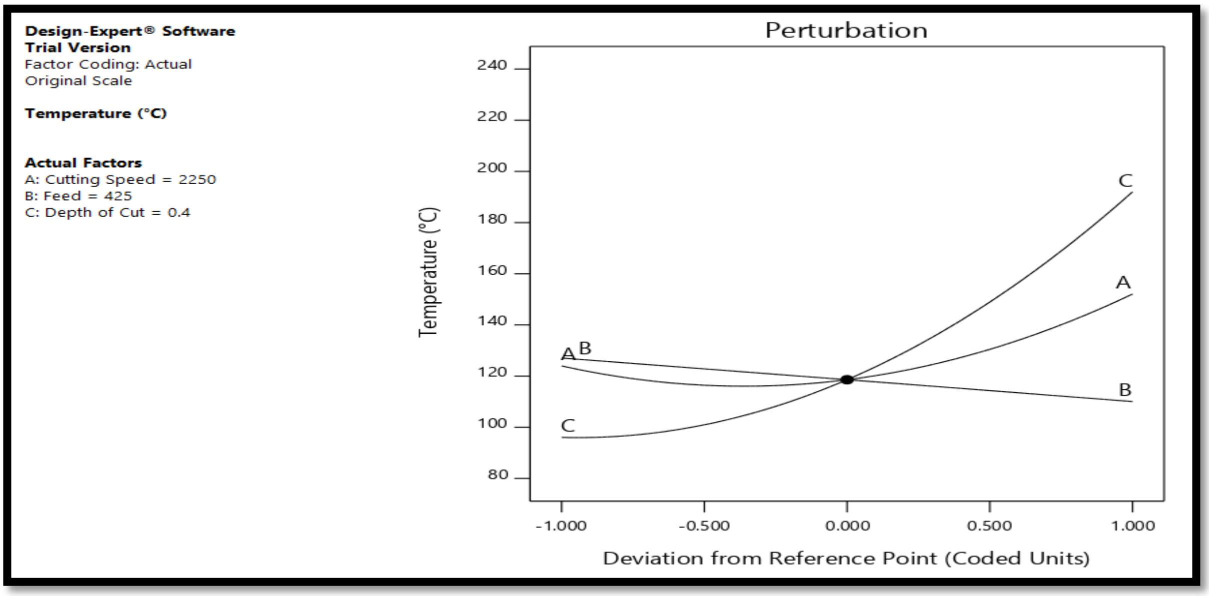


Figure 2: Perturbation plot for Temperature

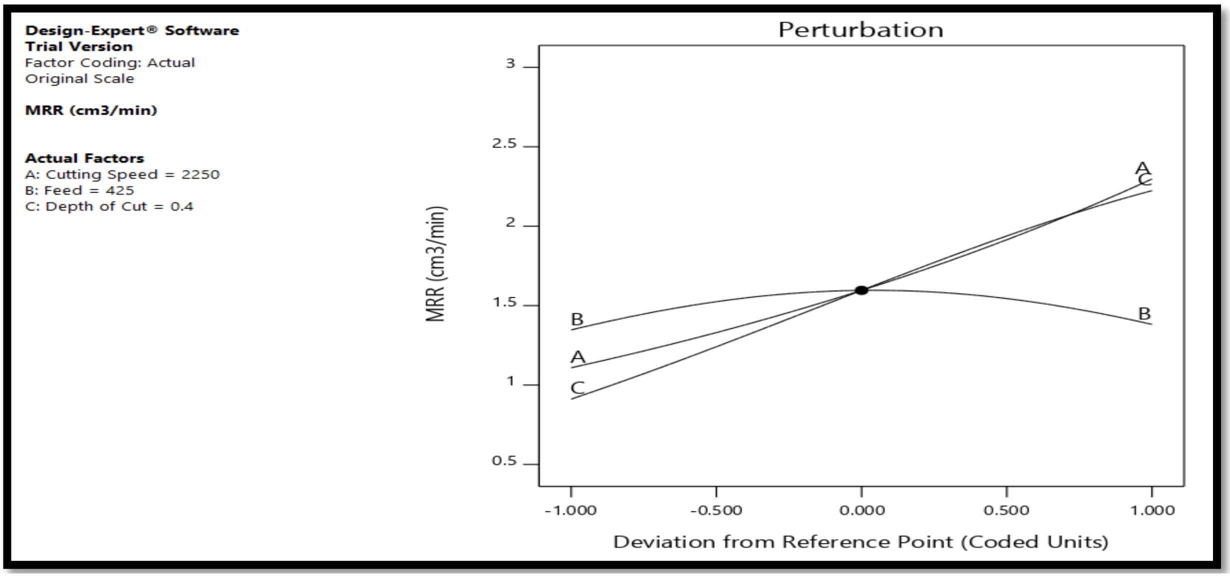
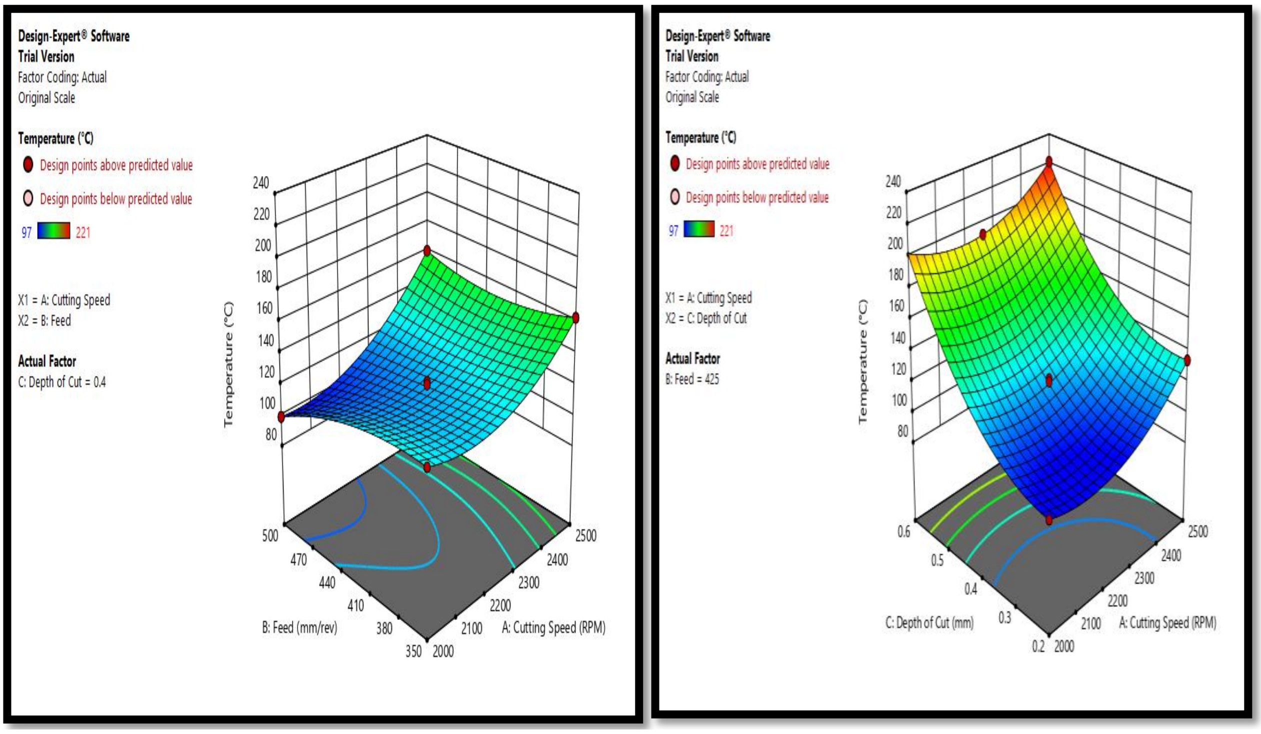


Figure 3: Perturbation plot for MRR

Figure 2 and 3 represents the perturbation curve to determine the effect of input responses on temperature and MRR respectively. It is clearly indicated that the cutting speed and depth of cut are the most influential factor in controlling the cutting temperature, as the slope is found to be maximum in depth of cut and then in cutting speed. In this case feed is the next influential factors which affect the cutting temperature as shown in figure 2. It is clearly indicated that the depth of cut and cutting speed are the most influential factor in controlling MRR, as the slope is found to be maximum. In this case feed rate the next influential factor which affects the MRR as shown in figure 3

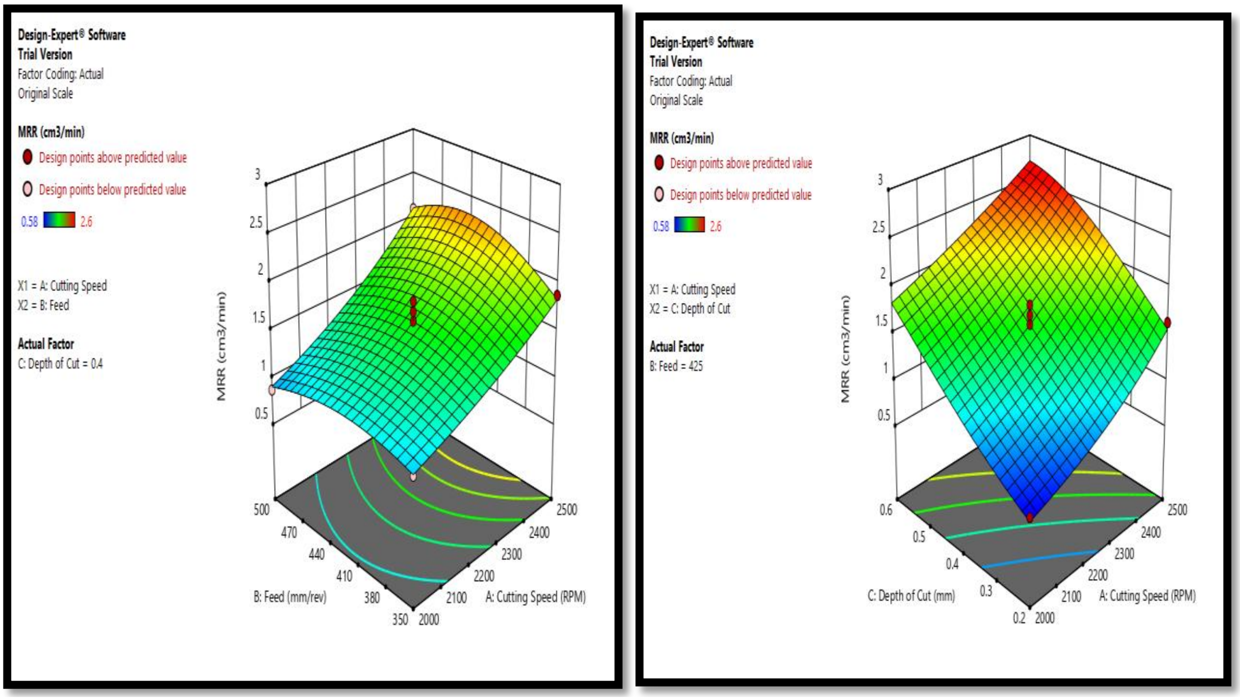
(c) 3D Graphs for The Cutting Temperature and MRR

Three dimensional graphs for the Temperature and MRR showing relation with the V_c, f and d.



(a) Interaction between v, f and T (b) Interaction between v, d and T

Figure 4: 3D interaction plot showing the effect between input parameters and Temperature



(a) Interaction between v, f and MRR (b) Interaction between v, d and MRR

Figure 5: 3D interaction plot showing effect between input parameters and MRR

Figure 4 (a) shows the minimum cutting temperature of 99˚C at feed rate 500 mm/min and cutting speed of 2000 rpm and keeps on increasing to maximum up to 163˚C at cutting speed of 2500 rpm at constant depth of cut 0.4 mm. In Figure 4 (b) the minimum cutting temperature of 97˚C at depth of cut of 0.2 mm and cutting speed of 2000 rpm at constant feed rate of 425 mm/min and keeps on increasing up to 221˚C with increase in both parameters that is maximum cutting speed and maximum depth of cut of 2500 rpm and 0.6 mm respectively. The combined effect of feed rate and depth of cut indicate that the minimum cutting temperature of 122˚C at feed rate of 350 mm/min and the value of cutting temperature increases to 192˚C with the increase in values of feed rate to maximum 500 mm/min and 0.6 mm depth of cut.

Figure 5 (a) shows the minimum MRR of 0.98 cm^3/min at minimum feed rate of 350 mm/min and minimum cutting speed of 2000 rpm. It start increasing with increase in both parameters up to 1.87 cm^3/min at maximum feed rate of 500 mm/min and maximum cutting speed of 2500 rpm. In Figure 5 (b) the minimum MRR of 0.58 cm^3/min at minimum depth of cut of 0.2 mm and cutting speed of 2000 rpm at constant feed rate and increases up to 1.81 cm^3/min at depth of cut of 0.4 mm. The combined effect of feed rate and depth of cut indicate that MRR is increases with increase in both the parameters.

2. Multi Response Optimization

A combination of factor levels were optimized simultaneously by selecting the required objectives for all response parameter to meet the requirements placed. The numerical multi response optimization criteria was employed to obtain the optimal input process parameter values for achieving minimum temperature and maximum MRR. The importance for all input machining parameters is selected to be the same as shown in Table 4 and optimized results are shown in Table 5.

Table 4. Selected optimization criteria for RSM

Name	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Cutting Speed (V_c)	2000	2500	1	1	3
Feed (f)	350	500	1	1	3
Depth of Cut (d)	0.2	0.6	1	1	3
MRR	-0.544727	0.955511	0.892442	1	3
Temperature	97	221	1	0.845221	5

Table 5. Optimized process parameters for machining

Cutting Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	MRR (cm^3/min)	Cutting Temperature (˚C)
2454.95	437.05	0.20	1.40	126.04

The optimal values of Temperature and MRR were 126.04 ˚C and 1.40 cm^3/min respectively at V_c of 2454.95 rpm, feed of 437.05 mm/min, and depth of cut of 0.20 mm as optimum value of input process parameters. The numerical optimization found a point that gives the maximum desirability value as 0.82 which corresponds to the minimum values of temperature and MRR

V. CONCLUSIONS

In the present work, face milling of Incoloy 800 was accomplished with Titanium coated cryogenic treated tungsten carbide inserts to optimize the input process variables viz. V_c, f and d for optimum Temperature (Temp.) and MRR. The three level BBD was employed for developing mathematical models for calculating the optimized values of Temperature and MRR. The conclusions extracted from the present work are discussed as follows:

1) The optimized process parameters obtained from machining through RSM were cutting speed of 2454.95 rpm, feed rate of 437.05 mm/min and depth of cut of 0.20 mm and the corresponding obtained response parameters i.e., cutting temperature and MRR were 126.04˚C and 1.40 cm^3/min respectively.
2) The variation of increase in cutting temp found to be in direct proportion with increase in cutting speed and depth of cut. The effect of depth of cut is more prominent than cutting speed, as suggested by the interaction plots where the slope of depth of cut was observed to be higher than the slop of cutting speed. The effect of feed was observed to be minimal.
3) Feed rate was found to have very less effect whereas depth of cut and cutting speed were found to have considerable impact on MRR.

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