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EXPERIMENTAL INVESTIGATION ON TURNING OF Al-TiC METAL MATRIX COMPOSITE USING CENTRAL COMPOSITE DESIGN (RSM)

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Abstract

Metal matrix composites are the emerging material in manufacturing industry which provides higher strength and lesser weight than alloys. Its hardness is the difficult task in the machining process to especially to obtain good quality of surface finish. This difficulty can be reduced to achieve good machine ability by selection of optimal values of cutting parameters. In this work an experimental investigation has been carried out on turning of 6063 Al -TiC metal matrix composite using PCD insert by formulating Response surface methodology based model to predict optimal cutting parameters in order to achieve good quality of surface finish.

Keywords: Response Surface Methodology (RSM), Metal matrix composites (MMC), Surface Roughness, Central composite design (CCD) etc.

1. INTRODUCTION

J.S.SenthilKumar et al. [1] has conducted an experimental study on turning and facing of Inconel 718 using uncoated carbide insert considering cutting parameters as cutting speed, feed, depth of cut and the responses as are surface roughness and flank wear. In this Flank wear analysis using image processing. It is predicted that for turning, cutting speed and depth of cut are dominant factors and for facing cutting speed, feed are dominant factors. B. Sidda Reddy et al. [2] has investigated on turning of Aluminium alloy using carbide cutting tool. The cutting parameters focused in this work are cutting speed, feed, depth of cut and the response is surface roughness. Adaptive Neuro Fuzzy Inference System (ANFIS) and Response Surface Methodology (RSM) are applied to predict the surface roughness.

Rodrigues.L.L.R. et al. [3] has conducted an experimental study on turning of Mild steel using High speed cutting tool. The cutting parameters considered in this work are cutting speed, feed, depth of cut and the response are surface roughness and cutting force. Experimental design is Response surface method. This work predicted that feed rate and depth of cut has significant influence on both surface roughness and cutting force. Madhu.V.N. et al [4] has investigated on turning of Titanium using Cubic boron Nitride (CBN). The cutting parameters focused in this work are cutting speed, feed, depth of cut and the response are surface roughness. Surface roughness analysis has been carried out using MAT lab and Artificial neural network to find optimal cutting parameters. It is suggested that to increase the number of neurons to improve the performance of network.

Yahya Isik et al. [5] has conducted an experimental study on turning of AISA 1050 steel using CVD coated carbide Tic+Al2 O3 +Ti N insert (ISO P25). This work focuses the cutting parameters cutting speed, feed, depth of cut and the responses flank wear, tool life, tool wear and surface roughness. The experiment carried out in both dry and wet cooled conditions, the tool wear is measured in term of flank wear (V_B), it was concluded that the reduction in tool wear increases the tool life and in turn reduces cutting zone temperature with favourable change in chip tool interaction. And also cutting fluid reduces the main cutting force due to the improved and intimate chip tool interaction. Harsimran Singh Sodhi et al. [6] have investigated an experimental study on turning of mild steel using carbide cutting tool. The cutting parameters focused in this work are cutting speed, feed rate, depth of cut and the response is surface roughness. Experiment is designed using Taguchi method. This work predicted that for turning cutting speed, depth of cut and feed rate are dominant factors for best value of surface.

Suleiman Abdulkareem et al. [7] has conducted an experimental study on turning of AISI 1045 medium carbon steel using molybdenum high speed steel turning tool. The cutting parameters considered in this work are depth of cut, feed rate, spindle speed and the response is surface roughness. The experiment is designed using Box Benhenken design. It is suggested that for high cutting speed and spindle speed has positive effect on surface roughness against feed rate. Hardeep Singhet al. [8] have conducted and experimental investigation on turning of EN-8 using carbide cutting tool. The cutting parameters focused in this work are depth of cut, feed rate and the response are surface roughness, MRR. Taguchi methodology has been applied to optimize cutting parameters is applied to analysis surface roughness. The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant factors. It is concluded that spindle speed is the most significant factor, depth of cut is the second most significant factor and the feed rate has less significance than spindle speed and depth of cut on surface roughness.

Tugrul Ozel et al. [9] has conducted an experimental study on turning of AISI D2 steels (60 HRC) using ceramic wiper tool. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the response are tool wear, surface roughness. Tool wear analysis using Neural Network Modeling. He suggested that for high feed rate maintaining good surface finish and best tool life was obtained in lowest feed rate and lowest cutting speed combinations.

S. Thamizhmanii et al. [10] have investigated an experimental study on turning of hard AISI 440C martensitic stainless steel using cubic boron nitride cutting tool. The cutting parameters focused in this wok are cutting speed, feed rate, depth of cut and the response are flank wear and surface roughness. This work suggested that for turning of martensitic stainless steel it is better to perform the turning with medium level cutting speed, high feed rate and high depth of cut. Diwakar Reddy et al. [11] has conducted an experimental investigation on turning of medium carbon steel using uncoated carbide tool. This work dealt with cutting parameters such as speed, feed and depth of cut and the response as surface roughness. ANN modeling is applied to find optimal cutting parameters. It is concluded that the model has been proved to be successful in terms of agreement with experimental results.

Pragnesh. R. Patel & V. A. Patel [12] has investigated an experimental study on turning of 6063 Al alloy TiC Composites (MMCs) for 5% TiC and 10% TiC composites using PCD tool. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the responses are surface roughness, Power consumption. It is predicted that Power consumption increases with increase in cutting speed, feed rate and depth of cut. K.A.Mahajan et al. [13] have conducted a series of face cutting experiments on Oxygen Free High Conductivity Copper (OFHC) using a sharp edge single point uncontrolled waviness diamond tool to analyse the surface roughness. The cutting parameters focused in this work are spindle speed, feed, depth of cut and tool nose radius. It was concluded that with using bigger tool nose radius the surface roughness improves drastically. Upinder Kumar Yadav et al [14] has conducted an experimental study on turning of Medium Carbon Steel AISI 1045 using STALLION-100 HS CNC lathe. The cutting parameters considered in this work are cutting speed, feed rate and depth of cut and the response is surface roughness. Experimental Design used in this work is Taguchi design (L27 orthogonal array). In this work it has been predicted that the surface roughness is mainly affected by feed rate and cutting speed. With the increase in feed rate the surface roughness increases and as decrease in cutting speed the surface roughness increases.

V. R. Kagade & R. R. Deshmukh [2011] [15] has investigated an experimental study on turning of High carbon high chromium steel (HCHC) using CNMG 09 03 08-PF carbide insert tool. The cutting parameters focused in this work are cutting speed, depth of cut, feed rate and the outcomes considered are surface roughness, spindle load. This work has revealed a conclusion that speed has maximum effect & depth of cut has minimum effect on surface roughness. Prof.A.V.N.L.Sharma et al [2012] [16] has conducted an experimental study on Hard turning of EN8 steel using High speed steel tool. This work deals with prediction of tool wear with application of Image processing with considering are cutting speed, feed rate and depth of cut as cutting parameters. It was concluded with comparision of deviation of results for tool wear between conventional method and image processing.

The issues from the above literature survey reveals out that no much concentration focused on the analysis of influence of cutting parameters on turning of Metal matrix composite in particular Al- TiC composites. Thus in this work material 6063 Al -TiC metal matrix composite is chosen for evaluation of machining parameters

2. MATERIALS AND METHODS

This analysis deals with the finding the optimal cutting conditions in turning of 6063 Al -TiC metal matrix composite using Poly Crystalline Diamond (PCD) insert of ISO coding DCMW 11T304 in CNC turning centre (JAQUAR- 100 HS) for three different values of spindle speed, feed and depth of cut. In this work the work piece material considered for study was 6063 Al alloy with 5% TiC MMC and 6063 Al alloy with 10% TiC MMC of size 30 mm diameter and 150 mm length. The physical and Mechanical properties of 6063 Al-TiC alloy are shown in the Table 1.

Table 1. Properties of 6063 Al-TiC alloy

Properties / Material	Density Kg/m^3	Elongation (%)	Yield strength MPa	Ultimate tensile strength MPa	Hardness (BHN)
6063 Al – 5% TiC	2632	3	103	140	95
6063 Al – 10% TiC	2734	1	127	152	113

3. EXPERIMENTAL DESIGN

Selection of experimental design is a decision making process which decides the degree of validity of the desired model in finding optimal cutting parameters. This work is carried out with Response surface methodology modeling using Central composite design (CCD) comes under Response surface methodology.

Response surface methodology is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to find optimized values of cutting parameters for minimization or maximization of response. The response surface design is a better design, as it generates a second order linear model of regression, which is better predictive model than a first order linear model. In this work, Central Composite Design (CCD) has been applied for the experimental investigation to find optimal cutting parameters for achieving better surface roughness. The values of cutting parameters for CCD are shown in Table 2.

Table 2. Response surface design (CCD)

Levels/Factors	-α	-1	0	1	α
Cutting Speed, V (m/min)	63	92	122	151	181
Feed, f (mm/rev)	0.107	0.159	0.210	0.262	0.313
Depth of cut, d (mm)	0.3	0.5	0.6	0.8	0.9

4. RESULTS AND DISCUSSION

Data collection plays a significant role in statistical analysis of any field, as it decides the progression of the analysis to the best or worst. A proper and suitable data collection leads to better results from analysis. In such focus it is very much essential to choose a well suitable data collection technique for the analysis. In this work, Data collection for the turning process is selected for proceeding with Response surface methodology design ie., a second order linear model. The values of surface roughness (Ra1) for Al with 5% TiC and surface roughness (Ra2) for Al with 10% TiC were predicted using the model in turning of Al-TiC MMC (for 5% TiC and 10% TiC) steel using carbide cutting tool has been shown in Table 3.

Any Data collected for responses against set of chosen parameters must be validated for the significant influence of parameters. In this manner the data collected surface roughness from Table 3, are validated for the significant effects of cutting parameters spindle speed, feed and depth of cut. This is done by test of hypothesis at 95% significance level using F- test. The results of the test of hypothesis for machining time, MRR and surface roughness for 5% and 10% TiC are shown in Table 4, 5.

Table 3. Data collection using Response Surface Methodology (Central composite design)

Sl.No	Cutting speed (m/min)	feed (mm/rev)	depth of cut (mm)	Ra1 5% TiC (micron)	Ra2 10% TiC (micron)
1	122	0.107	0.6	1.871	1.937
2	122	0.210	0.6	3.286	4.633
3	122	0.210	0.9	3.48	4.84
4	151	0.262	0.8	4.008	5.05
5	92	0.262	0.8	4.838	6.32
6	151	0.159	0.5	2.047	2.792
7	92	0.159	0.5	2.612	3.542
8	151	0.262	0.5	3.795	4.89
9	122	0.210	0.6	3.286	4.633
10	92	0.159	0.8	2.989	3.856
11	122	0.210	0.6	3.286	4.633
12	122	0.210	0.6	3.286	4.633
13	92	0.159	0.8	2.989	3.856
14	92	0.159	0.5	2.612	3.542
15	151	0.262	0.8	4.008	5.05
16	122	0.210	0.6	3.286	4.633
17	92	0.262	0.5	4.508	6.028
18	122	0.210	0.6	3.286	4.633
19	151	0.159	0.5	2.047	2.792
20	63	0.210	0.6	4.109	5.281
21	151	0.159	0.8	2.307	2.974
22	122	0.210	0.6	3.286	4.633
23	151	0.262	0.5	3.795	4.89
24	151	0.159	0.8	2.307	2.974
25	122	0.313	0.6	5.468	6.5
26	92	0.262	0.8	4.838	6.32

27	92	0.262	0.5	4.508	6.028
28	181	0.210	0.6	2.714	3.261
29	122	0.210	0.3	2.89	4.366

Table 4 determines that all the factors Spindle speed, Feed and Depth of cut are having significant influence on Surface roughness for Al with 5% composition of TiC MMC. As the R^2 value of Surface roughness is 0.9970 which is greater than 0.8 shows that the model is suitable to navigate the design space.

Table 5 determines that all the factors Spindle speed, Feed and Depth of cut are having significant influence on Surface roughness for Al with 10% composition of TiC MMC. As the R^2 value of Surface roughness is 0.9985 which is greater than 0.8 shows that the model is suitable to navigate the design space.

Table 4. ANOVA for Surface Roughness of Al with 5% TiC MMC

Source	**Sum of** Squares	**DOF**	**Mean Square**	**F Value**	**p-value** Prob > F	
Model	22.69658	9	2.521842	694.9159	< 0.0001	significant
A- Cutting Speed	3.007324	1	3.007324	828.6946	< 0.0001	
B-feed	18.14066	1	18.14066	4998.82	< 0.0001	
C-depth of cut	0.562346	1	0.562346	154.9595	< 0.0001	
AB	0.020808	1	0.020808	5.733846	0.0271	
AC	0.03249	1	0.03249	8.952924	0.0075	
BC	0.000264	1	0.000264	0.072765	0.7903	
A^2	0.040897	1	0.040897	11.26948	0.0033	
B^2	0.203604	1	0.203604	56.10481	< 0.0001	
C^2	0.000109	1	0.000109	0.030113	0.8641	
Residual	0.068951	19	0.003629			
Lack of Fit	0.004445	5	0.000889	0.192957	0.9602	not significant
Pure Error	0.064506	14	0.004608			
Cor Total	22.76553	28				

$R^2 = 0.9970$; Adj $R^2 = 0.9955$: Pred $R^2 = 0.9938$;

Table 5. ANOVA for Surface Roughness of Al with 10% TiC MMC

Source	**Sum of** Squares	**DOF**	**Mean Square**	**F Value**	**p-value** Prob > F	
Model	39.80724	9	4.423027	1387.302	< 0.0001	significant
A-Cutting speed (V)	5.240849	1	5.240849	1643.815	< 0.0001	
B-feed (f)	31.59421	1	31.59421	9909.661	< 0.0001	
C-depth of cut (d)	0.368456	1	0.368456	115.568	< 0.0001	
AB	0.17682	1	0.17682	55.46044	< 0.0001	

AC	0.002916	1	0.002916	0.914616	0.3509	
BC	0.000272	1	0.000272	0.085392	0.7733	
A^2	0.217849	1	0.217849	68.32932	< 0.0001	
B^2	0.3262	1	0.3262	102.3141	< 0.0001	
C^2	0.000601	1	0.000601	0.188539	0.6690	
Residual	0.060576	19	0.003188			
Lack of Fit	0.008648	5	0.00173	0.466329	0.7950	not significant
Pure Error	0.051928	14	0.003709			
Cor Total	39.86782	28				

$R^2 = 0.9985$; Adj $R^2 = 0.9978$; Pred $R^2 = 0.9966$

5. RESULTS AND DISCUSSION

The mathematical modeling is a better statistical tool used to evaluate the values of response outcomes for various combinations of input parameters. This method of data evaluation helps in theoretical decision making for finding optimal cutting conditions. Mathematical model can be derived by using Regression Analysis. In this work, a second order linear model has been deduced for the readings obtained from Response Surface method (Central composite design). The Central composite design enables the model to generate a second order correlation between the cutting parameters and the responses. A typical model of second order mathematical model has shown in equation 1.

$$y = n\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1^2 + \beta_4 x_2^2 + \beta_5 x_1 x_2 + \ldots\ldots\ldots\ldots\ldots + \beta_n x_n \qquad \text{(eqn. 1)}$$

Where y - Response

n- Regression constant

B – Correlation coefficient

$x_1, x_2, \ldots\; x_n$ – are cutting parameters

The mathematical (Regression) models of Surface roughness for Al with 5% and 10% TiC MMC deduced is shown in equations 2 & 3.

For 5% TiC Surface Roughness (R_a),

$$Ra1 = +1.23412 - 0.012084 * V + 6.61077 * f + 2.45251 * d - 0.023787 * V * f - 0.010205 * V * d$$

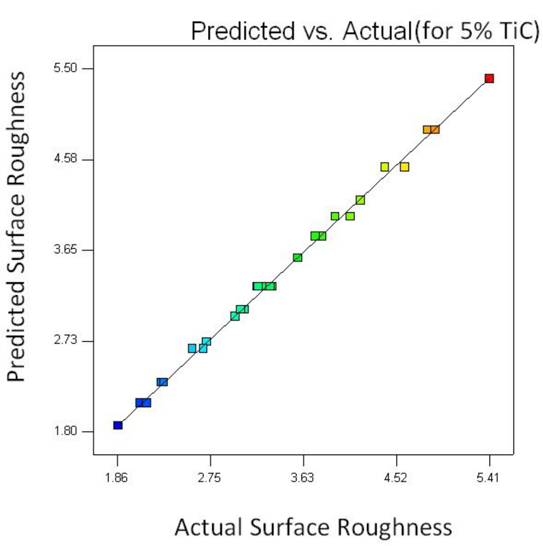
$$- 0.52589 * f * d + 4.49877 \text{ X } 10^{-5} * V^2 + 32.79661 * f^2 - 0.089565 * d^2 \qquad \text{(eqn. 2)}$$

For 10% TiC Surface Roughness (R_a),

$$Ra2 = -3.90260 + 0.023797 * V + 48.66301 * f + 1.56682 * d - 0.069342 * V * f - 3.05732 \text{ X } 10^{-3} * V * d$$

$$-0.53398 * f * d - 1.03831 \text{X } 10^{-4} * V^2 - 41.51243 * f^2 - 0.21006 * d^2 \qquad \text{(eqn. 3)}$$

It is important to check the adequacy of fitness of model in order to avoid misleading conclusions. This is done by Analysis of Variance in Table 4 & 5 and the model fitness graphs are shown below.



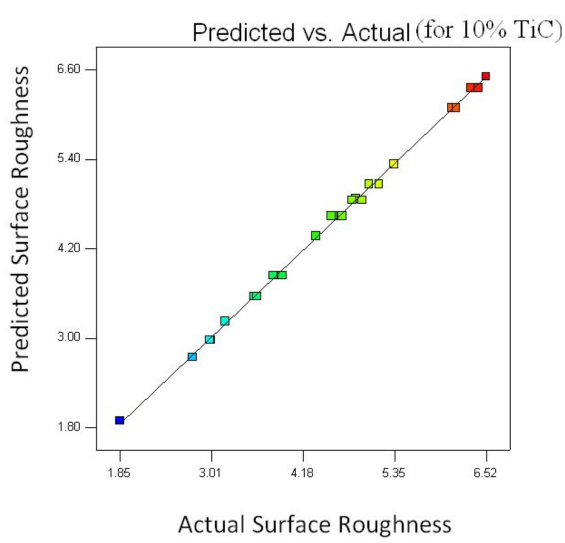
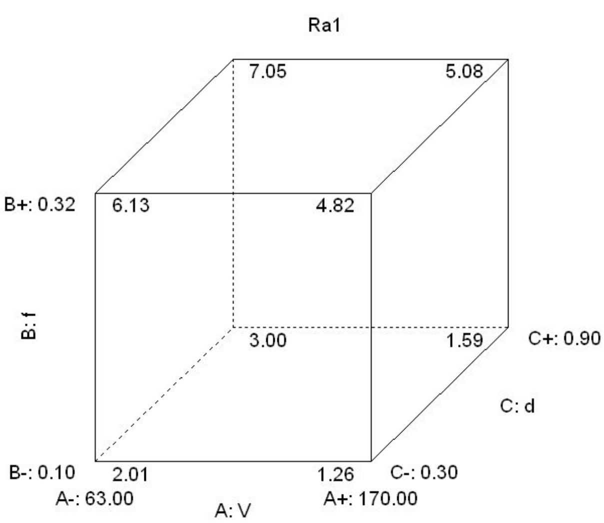


Figure 1. Predicted Vs Actual Ra for 5% TiC Figure 2. Predicted Vs Actual Ra for 10% TiC

The Figure 1 & 2 shows Surface Roughness that the surface roughness values obtained in this work compared with predicted value calculated from the model. As all the points on the plot are appears to be closer to form a straight line, which shows that the regression model is reasonably well fitted with the observed values.

INTERACTION PLOTS

The interaction plots of the surface roughness (R_a) for 5% TiC and 10% TiC are shown as cubes in below figure.



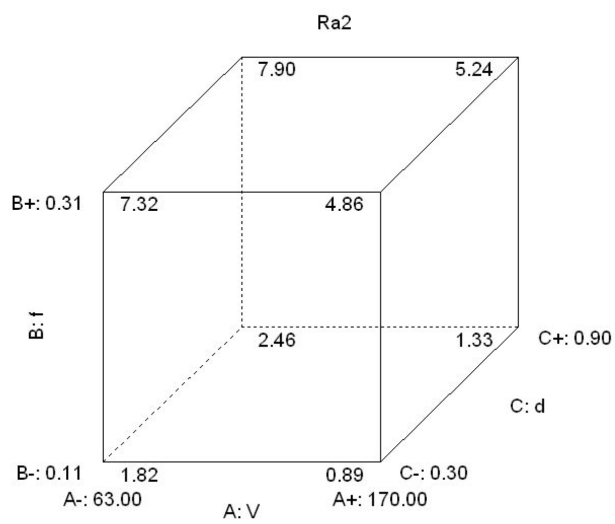


Figure 3 Effects of Speed, feed, depth of cut for R_a for 5% TiC

Figure 4.Effects of Speed, feed, depth of cut for R_a for 10% TiC

From Figure 3 & 4 the following inferences were found:

a. when the feed rate remain constant, the surface roughness increases with increase in depth of cut and for any instant of cutting speed and decreases with increase in Cutting speed.

b. When the cutting speed remains constant, the surface roughness increases with the increase in feed rate for any instant of depth of cut.

c. When the depth of cut remains constant the surface roughness tends to increase with increase in feed rate at high cutting speeds.

6. CONCLUSION

This paper presents the findings of an experimental investigation into the effect of Cutting speed, feed, and depth of cut on the surface roughness when turning Al with 5% TiC and Al with 10% TiC with PCD insert. The following conclusions were revealed.

i. From table 3 most of the observations shows that surface roughness of 5% TiC is lesser than 10% TiC.

ii. The Surface roughness is highly influenced by feed rate.

iii. Figure 3,4 shows that for 5% TiC with low feed and low depth of cut at instant of cutting speed better surface finish can be achieved.

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