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Optimize the effects of cutting parameters on average surface roughness during turning of Al6061 metal matrix composite

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Abstract

Machining parameter play a very important role in estimating the performance of machining operations. It can be achieved by mathematical modeling of performance as a function of machining conditions using design of experiments (DOE). The Design of experiments based on two level factorial design with three numeric factors (cutting speed, feed rate and depth of cut) and one category factor (nose radius) have been used to develop relationships for surface roughness, aerial removal rate and resultant cutting forces.Model adequacy tests were conducted using ANOVA table and the effects of various parameters were investigated and presented in the form of contour plots and 3D surface graphs. Numerical optimization was carried out considering all the input parameters within range so as to minimize the surface roughness, resultant cutting force and maximize material removal rate.

Keywords:*Feed, Speed, Depth of Cut, Nose Radius (Category), DOE, Factorial Design ANOVA*

1. INTRODUCTION

Surface finish is the method of measuring the quality of a Product. This chapter reveals the importance of surface excellence and cutting forces in machining. The surface finish of the machined work piece is greatly influenced by various factors such as cutting tool properties, machining parameters, work piece properties and cutting phenomenon. The proposed work will be employed for investigating the effect of turning parameters on surface roughness in turning of METAL MATRIX COMPOSITE.

Machining is one of the most widespread metals shaping process used in manufacturing industry. Worldwide investment in metal-machining processes continues to increase year after years. The machining is more expensive than other production process, viz. molding, casting, and forming etc., but it is often justified for precision requirement.

Metal cutting is one of the most significant manufacturing processes in material removal. Metal cutting can be defined as the removal of metal from a work piece in the form of chips in order to obtain a finished product with desired size, shape, and surface roughness. There are different methods of metal cutting such as turning, milling etc.

Turning is one of the commonest among these methods. Turning is the process of machining external cylindrical and conical surfaces (Nalbant et al. 2006). In this process the work material will held in the chuck of a lathe and rotated. The tool is held rigidly in a tool post and moved at a constant rate along the axis of the bar, cutting away a layer of metal to form a profile.

The turning process is the most productive process, the study is expected to be quite beneficial. Metal matrix composites (MMCs) have become a large leading material in composite materials. And particle reinforced aluminum MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials, because of the hardness and abrasive nature of reinforcement element like silicon carbide (SiC) particles. Main engineering materials in various industries such as aerospace.

2. LITERATURE REVIEW

To overcome these problems, many studies have been carried out to investigate and formulate the effect of cutting conditions for the optimization of surface roughness in turning using different techniques. The published work of various authors in the referred area is mentioned here.

Reddy et al.,(2005) developed a prediction model based on the investigational effects to achieve surface roughness and machining parameters such as speed, feed, radial rake angle and nose radius and genetic algorithm was used to optimize the machining parameters. The results were ratified by the comparison of machining conditions obtained from experiments.

Pramanik et al., (2006)developed a mathematical model to find the forces during machining of ceramic reinforced Al alloy. They confirmed that the force produced from chip formation was comparatively higher than the force produced during the plowing and particle fracture.

Palanikumar,(2007) developed an RSM model for GFRP composites to evaluate the surface roughness. The model uses the CCD-based four factors five level rotatable design to perform the investigation and for analysis, and the model was verified using ANOVA.

Zhang and Chen,(2008) proposed a condition of monitoring method for the end milling process with the help of the measurement of vibration and micro controlled data acquisition system.

SyungLanT.,(2009)]used Taguchi methodology to investigate the effect of cutting parameters (cutting speed, depth of cut, feed rate and tool nose radius) on MRR during turning. Additionally, nine fuzzy control rules using triangle membership function with respective to five linguistic grades for the MRR is constructed. The results show that proposed fuzzy Taguchi deduction methodology improve MRR .Muthukrishnan and Paulo.

Davim,(2009) developed prediction models for the surface roughness using ANN and DOE. The ANOVA results of DOE showed that the feed rate was essentially substantial with statistical influence on the surface roughness also by the spindle speed and depth of cut and found that the ANN provides better results and the converging time is less.

Bhushan et al.,(2010)experimentally investigated the influence of cutting parameters on surface roughness and wear rate. The cutting speed, depth of cut and feed rate have been considered as cutting parameters. The turning experiments were carried out on 7075 Al alloy and 10 wt.% SiC particulate metal-matrix composites using tungsten carbide and polycrystalline diamond (PCD) inserts. It has been concluded from the results that the surface roughness of Al alloy is less as compared to Al alloy composite at same machining conditions with both inserts. Also wear of carbide and PCD inserts has been found less for Al alloy as compared to Al alloy composite.

Aouici et al., (2011) investigated the influences of feed rate, speed and cutting time in tool wear and surface roughness. During the machining of hardened AISI H11(X38CrMoV5-1) material with CBN tool in the turning process the flank wear was affected by the cutting time and cutting speed and the feed rate was found to be the highly influencing factor in the surface roughness.

S. P. Dwivedi et al.,(2012)fabricated A356 alloy 5 wt% SiC composite by electromagnetic stir casting process. An attempt has been made to investigate the effect of CNC lathe process parameters like cutting speed, depth of cut, and feed rate on surface roughness during machining of A356 alloy 5 wt% SiC particulate metal-matrix composites in dry condition. Response surface methodology (Box Behnken Method) is chosen to design the experiments. The results reveal that cutting speed increases surface roughness decreases, whereas depth of cut and feed increase surface roughness increase. Optimum values of speed (190 m/min), feed (0.14 mm/rev) and depth of cut (0.20 mm) during turning of A356 alloy 5 wt% SiC composites to minimize the surface roughness (3.15>m) have been find out. The mechanical properties of A356 alloy 5 wt% SiC were also analyzed.

Thus objectives and the steps of the present study are:

1. Development of average surface roughness prediction models using design of experiment based on two level factorial design to analyze the effect of turning parameters (cutting speed, feed rate, nose radius and depth of cut) on average surface

roughness parameters during turning of metal matrix composite.

3. EXPERIMENTAL STUDY

In the present work, 2 level full factorial designs is applied to investigation of turning references on SR, and analysis the cutting force while we are performing the turning operation of Al6061 MMC.

3.1 Experimental details

The experimental details include the detail of test specimen, spectral analysis of MMC, cutting tool for turning, coolant, the machine tool used for turning (lathe), surf coder for surface roughness measurement and lathe tool dynamometer for measuring resultant cutting force.

3.1.1 Test specimens

For machining the cylindrical parts, turning operation method is a common method which is applied globally. In my practical work specimens is round bar of dimensions $\emptyset 31 \times 100\ mm, \emptyset 46.6 \times 100\ mm, \emptyset 62 \times 100\ mm$ have been used for the experiment. We have been selected three different dimension work piece to take the three level cutting speeds. **3.1.2 Machine used for turning**

All geared lathe machine is very important machine in manufacturing industries which can perform various operation with high productivity as well as product quality.

For carrying out research work in which we need to do turning operation of Al 6061 composite we have used **BANKA 34, RAJKOT** lathe. The spindle speed of lathe is up to 1025 rpm with 2 HP motor drive.

3.1.3 Measurement of surface roughness

One of the important constraints in product quality is surface roughness. In this experimental research work, a surface roughness tester (Model No TR 210) has been used which is used to measure surface roughness indicators of processed work pieces.

3.2 Design of Experiments

D.O.E stands for design of experiment through which we determined the number of experiment required .it is mainly depends on the approach which is adopted for the DOE. So finally, it is important to have a well-designed experiment so that we can minimize number of experiments required.

In this work, the design is suggested by 2 level full factorial design which is applied for analyzing the effect of four independent parameters for turning i.e. cutting speed, feed rate ,depth of cut and nose radius on surface roughness ,resultant cutting force and material removal rate.

TABLE 3.1 PROCESS PARAMETERS WITH THEIR LEVELS IN TURNING OF METAL MATRIX COMPOSITE

Factors	Symbol	Units	Levels		
			-1	0	+1
Cutting Speed	A	m/min	100	175	250
Feed rate	B	mm/rev	0.10	0.25	0.40
Depth of cut	C	Mm	0.10	0.25	0.40
Nose radius*	D	Mm	0.4		0.8

***Category factor**

The process parameters and their different levels are shown in Table 3.1. The layout for complete design for experiments with experimental results is summarized in Table 3.2.
Total twenty four experiments constitute 2^3 factorial point and four center point.

TABLE 3.2 EXPERIMENTAL DESIGN LAYOUT FOR THE TURNING OF MATERIAL MATRIX COMPOSITE

Std	Run	A Cutting Speed	B Feed	C Depth of Cut	D Nose Radius	Surface roughness (microns)
		m/min	mm / rev	mm	Mm	micron
1	21	100	0.1	0.2	0.8	1.383
2	13	200	0.1	0.2	0.8	0.589
3	17	100	0.3	0.2	0.8	3.303
4	18	200	0.3	0.2	0.8	2.853
5	15	100	0.1	0.6	0.8	1.722
6	14	200	0.1	0.6	0.8	1.19
7	23	100	0.3	0.6	0.8	3.612
8	20	200	0.3	0.6	0.8	3.227
9	4	100	0.1	0.2	0.4	1.46
10	1	200	0.1	0.2	0.4	0.721
11	5	100	0.3	0.2	0.4	3.371
12	11	200	0.3	0.2	0.4	3.045
13	12	100	0.1	0.6	0.4	1.879
14	10	200	0.1	0.6	0.4	1.512
15	9	100	0.3	0.6	0.4	3.771
16	7	200	0.3	0.6	0.4	3.551
17	19	150	0.2	0.4	0.8	2.13
18	8	150	0.2	0.4	0.4	2.36
19	22	150	0.2	0.4	0.8	2.24
20	6	150	0.2	0.4	0.4	2.36
21	24	150	0.2	0.4	0.8	2.12
22	3	150	0.2	0.4	0.4	2.38
23	16	150	0.2	0.4	0.8	2.16
24	2	150	0.2	0.4	0.4	2.36

4.1 DEVELOPMENT OF SURFACE ROUGHNESS PREDICTION MODEL

To check the assumption of normal distribution, the normal probability plot of the residuals for surface roughness is shown in fig.4.1. it is showing that the residuals generally fall on a straight line disclosed that the errors are normally distributed.

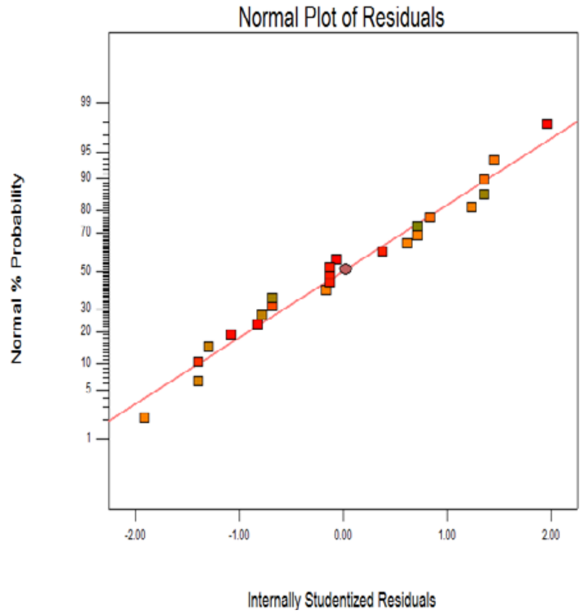

Fig. 4.1 Normal probability plot of residuals for surface roughness

The fig.4.2 shows the plot between residuals and the predicted surface roughness which describe about the assumption of constant variance. As according to plot, all the scatters are random and unusual structure. There is no pattern exists so no reason to suspect any order of the independence.

The fig.4.3 shows the plot between actual surface roughness and the predicted surface roughness which helps to find a value, or cluster of values, which is not easily foreseen by the model. The statistics should split evenly by the 45-degree line. It is shown in figure reveals all the statistics split evenly by the 45-degree line.

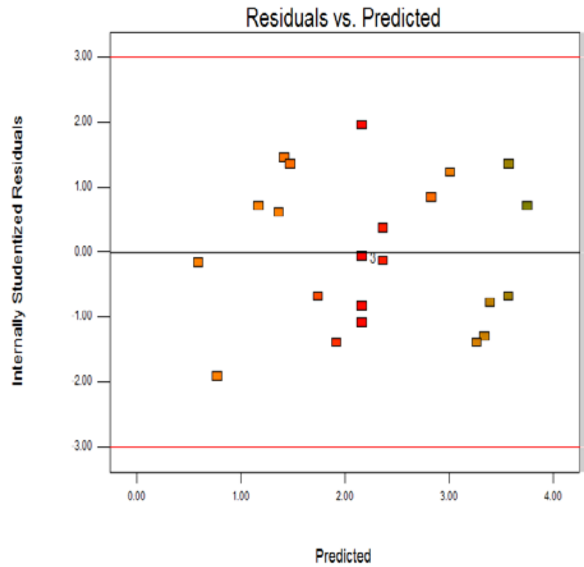

Fig. 4.2 Plot of residuals v/s predicted surface roughness

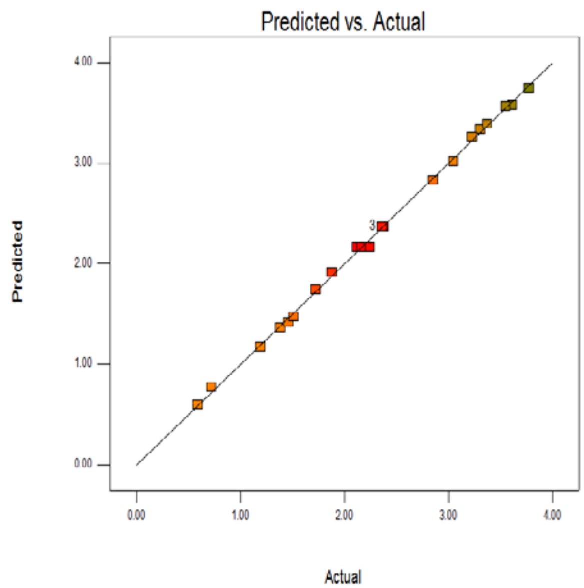

Fig. 4.3 Plot of predicted v/s actual surface roughness

For surface roughness prediction model the analysis of variance (ANOVA) has been carried out for a level of $\alpha=0.05$ which is significant level for a 95% confidence level, is shown in table 4.1.

TABLE 4.1 RESULTING ANOVA TABLE FOR SURFACE ROUGHNESS

Source	Sum of Squares	Degree of freedom	Mean Square	F-Value	p-value Prob> F
Model	18.7111	9	2.079	643.567	< 0.0001
A-Cutting Speed	0.9087	1	0.909	281.288	< 0.0001
B-Feed	16.5588	1	16.559	5125.854	< 0.0001
C-Depth of Cut	0.8738	1	0.874	270.476	< 0.0001
D-Nose Radius	0.2093	1	0.209	64.775	< 0.0001
AB	0.0690	1	0.069	21.371	0.0004
AC	0.0405	1	0.041	12.537	0.0033
AD	0.0162	1	0.016	5.012	0.0419
BC	0.0197	1	0.020	6.089	0.0271
CD	0.0152	1	0.015	4.702	0.0478
Residual	0.0452	14	0.003		
Lack of Fit	0.0361	8	0.005	2.947	0.1024
Pure Error	0.0092	6	0.00153		
Cor Total	18.7563	23			
Std. Dev.	0.05kn68		R-Squared		0.998
Mean	2.3041		Adj R-Squared		0.996
C.V. %	2.4668		Pred R-Squared		0.992
PRESS	0.1567		Adeq Precision		86.278

ANOVA Table indicates that the value of "Prob. > *F*" for predicted model is 0.0001 which is lower than 0.05, this point out that the model is significant, which is wanting as it shows that the terms in the model have a substantial effect on the surface roughness.

The regression model for surface roughness in terms of coded factors is given below:

$$(\boldsymbol{Surfaceroughness}) = \mathbf{2.3} - \mathbf{0.24} * \boldsymbol{A} + \mathbf{1.021} * \boldsymbol{B} + \mathbf{0.23} * \boldsymbol{C} - \mathbf{0.93}\ \boldsymbol{D} + \mathbf{0.066} * \boldsymbol{A} * \boldsymbol{B} + \mathbf{0.05} * \boldsymbol{A} * \boldsymbol{C} - \mathbf{0.032} * \boldsymbol{A} * \boldsymbol{D} - \mathbf{0.035} * \boldsymbol{B} * \boldsymbol{C} - \mathbf{0.031} * \boldsymbol{C} * \boldsymbol{D} \quad (4.1)$$

While, the equations 4.2 and 4.3 shows the surface roughness prediction models in form of actual factors at nose radius 0.4mm and 0.8 mm.

$$(Surfaceroughness) = 1.009 - 0.0087 * Cutting\ speed + 8.9 * Feed + 0.92 * Depth\ of\ cut + 0.013 * Cutting\ speed * Feed + 0.005 * Cutting\ speed * Depth\ of\ cut - 1.75 * Feed * Depth\ of\ cut \tag{4.2}$$

$$(Surfaceroughness) = 1.13 - 0.01 * Cutting\ speed + 8.9 * Feed + 0.61 * Depth\ of\ cut + 0.013 * Cutting\ speed * Feed + 0.005 * Cutting\ speed * Depth\ of\ cut - 1.75 * Feed * Depth\ of\ cut \tag{4.3}$$

4.2 CONTRIBUTION OF TURNING PARAMETERS ON SURFACE ROUGHNESS

The fig. 4.4, shows the half normal plot, the extreme right side factor has the highest effect on the response, however as the dots corresponding to the particular factor comes nearer and nearer to the line, it shows these value affects the least.

The value at the right extreme has the strongest effect on the surface roughness and keeps on decreasing as it comes nearer and nearer to the line.

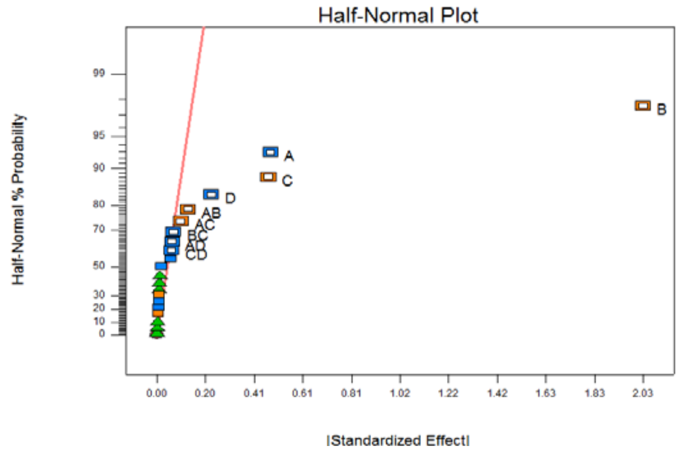

Fig.4.4: A half normal plot shows the effectiveness of the factors

5.1 EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS

Influence of cutting speed on surface roughness at feed rate (0.2 mm/rev), depth of cut (0.4 mm) nose radius (0.4 mm) and at feed rate (0.2 mm/rev), depth of cut (0.4 mm) nose radius (0.8 mm) is shown in fig. 5.1 and fig. 5.2 respectively. The result from the both figures shows that the surface roughness continuously decrease as the cutting speed increases from 100 m/min to 200 m/min because as the cutting speed increases, temperature during cutting also increases, which soften the material to enhance the cutting performance leading to reduced surface roughness.

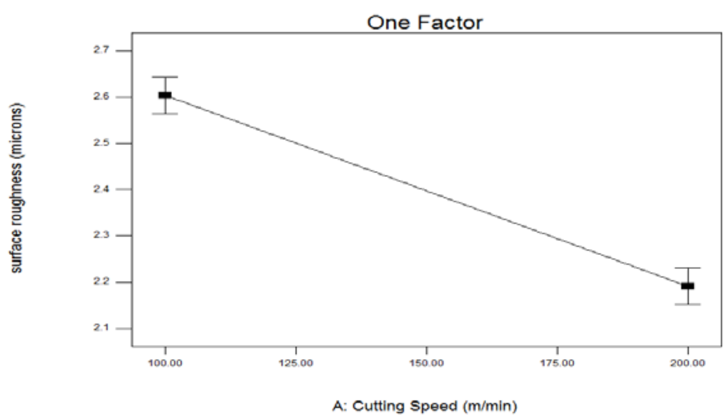

Fig. 5.1 Plot between roughness and cutting speed at feed (0.2 mm/rev) depth of cut (0.4 mm)and nose radius (0.4 mm)

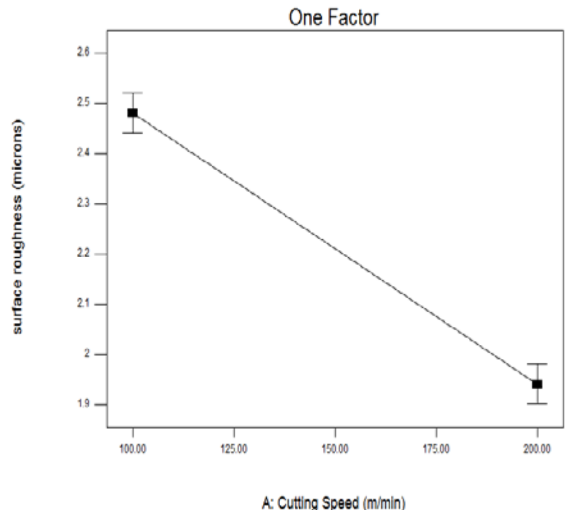

Fig. 5.2 Plot between roughness and cutting speed at feed (0.2 mm/rev) depth of cut (0.4 mm) and nose radius (0.8 mm)

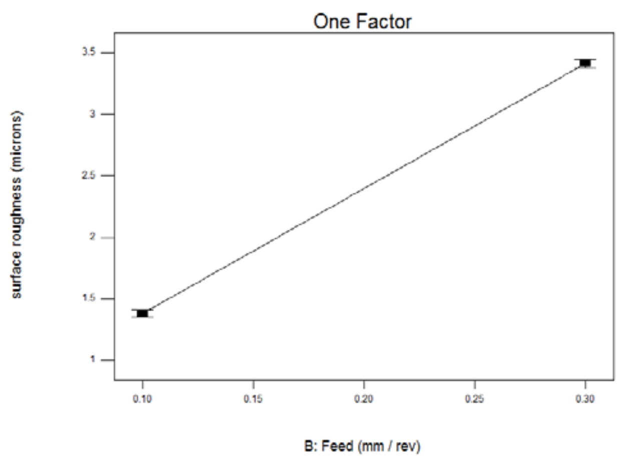

Fig. 5.3 Plot between roughness and feed at cutting speed (150 m/min), depth of cut (0.4 mm) and nose radius (0.4 mm)

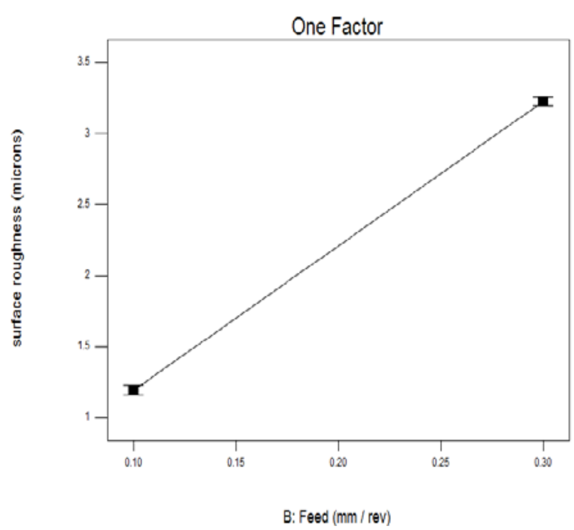

Fig. 5.4 Plot between roughness and feed at cutting speed (150 m/min), depth of cut (0.4 mm) and nose radius (0.8 mm)

The figure 5.3 and 5.4 shows the effect of feed on surface roughness at constant cutting speed (150 m/min), constant depth of cut (0.4 mm), nose radius (0.4 mm) and constant cutting speed (150 m/min), constant depth of cut (0.4 mm), nose radius (0.8 mm) respectively. From the both plots it is visible that surface roughness continuously increases as the feed increase from 0.1 mm/rev to 0.3 mm/rev. This is due to the fact that at higher feed rate, tool traverses the work piece too fast, resulting in deteriorated surface quality and also high feed increase the chatter, which leads to higher surface roughness.

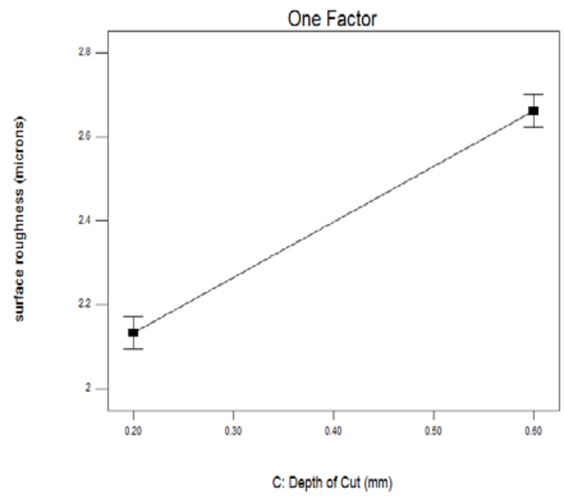

Fig. 5.5 Plot between roughness and depth of cut at cutting speed (150 m/min), feed (0.2 mm/rev) and nose radius (0.4 mm)

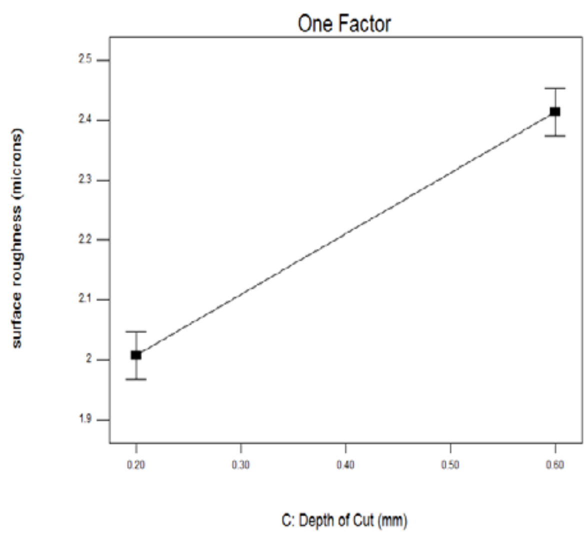

Fig. 5.6 Plot between roughness and depth of cut at cutting speed (150 m/min), feed (0.2 mm/rev) and nose radius (0.8 mm)

The figure 5.5 and 5.6 shows the effect of depth of cut on surface roughness at constant cutting speed (150 m/min), constant feed (0.2 mm), nose radius (0.4 mm) and constant cutting speed (150 m/min), constant feed (0.2 mm), nose radius (0.8 mm) respectively. From the both plots it is visible that surface roughness continuously increases as the depth of cut increase from 0.2 mm to 0.6 mm. This is due to the fact that as the depth of cut increase, the cutting tool vibration also increases, resulting in deteriorated surface quality.
The figure 5.7 shows the effect of nose radius on surface roughness at constant speed 150 m/min, constant feed 0.2 mm/rev. And constant depth of cut 0.4 mm. From the figure it is reveals that surface roughness decreases as the nose radius increases from 0.4mm to 0.8 mm.

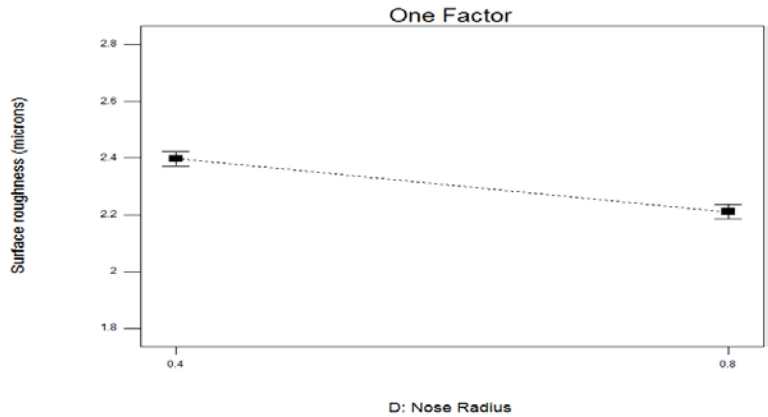

Figure 5.7 Plots between surface roughness and nose radius

The figures 5.8 and 5.9 shows the 3 D plots for surface roughness between speed and feed at nose radius 0.4 mm and 0.8 mm respectively. From the 3D plots it is clear that surface roughness increases with increase in feed while decreases as increase in cutting speed. The minimum surface roughness is achieved at low feed and higher value of cutting speed.

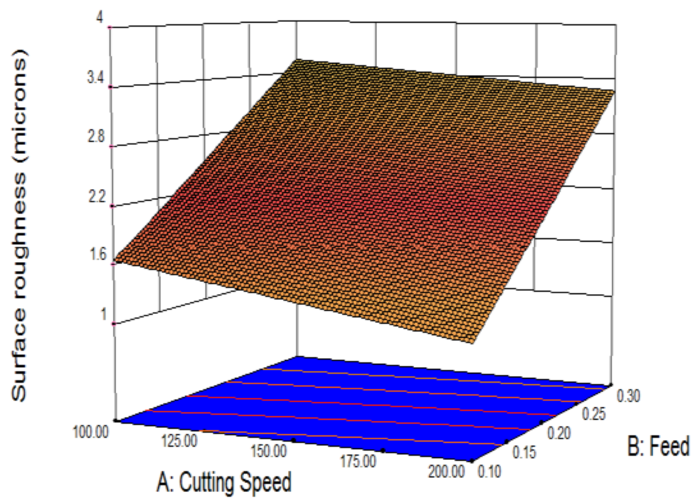

Fig 5.8 3D plot for surface roughness between cutting speed and feed at 0.4 mm nose radius

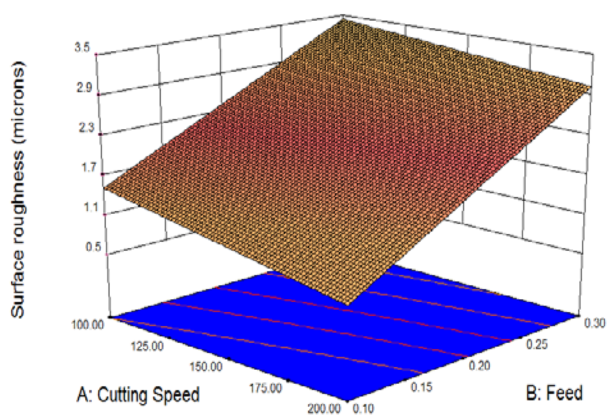

Fig 5.9 3D plot for surface roughness between cutting speed and feed at 0.8 mm nose radius

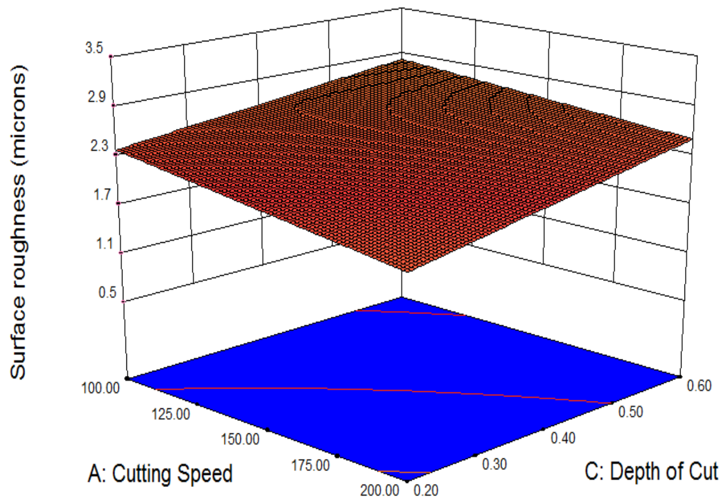

Fig 5.10 3D plot for surface roughness between cutting speed and depth of cut at 0.4 mm nose radius

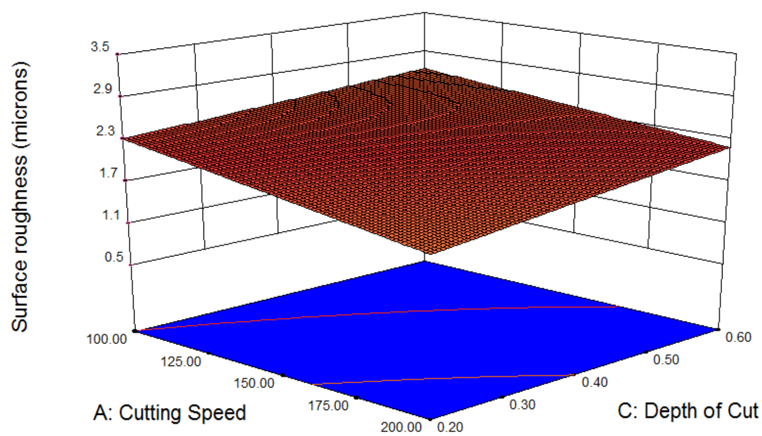

Fig 5.11 3D plot for surface roughness between cutting speed and depth of cut at 0.8 mm nose radius

5.2 OPTIMIZATION OF CUTTING CONDITION

In the present study, the aim is to obtain the optimal values of cutting parameters in order to minimize the value of surface roughness, resultant cutting force and maximize the MRR during the turning process. The constraints used during the optimization process are summarized in table 5.1.The optimal solution for surface roughness, table 5.2.

TABLE 5.1 CONSTRAINTS FOR OPTIMIZATION OF CUTTING CONDITIONS

Name	Goal	Lower limit	Upper limit
A:Cutting Speed	is in range	100	200
B:Feed	is in range	0.1	0.3
C:Depth of Cut	is in range	0.2	0.6
D:Nose Radius	is in range	0.4	0.8
Surface roughness	Minimize	0.589	3.771

TABLE 5.2 OPTIMIZATION RESULTS FOR SURFACE ROUGHNESS

Cutting speed (m/min)	Feed (mm/rev.)	depth of cut (mm)	Nose radius (mm)	Surface roughness	Desirability
200.00	0.10	0.20	0.8	0.569375	1

6. CONCLUSION

The important conclusions drawn from the present work are summarized as follows:

1) The minimum surface roughness 0.569 microns has been obtained at cutting speed 200 m/min, feed 0.1 mm/rev, depth of cut 0.2 mm and nose radius 0.8mm.

2) The optimal level of machining parameters setting for simultaneously multi optimization of surface roughness is cutting speed (200 m/min), feed (0.1 mm/rev), nose radius (0.8 mm) and depth of cut (0.33 mm) and optimum values of surface roughness,

3) The mathematical prediction models between turning parameters and surface roughness has been developed. The predicted results are in good agreement with the measured ones. These relationships are applicable within the ranges of tested parameters.

4) All the four independent parameters (cutting speed, feed, depth of cut and nose radius) seem to be the influential turning parameters that affect the surface roughness.

5) The ANOVA table for surface roughness clearly shows that the feed seems to be the most significant factor that affects the surface roughness.

6) Surface roughness decreases as the increase in cutting speed, increase in nose radius, decrease in feed and decrease in depth of cut.