# EFFECT OF MACHINING PARAMETERS ON SURFACE ROUGHNESS FOR 6063 AL-TIC (5 & 10 %) METAL MATRIX COMPOSITE USING RSM

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## Abstract

*Metal matrix Composites are new class of material which offers superior Properties over alloys. Problem associated with MMCs is that they are very difficult to machine and quality of machining specially surface finish due to the hardness and abrasive nature of Carbide particles. Characteristics of machined surfaces are known to influence the product performance significantly since they are directly linked to the ability of the material to withstand stresses, temperature, friction and corrosion. This paper presents an experimental work on the analysis of machined surface quality on 6063 Al/TiC metal matrix composites with PCD insert in hard turning leading to Response surface methodology based model to predict the surface roughness.*

***Index Terms:*** *Metal matrix composite, Surface Roughness, Response surface methodology.*

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## 1. INTRODUCTION

Increasing quantities of metal matrix composites (MMCs) are being used to replace conventional materials in many applications, especially in the automobile and recreational industries. The most popular types of MMCs are aluminum alloys reinforcing with ceramic particles. These low cost composites provide higher strength, stiffness and fatigue resistance with a minimal increase in density over the base alloy [1]. Al–TiC belongs to the new generation of particulate reinforced aluminium alloy based metal-matrix composites (MMCs). Particle reinforced metal-matrix composites are likely to find high commercial application due to their low cost, ease of fabrication and improved properties. The practical applications of Al–TiC metal-matrix composites are in aerospace, automobile and structural industries [2]. A continuing problem with MMCs is that they are difficult to machine, due to the hardness and abrasive nature of the TiC or other reinforcing particles. The particles used in MMCs are harder than tungsten carbide (WC), the main constituent of hard metal and even than most of the cutting tool materials. Diamond is exception, for instance, which is approximately three to four times harder than hard metal [3]. That's why PCD tool was used as wear resistive tool in order to achieve desire surface finish.

Caroline J.E. Andrewes, Hsi-Yung Feng, W.M. Lau et al. [4] were carried out to machine a DuralcanAL/SiC composite using Kennametal's PCD and CVD diamond inserts. The present results indicate that crater wear may not be a main concern to the diamond inserts due to the very low coefficient of friction and the high thermal conductivity of diamonds. YanmingQuan, Bangyan Ye et al. [5] investigated the hardness and residual stress of composites in the surface layer affected by machining. The results indicate that the work hardening and residual stress of composites in the machined surface layer have some peculiarities. Mariam S. El-Gallab, Mateusz P. Skladet al. [6] developed 3D thermo-mechanical finite element model of the machined composite workpiece. The model is used to predict the effect of the different cutting parameters on the workpiece subsurface damage produced due to machining. The modelpredicts high localized stresses in the matrix material around the SiC reinforcement particles, leading to matrix cracking. ShibenduShekhar Roy et al. [7] design an expert system using two soft computing tools, namely fuzzy logic and genetic algorithm, so that the surface finish in ultra-precision diamond turning of metal matrix composite can be modeled for set of given cutting parameters, namely spindle speed, feed rate and depth of cut.

Ultra-precision turning tests on SiCp/2024Al and SiCp/ZL101A composites were carried out to investigate the surface quality using single point diamond tools (SPDT) and polycrystalline diamond (PCD) cutters. Examined by SEM and AFM, the machined surfaces took on many defects such as pits, voids, micro cracks, grooves, protuberances, matrix tearing and so on. It was found that cutting parameters, tool material and geometries, particle reinforcement' size and distribution, reinforcement' volume fraction and cooling conditions all had a significant effect on the surface integrity when ultra-precision turning [8]. N. Muthukrishnan, M. Murugan& K. PrahladaRao et al. [9] presents the results of an experimental investigation on the machinability of fabricated aluminum metal matrix composite (A356/SiC/10p) during continuous turning of composite rods using medium grade polycrystalline diamond (PCD 1500) inserts. MMC's are very difficult to machine and PCD tools are considered by far, the best choice for the machining of these materials. A. Pramanik, L. C. Zhang, J. A. Arsecularatne et al. [10] investigated experimentally the effects of reinforcement particles on the machining of MMCs. The major findings are: (a) the surface residual stresses on the machined MMC are compressive; (b) the surface roughness is controlled by feed; (c) particle pull-out influences the roughness when feed is low; (d) particles facilitate chip breaking and affect the generation of residual stresses; and (e) the shear and friction angles depend significantly on feed but are almost independent of speed. Rajesh Kumar Bhushan&Sudhir Kumar & S. Das et al. [11] investigated the influence of cutting speed, depth of cut, and feed rate on surface roughness during machining of 7075 Al alloy and 10 wt.% SiC particulate metal-matrix composites. The experiments were conducted on a CNC Turning Machine using tungsten carbide and polycrystalline diamond (PCD) inserts. Surface roughness of 7075Al alloy with 10 wt.%SiC composite during machining by tungsten carbide tool was found to be lower than PCD.

Not much work to be done in the area of machinability of composite materials particularly Al–TiC. MMCs in general are difficult to machine (turning, milling, drilling, threading and shaping) due to their hardness and abrasive nature of reinforced particles. The objective of the present work is, therefore, to evaluate the machining behaviour of these composites (Al–TiC).

## 2. EXPERIMENTAL DETAILS

### 2.1 Workpiece and cutting tool

**Table 1** physical and Mechanical properties of 6063Al-TiC

| Properties | Material | |
|---|---|---|
| | **Al alloy 5 % TiC** | **Al alloy 10 % TiC** |
| Density (Kg/m3) | 2632 | 2734 |
| Hardness (BHN) | 95 | 113 |
| Modulas Elasticity (Gpa) | 77 | 82 |
| Tensile Strength yield strength (Mpa) | 103 | 127 |
| Tensile Strength Ultm strength (Mpa) | 140 | 152 |
| % Elongation | 3 | 1 |

The work material selected for the study was 6063 Al alloy 5 % TiC MMC and 6063 Al alloy 10% TiC MMC of cylinder bars (36 mm Diameter and 200 mm length). Table 1 show the physical and mechanical properties of 6063 Al alloy TiC. The chemical composition of this material kept confidential.

The cutting tool selected for machining of Al-TiC Metal matrix composites was polycrystalline diamond insert of fine grade (2000), because it had been found that PCD tool is best choice for machining of MMCs due to its high wear resistance. The cutting tool used had PCD insert: ISO coding DCMW 11T304. The Characteristics of insert are as follows: Average particles Size - 10μm, Volume fraction of Diamond – 89 to 93 %, Transverse Rapture strength - 2.20 GPa, Knoop hardness at 3 Kg load - 8378.5 kg/mm$^2$.

### 2.2 Experimental procedure

The cutting inserts were clamped on a right-hand tool holder with ISO designation PCLNR 25×25 M12. The clamping of the insert on the tool holder resulted in -6$^0$ rake angle, -6$^0$ clearance angle, and 93$^0$ approach angle. The turning tests on the workpiece were conducted under dry conditions on an Engine lathe having spindle power of 2 Kw.

The surface roughness of the machined samples was measured with a surface roughness analyzer (Mitutoyo, surftest set no: 178-923e) with a cut-off length of 0.8mm over three sampling lengths. The average value of surface roughness (Ra) was used to quantify the roughness achieved on machined surfaces.

### 2.3 Design of experiments

In order to investigate the influence of machining conditions on surface roughness - cutting speed, feed rate and depth of cut were selected as the input parameters. The RSM was employed to quantify the relationship between the individual response factors and the input machining parameters of the following form:

Y= f (A, B, C)

Where Y is the desired response and F is the response function or response surface.

RSM is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which the response of interest is influenced by several variables and objective is to optimize this response [12]. In order to design the experimental plan, full factorial method was chosen to determine the relationship between four operating variables namely cutting speed, feed rate and depth of cut. In order to study the effects of the EDM parameters on the above mentioned machining criteria, second order polynomial response surface mathematical models can be developed. In the general case, the response surface is described by an equation of the form:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^{\,2} + \sum_{i<j=2}^{2} \beta_{ij} x_i x_j + \varepsilon_r$$

Where $Y$ is the corresponding response, $x_i$ is the input variables, $x_i^2 i$ and $x_i x_j$ are the squares and interaction terms, respectively, of these input variables. The unknown regression coefficients are $\beta_0, \beta_{i,} \beta ij$ and $\beta_{ii}$.

**Table 2:** Process parameters and their levels

| Factors | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Cutting Speed (m/min) | 170 | 103 | 63 |
| Feed Rate (mm/rev) | 0.107 | 0.215 | 0.313 |
| Depth of cut (mm) | 0.3 | 0.6 | 0.9 |

## 3. RESULTS AND DISCUSSION

In order to design the experimental plan, full factorial design in design of Experiment with three levels and three factors was used. According to this 33 Design, total 27 No of experimental run was Conducted as shown in table 3.

**Table 3**: Experimental Plan with Results of Surface Roughness for 6063 Al alloy 5 % and 10 %

| Exp. run | Process Parameters | | | 5 % TiC | 10 % TiC |
|---|---|---|---|---|---|
| | Cutting Speed | Feed Rate | Depth of cut | Surface Roughness, Ra | |
| | m/min | mm/rev | mm | µm | µm |
| 1 | 170 | 0.107 | 0.9 | 1.556 | 1.628 |
| 2 | 170 | 0.215 | 0.9 | 3.102 | 3.421 |
| 3 | 170 | 0.313 | 0.9 | 5.014 | 5.213 |
| 4 | 170 | 0.107 | 0.6 | 1.356 | 1.582 |
| 5 | 170 | 0.215 | 0.6 | 2.918 | 3.196 |
| 6 | 170 | 0.313 | 0.6 | 4.818 | 5.134 |
| 7 | 170 | 0.107 | 0.3 | 1.098 | 1.168 |
| 8 | 170 | 0.215 | 0.3 | 2.645 | 3.201 |
| 9 | 170 | 0.313 | 0.3 | 4.627 | 5.162 |
| 10 | 103 | 0.107 | 0.9 | 2.456 | 1.943 |
| 11 | 103 | 0.215 | 0.9 | 3.842 | 5.628 |
| 12 | 103 | 0.313 | 0.9 | 5.703 | 7.316 |
| 13 | 103 | 0.107 | 0.6 | 2.110 | 1.617 |
| 14 | 103 | 0.215 | 0.6 | 3.713 | 5.219 |
| 15 | 103 | 0.313 | 0.6 | 5.543 | 7.137 |
| 16 | 103 | 0.107 | 0.3 | 1.846 | 1.537 |
| 17 | 103 | 0.215 | 0.3 | 3.281 | 4.618 |
| 18 | 103 | 0.313 | 0.3 | 5.172 | 6.943 |
| 19 | 63 | 0.107 | 0.9 | 2.843 | 2.617 |
| 20 | 63 | 0.215 | 0.9 | 4.431 | 5.813 |
| 21 | 63 | 0.313 | 0.9 | 6.826 | 7.631 |
| 22 | 63 | 0.107 | 0.6 | 2.546 | 2.273 |
| 23 | 63 | 0.215 | 0.6 | 4.343 | 5.774 |
| 24 | 63 | 0.313 | 0.6 | 6.512 | 7.218 |
| 25 | 63 | 0.107 | 0.3 | 1.914 | 1.905 |
| 26 | 63 | 0.215 | 0.3 | 3.214 | 5.267 |
| 27 | 63 | 0.313 | 0.3 | 6.327 | 6.751 |

The unknown coefficients are determined from the experimental data as presented in Table-3. The standard errors on estimation of the coefficients are tabulated in the column SE coef.

**Table 4:** Estimated Regression Coefficients for Surface Roughness (5 % TiC)

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 0.8995 | 0.72489 | 1.241 | 0.232 |
| Cutting Speed (A) | -0.0116 | 0.00820 | -1.409 | 0.177 |
| Feed Rate (B) | 6.1732 | 3.74735 | 1.647 | 0.118 |
| Depth of cut (C) | 3.4548 | 1.27204 | 2.716 | 0.015 |
| A×A | 0.0000 | 0.00003 | 1.138 | 0.271 |
| B×B | 36.124 | 7.94923 | 4.544 | 0.000 |
| C×C | -1.1241 | 0.93446 | -1.203 | 0.245 |
| A×B | -0.0244 | 0.01067 | -2.287 | 0.035 |
| A×C | -0.0066 | 0.00367 | -1.799 | 0.090 |
| B×C | -1.5169 | 1.92380 | -0.788 | 0.441 |
| R-Sq = 98.99% R-Sq(pred) = 97.38% R-Sq(adj) = 98.45% | | | | |

$$Ra = 0.8995 - 0.0116 \times A + 6.1732 \times B + 3.4548 \times C + 36.124 \times B \times B - 1.1241 \times C \times C - 0.0244 \times A \times B - 0.0066 \times A \times C - 1.5169 \times B \times C$$

**Table 5:** Estimated Regression Coefficients for Surface Roughness (10 % TiC)

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | -4.0706 | 1.2372 | -3.290 | 0.004 |
| Cutting Speed (A) | 0.0262 | 0.0140 | 1.874 | 0.078 |
| Feed rate (B) | 46.8025 | 6.3955 | 7.318 | 0.000 |
| Depth of cut (C) | 2.2464 | 2.1710 | 1.035 | 0.315 |
| A×A | -0.0001 | 0.0001 | -1.930 | 0.070 |
| B×B | -39.098 | 13.5668 | -2.882 | 0.010 |
| C×C | -0.3321 | 1.5948 | -0.208 | 0.838 |
| A×B | -0.0641 | 0.0182 | -3.516 | 0.003 |
| A×C | -0.0075 | 0.0063 | -1.192 | 0.250 |
| B×C | -0.7091 | 3.2833 | -0.216 | 0.832 |
| R-Sq = 98.26% R-Sq(pred) = 95.69% R-Sq(adj) = 97.34% | | | | |

$$Ra = -4.0706 + 0.0262 \times A + 46.8025 \times B + 2.2464 \times C - 0.0001 \times A \times A - 39.0986 \times B \times B - 0.3321 \times C \times C - 0.0641 \times A \times B - 0.0075 A \times C - 0.7091 \times B \times C$$

It is important to check the adequacy of the fitted model, because an incorrect or under-specified model can lead to misleading conclusions. By checking the fit of the model one can check whether the model is under specified. The model adequacy checking includes the test for significance of the regression model, model coefficients, and lack of fit, which is carried out subsequently using ANOVA on the curtailed model (Table-6, 7).

**Table 6: Analysis of Variance for Surface Roughness (5 % TiC)**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 9 | 70.361 | 70.361 | 7.817 | 184.2 | 0.000 |
| Linear | 3 | 68.983 | 0.5271 | 0.175 | 4.14 | 0.022 |
| Square | 3 | 0.9928 | 0.9927 | 0.330 | 7.80 | 0.002 |
| Interaction | 3 | 0.3857 | 0.3857 | 0.128 | 3.03 | 0.058 |
| Residual Error | 17 | 0.7215 | 0.7214 | 0.042 | | |
| Total | 26 | 71.083 | | | | |

**Table 7: Analysis of Variance for Surface Roughness (10 % TiC)**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 9 | 118.60 | 118.60 | 13.177 | 106.6 | 0.00 |
| Linear | 3 | 115.39 | 6.8144 | 2.2714 | 18.38 | 0.00 |
| Square | 3 | 1.493 | 1.4926 | 0.4975 | 4.02 | 0.02 |
| Interaction | 3 | 1.710 | 1.7097 | 0.5699 | 4.61 | 0.01 |
| Residual Error | 17 | 2.101 | 2.1014 | 0.1236 | | |
| Total | 26 | 120.70 | | | | |

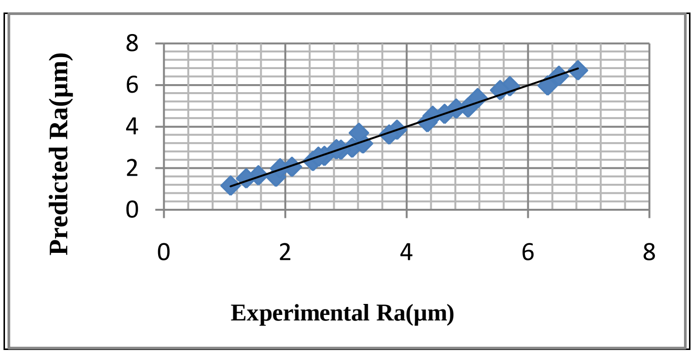


**Fig- 1a:**Predicted vs. experimental SR for 5% TiC

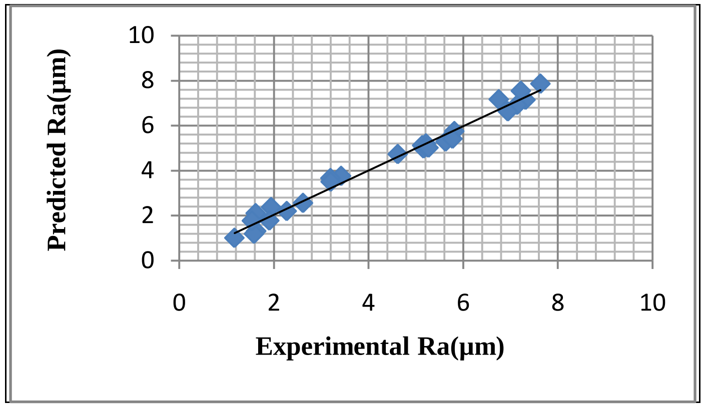


**Fig- 1b:** Predicted vs. experimental SR for 10% TiC

SR obtained from the experiment is compared with the predicted value calculated from the model in Fig. 1. Since all the points on plot come close to form a straight line, it implies that the data are normal. It can be seen that the regression model is reasonably well fitted with the observed values.

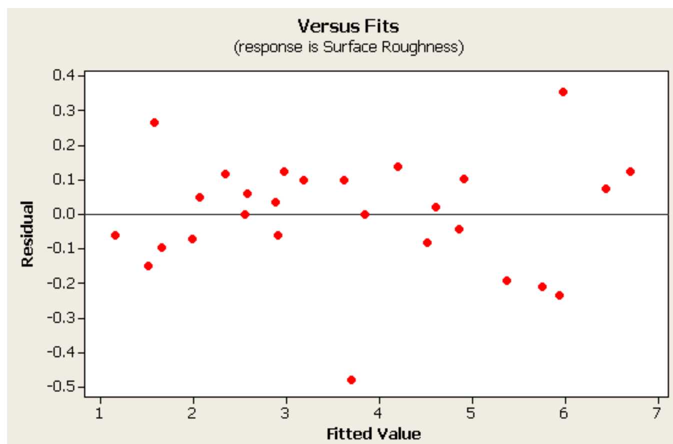


**Fig- 2a:** Plot of residuals vs. fitted value for 5% TiC

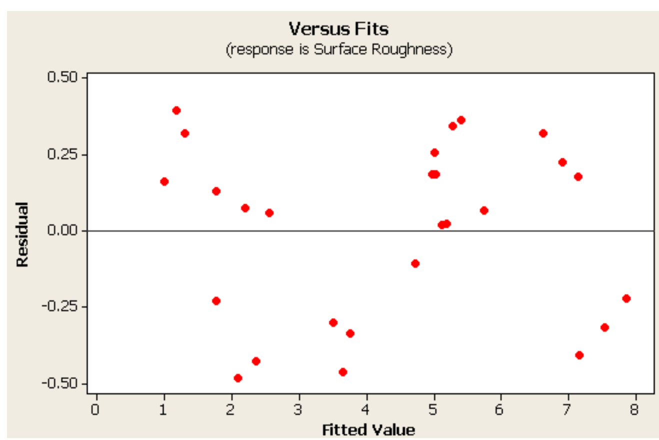


**Fig- 2b:** Plot of residuals vs. fitted value for 10% TiC

In addition, the plot of the residues verse predicted SR illustrates that there is no noticeable pattern or unusual structure present in the data as depicted in Fig 2.

Since hard turning is sought to be used as a replacement of grinding, the major focus of research is to find cutting conditions for which desired surface roughness can be achieved. Hence, the contour plots of the surface roughness in feed rate, depth of cut and cutting speed for 5% and 10 % are shown in Figs 3-5 and Fig. 6-8 respectively.

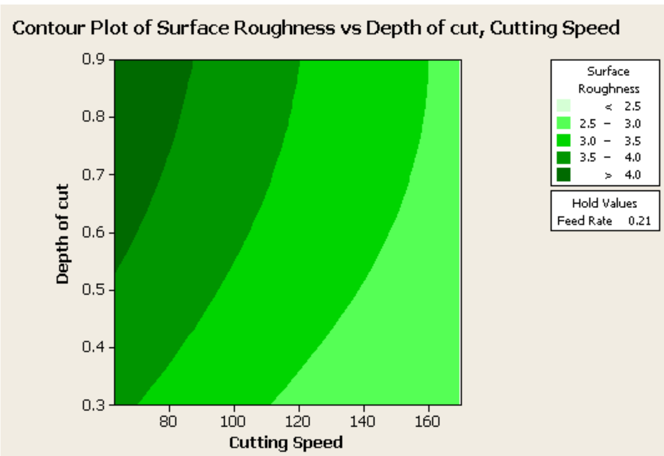


**Fig- 3:**Effect of Depth of Cut & Cutting Speed on SR

Fig. 3 shows the estimated response surface for Surface Roughness in relation to the process parameters of depth of cut and cutting speed while feed rate remain constant at their middle value. It can be seen from the figure, the SR tends to increase significantly with the increase in Depth of cut for any value of Cutting speed. However, the SR tends to decrease with increase in Cutting speed, especially at higher Cutting speed.

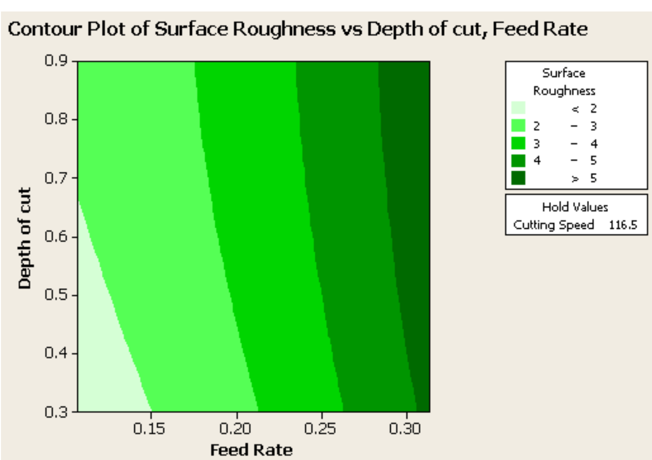


**Fig- 4:** Effect of Depth of Cut & Feed Rate on SR

Fig. 4 shows the estimated response surface for Surface Roughness in relation to the process parameters of depth of cut and feed rate while cutting speed remains constant at their middle value. It can be seen from the figure, the SR tends to increase significantly with the increase in Feed rate for any value of depth of cut.

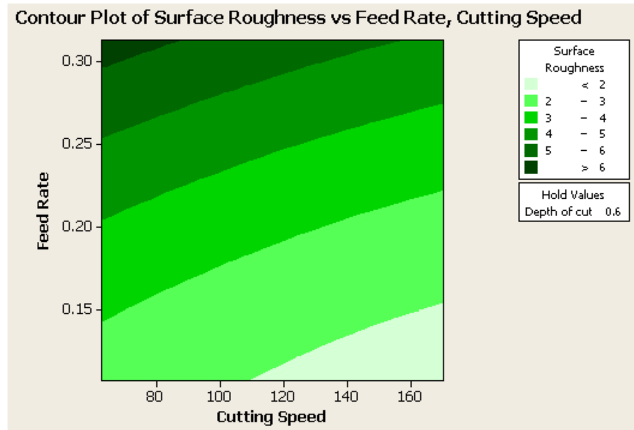


**Fig- 5:**Effect of Feed Rate & Cutting Speed on SR

Fig. 5 shows the best surface roughness is achieved with the combination of lowest feed rate and highest cutting speed, as reported by earlier investigators. The surface roughness does not vary much with feed rate at low cutting speed ranges, but tends to increase almost linearly with increasing feed rate at higher cutting speed.

The effect of workpiece hardness on surface roughness is of statistical importance. It is clearly shown from the results that Surface roughness decreases in 10 % TiC.

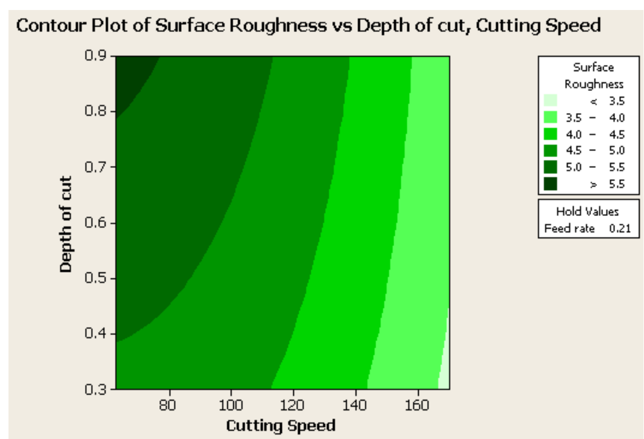


**Fig- 6:**Effect of Depth of Cut & Cutting Speed on SR

Figs. 6–8clearly show that a good surface finish can be achieved for any level of cutting speed, when feed rate is low and depth of cut is low as mentioned in 5% TiC.

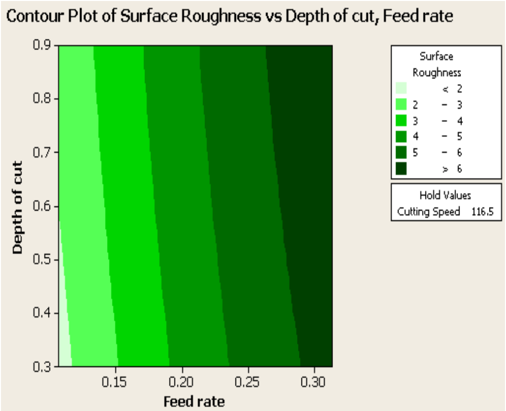


**Fig-7:**Effect of Depth of Cut & Feed Rate on SR

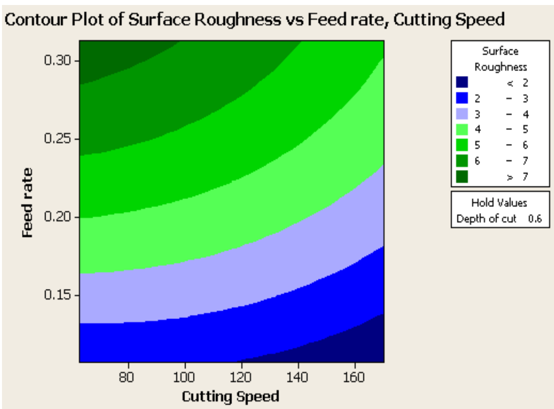


**Fig-8:** Effect of Feed Rate & Cutting Speed on SR

## CONCLUSIONS

In this paper, RSM was applied to develop mathematical models of surface roughness in order to investigate the influence of machining parameters during finish turning of 6063 Al/TiC metal matrix composite with a PCD insert. The experimental study has led to the following conclusions.

- In majority of results, surface finish of workpiece having 5 % TiC is better than workpiece having 10 % TiC.
- Surface roughness model: the feed rate provides primary contribution and influences most significantly on the surface roughness. The interaction between feed rate and depth of cut, quadratic effect of feed rate and interaction effect of speed and depth of cut provide secondary contribution to the model.
- Contour plots can be used for selecting the cutting parameters for providing the given desired surface roughness.
- Feed rate is found the most significant effect on surface roughness. The increase of feed rate increases the surface roughness.

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