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Research Article

Machining optimization of composite material by using response surface methodology

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Abstract
In this paper, the main objective is an experimental investigation of the various process (input) parameters and performed on a CNC milling machine because it is much better in comparison with other machines in context of accuracy and surface finish. The focus on the properties of the materials along with the cutting condition of the cutting tool and work piece has been made. Design of experiments has been used to study the effect of the main milling parameters such as cutting speed, feed rate and depth of cut on the surface roughness and material removal rate (MRR) of composite material (Al 6063-SiC). After this we use surface roughness and MRR as a response (output) variable in analysis the mathematical model and response surface methodology (RSM) is used for investigation the effect of parameter on surface roughness and MRR. RSM is also used for optimization of these parameters. The effects of three different parameters on the milling process are shown here, which are called cutting speed, depth of cut and feed rate. For this work we conducted 27 experiments from L27 orthogonal array methodology, we use different variables in every single experiment. The value of twenty-seven experiments of surface roughness and material removal rate was achieved by these tests. In this work, this study also serves to determine the contribution of each machining parameters and their interaction for surface roughness and MRR. The results show that the interaction of cutting speed and feed rate is the most relevant parameters of minimizing the surface roughness, feed rate or depth of cut is the influencing factors on maximization of material removal rate.

Keywords
Metal matrix composite, CNC milling machine, Process parameter, Surface roughness, MRR, RSM.

1.Introduction
Composites are combinations of two materials in which one material is named as the matrix and the other is named as reinforcement. There are different types of composite material based on the type of matrix and reinforcement. We have used metal matrix composite as a composite material. We use Aluminum (Al 6063) as base metal and 5% SiC as reinforcement for matrix composite. We have prepared composite material by using the stir casting process which includes electric furnace and rotating motor setup for stirring.

It is important to improve system performance and increase process performance without increasing cost. The method used for this purpose is called optimization. Many researchers are working on optimizing processing parameters.

Response surface methodology (RSM) is a dynamic and, first of all, an important tool for the design of experiment (DOE), where the relationship between outputs of the process (s) and input decision variables is mapped to achieve the goal of maximizing or minimizing output properties. RSM has been successfully applied for prediction and optimization of cutting parameters.

Chemical composition of the aluminum alloy (Al-6063)
We have shown the chemical composition of the Aluminum alloy (Al-6063) in *Table 1*

Table 1 Chemical composition of the aluminum alloy (Al-6063)

Elements	Composition (Wt. %)
Si	0.2-0.6%
Fe	Max 0.35%
Cu	Max 0.10%

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Elements	**Composition (Wt. %)**
Mg	Max 0.10%
Mn	0.45-0.90%
Elements	Composition (Wt. %)
Zn	Max 0.10%
Cr	Max 0.10%
Ti	Max 0.10%
Other	0.05-0.15%
Al (Remaining)	Max 97.5%

Characteristics of material

We have shown the characteristics of Aluminum alloy (Al-6063) in *Table 2*.

Table 2 Characteristics of material

Melting temperature (Tm)	615ºC
Density(ρ)	2.69 g/cm3
Young's modulus (E)	68.3 GPa
Tensile strength (σt)	145-186 MPa
Thermal conductivity (k)	201-218 W/m*K

Literature review

Patel (2015) [1] had taken process (input) parameters like cutting speed, feed rate, depth of cut, coolant, tool geometry etc. which delivers greater enhancement in productivity, increase the quality of parts of the machine and minimize the production cost.

Malay et al. (2016) [2] took various milling process parameters such as spindle speed, feeding speed and cutting depth were investigated to reveal the impact on surface finish and the material removal rate (MRR). As a result, the feed rate is considered to be the most influential factor for modeling the surface finish according to the authors.

Raju et al. (2015) [3] suggested wire-cut electrical machining process (WEDM) parameters such as pulse on time, pulse off time and peak current to show the most influence factor on smooth surfaces and MRR in aluminum work. The RSM was used as an experimental data optimization.

Ribeiro et al. (2017) [4] suggested four milling parameters such as cutting speed, feed speed, radial depth, and axial depth. These parameters have influenced the roughness of the surface. For this purpose, the L16 orthogonal array, which is part of the Taguchi optimization method, was used to optimize data.

Vishnu et al. [5] discussed the experimental investigation and optimization of the machining parameters of the CNC milling process on the P20 steel work piece. A "box-Behnken" project of RSM was used to collect study data. At this cutting speed, feed rate and cutting depth were used as a process (Input) parameter and MRR, tool wear, surface roughness, cutting forces are considered response (Output) variables. A non-dominant genetic sorting algorithm (NSGA-II) has been proposed by the authors to improve the efficiency of the milling process.

Hashmi et al. (2015) [6] had used, titanium and its alloys have poor thermal conductivity. Author described that in this research only depth of cut effect on composite material by using response surface methodology, technique but by using different cutting speed and feed rate can also be effective response surface methodology.

Vardhan et al. [7] worked on P20 Steel using surface response methodology and Taguchi method to the milling process. They have shown that both techniques offer the same result, but according to few researches, the Taguchi method is not too precise than RSM and RSM provide more accuracy.

Based on the analysis of the literature, we found that the milling machine is better than other machines for accuracy and efficiency. Many parameters of the milling process, such as spindle speed, feed rate, depth of cut, nose radius, cooling agent, tool geometry effect on surface roughness, and MRR. We have chosen only three parameters: spindle speed, feed rate and depth of cut based on the literatures. We have selected RSM for optimizing the experimental results.

Research objectives

1. RSM is used for the purpose of multi-objective parameters to be optimized.
2. To focus on cutting tool life and accuracy along with surface roughness and MRR and material properties along with cutting condition of cutting tool and workpiece.

Importance of work

1. We optimized multi-objective parameters at a time so we can reduce the time.
2. To increasing production rate by reducing time.
3. The composite material we selected would be used in automotive and aerodynamics.
4. To optimized better composite material.

2. Experimental setup and methodology

Experimental setup

1. Selecting of composite material (Al 6063–SiC) depending upon the application such as to make railway tracks due to their good properties, this composite material used in automotive parts show high tensile strength and flexural module like a wheel, cylinder head and manifolds. *Figure 1* shows the composite material.

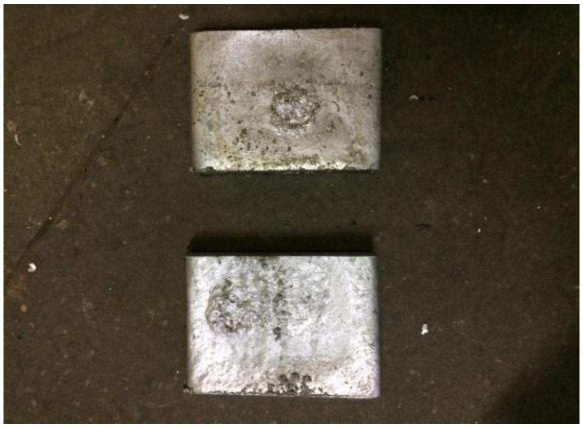


Figure 1 Composite material

2. We have selected the CNC milling machine for machining of the composite material. *Figure 2* shows the vertical CNC milling machine.

Figure 2 Vertical CNC milling machine

3. We have chosen three different levels of each control factors such as spindle speed, feed rate and depth of cut.

Table 3 shows the input parameter and their levels.

Table 3 Input parameter and their levels

Control factors (unit)	Level 1	Level 2	Level 3
Spindle Speed (rpm)	2000	2200	2400
Feed Rate (mm/min)	70	80	90
Depth of Cut (mm)	0.4	0.6	0.8

4. We have conducted 27 experiments for the optimization process [4, 7−10].
5. For each experiments test is found out and noted, then we calculated the material removal rate with the help of machining time.
6. Surface roughness are measured by the surface roughness measuring tester (SJ-210) and also obtained the graph by each experiment's test of surface roughness. *Figure 3* shows the surface roughness measuring tester (SJ-210).

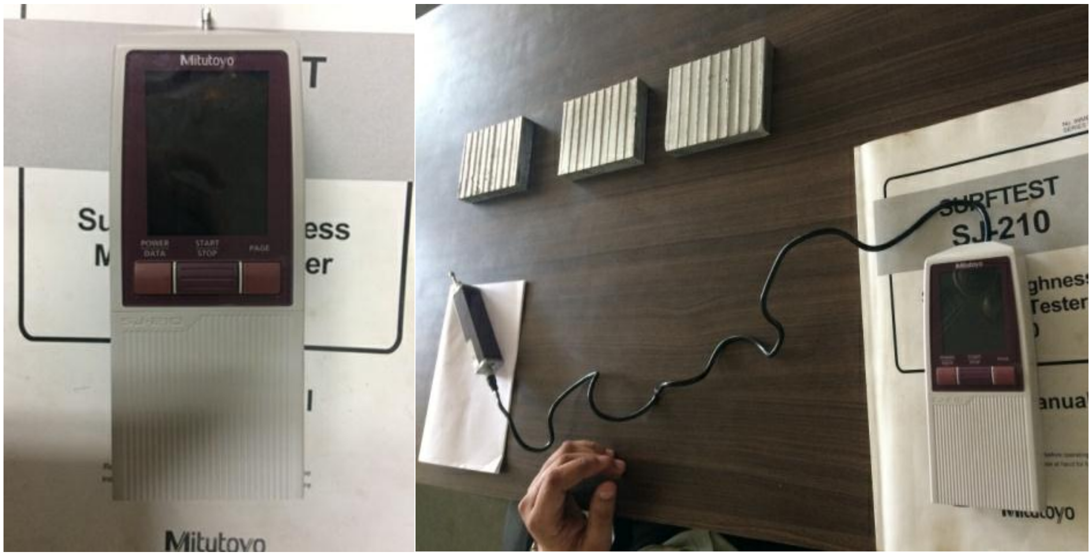


Figure 3 Surface roughness measuring tester (SJ-210)

7. The optimum results, are carried out by the response surface methodology with the help of Minitab software

Methodology

RSM is used to optimize the obtained result. The investigation is carried out by going through the following phases:

1) Screening
2) Improvement
3) Determination of optimum

i.Screening

Screening is used to determine which factors really influence the outcome; tool: screening designs like fractional factorial.

ii.Improvement

Improvement used to approach optimum by repeated change of factor setting; tool: Box/simplex or steepest ascent approach.

iii.Determination of optimum

Find an optimal setting of factor setting; tool: response surface design like central composite design (CCD) or Box-Behnken + analysis of response surface using Eigen values.

3.Results and discussion

Milling machine parameters are optimized for Aluminum composite material using RSM. The influential parameters chosen are cutting speed, depth of cut, feed rate and machining time Surface roughness are determined by the surface roughness tester. *Table 4* shows the process control parameter.

Table 4 Process control parameter

Experiment No.	Cutting Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	MRR (mm^3/min)	Surface roughness (R_a) (μm)
1	2000	70	0.4	290	2.622
2	2000	70	0.6	414.3953427	4.916
3	2000	70	0.8	566.3140765	4.488
4	2000	80	0.4	315.598549	3.274
5	2000	80	0.6	485.0549791	3.645
6	2000	80	0.8	631.6744819	7.450
7	2000	90	0.4	361.9972261	2.113
8	2000	90	0.6	533.0156569	4.003
9	2000	90	0.8	726.2608696	3.998
10	2200	70	0.4	288.0794702	1.711
11	2200	70	0.6	419.2771084	4.052
12	2200	70	0.8	594.4483986	4.259
13	2200	80	0.4	341.7348609	2.107
14	2200	80	0.6	499.9201915	2.478
15	2200	80	0.8	627.21538	8.602

Experiment No.	Cutting Speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	MRR (mm^3/min)	Surface roughness (R_a) (µm)
16	2200	90	0.4	379.3604651	2.090
17	2200	90	0.6	528.4292222	5.078
18	2200	90	0.8	758.4453324	6.263
19	2400	70	0.4	288.7966805	1.730
20	2400	70	0.6	426.2384322	4.344
21	2400	70	0.8	556.0733974	2.670
22	2400	80	0.4	321.2307692	4.920
23	2400	80	0.6	462.902749	4.422
24	2400	80	0.8	600.0862193	2.247
25	2400	90	0.4	390.5723906	4.997
26	2400	90	0.6	570.9077652	2.660
27	2400	90	0.8	740.6881873	2.094

Calculation of MRR

The material removal rate is obtained using following formulae:

$$MRR = \frac{W \times D \times L}{Tm}$$

Where W= width of the specimen mild,
d= 10mm, D= Depth of cut
L= Length of the specimen mild=87mm
T_m= Machining time

In the *Figure 4* of main effect plots for roughness show that surface roughness is decreased with increasing the cutting speed and then we found a point in which R_a is minimized and then also Ra is increasing. R_a lies between the 2-3µm with increasing the feed rate. Surface roughness slightly decrease with the depth of cut and then increases the roughness with increasing depth of cut. *Table 5* shows the regression coefficients for surface roughness (R_a).

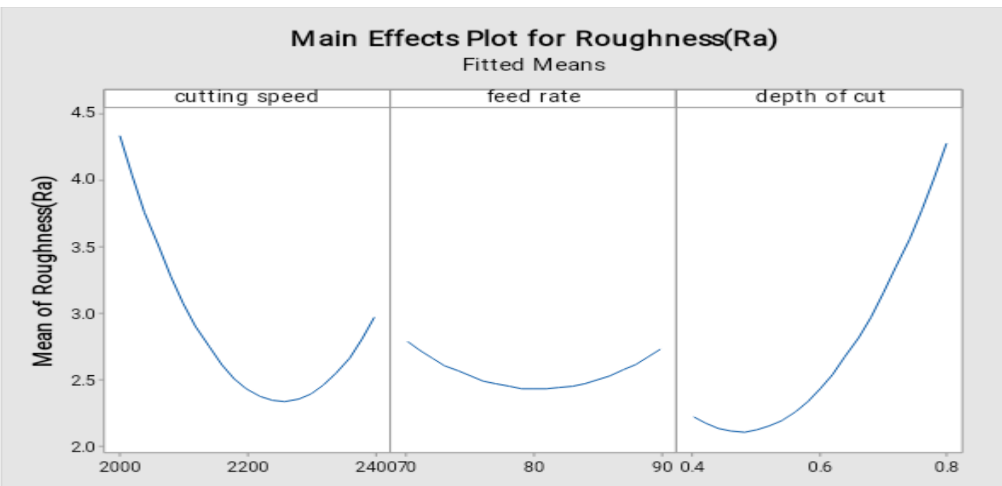


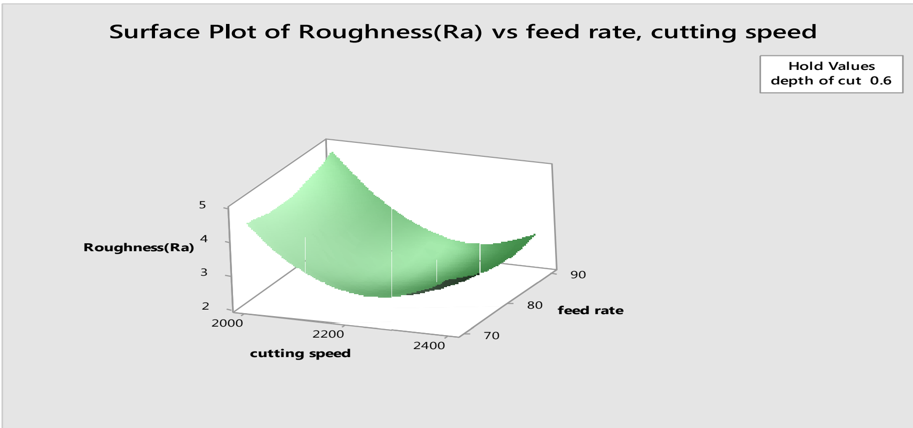
Figure 4 Main effects plot for roughness (R_a)

Table 5 Regression coefficients for surface roughness (R_a)

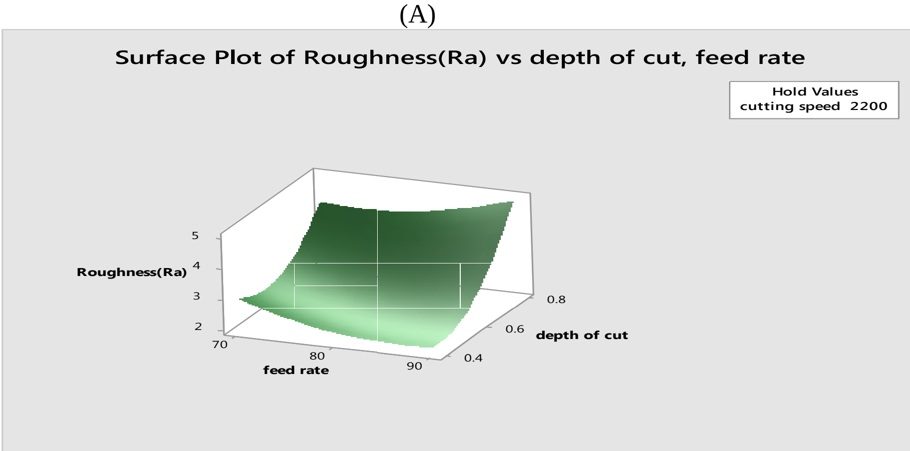
Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		2.433	0.676	3.60	0.016	
Cutting speed	-1.368	-0.684	0.414	-1.65	0.159	1.00
Feed rate	-0.054	-0.027	0.414	-0.06	0.951	1.00
Depth of cut	2.056	1.028	0.414	2.49	0.055	1.00
Cutting speed*cutting speed	2.439	1.220	0.609	2.00	0.102	1.01
Feed rate*feed rate	0.655	0.328	0.609	0.54	0.614	1.01
Depth of cut*depth of cut	1.639	0.820	0.609	1.35	0.236	1.01
Cutting speed*feed rate	-0.386	-0.193	0.585	-0.33	0.755	1.00
Cutting speed*depth of cut	-3.425	-1.712	0.585	-2.93	0.033	1.00
Feed rate*depth of cut	0.812	0.406	0.585	0.69	0.518	1.00

Regression equation in uncoded units

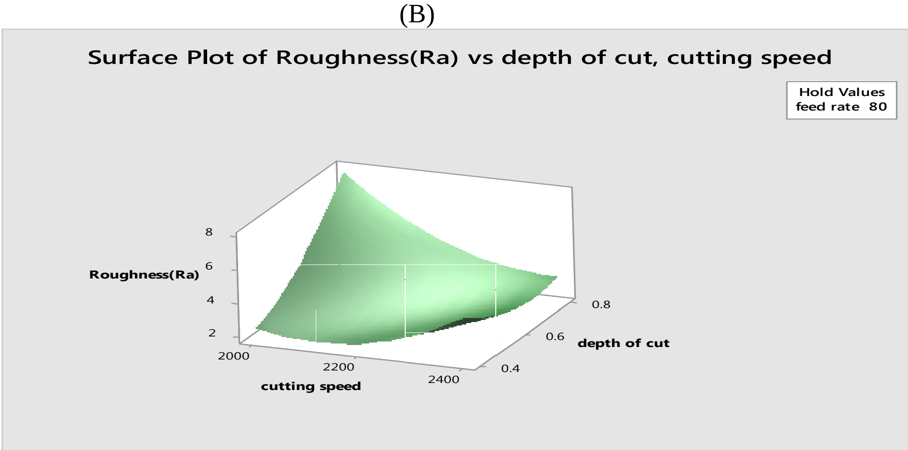
Roughness (R_a) = 119 − 0.1042 cutting speed − 0.44 feed rate + 58.5 depth of cut + 0.000030 cutting speed × cutting speed + 0.00328 feed rate × feed rate+ 20.5 depth of cut × depth of cut0. 000096 cutting speed × feed rate − 0.0428 cutting speed × depth of cut + 0.203 feed rate × depth of cut



(A)



(B)

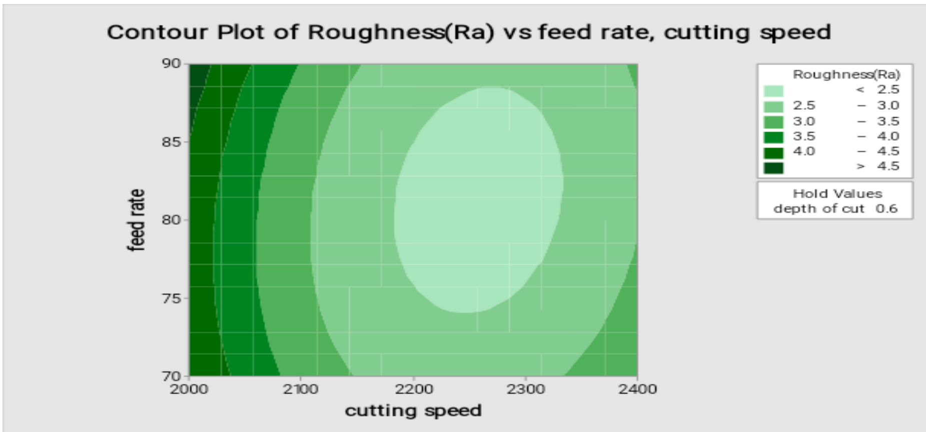


(C)

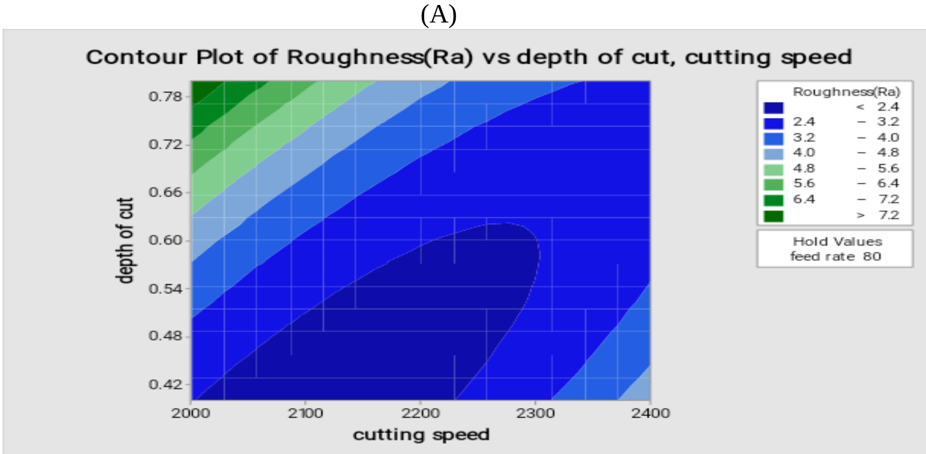
Figure 5 Response surface of surface roughness vs. cutting speed, feed rate & depth of cut

Table 6 Response optimization for surface roughness parameter components

Response	Goal	Lower	Target	Upper	Weight	Importance
Roughness (Ra)	Minimum	1.711	7045	1	1	



(A)



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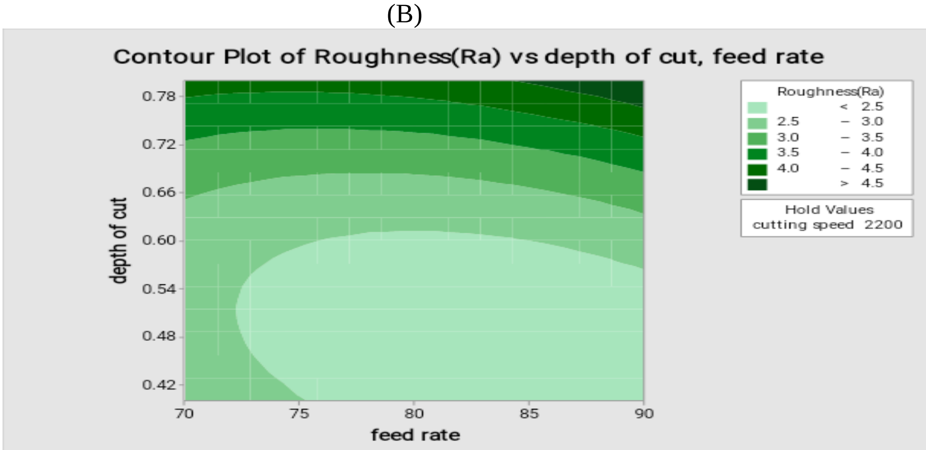

(C)

Figure 6 Contour plot of surface roughness (Ra) vs. Cutting speed, feed rate, & depth of cut

Figure 5 shows the response surface of surface roughness vs. cutting speed, feed rate & depth of cut. *Table 6* shows the response optimization for surface roughness parameter components. *Figure 6 (A)* shows that the surface roughness is decreased with increasing cutting speed and increasing feed rate.

Figure 6 (B) shows that the surface roughness is decreased with increasing cutting speed and decreasing the depth of cut. *Figure 6 (C)* shows that the surface roughness is decreasing with the increasing feed rate and decreasing the depth of cut. *Figure 7* shows the interaction plot for roughness (Ra). *Figure 8* shows the optimization plot of surface roughness (Ra). *Table 7* shows the response optimization solution for R_a. *Figure 9* shows the main effect plot of MRR. *Table 8* shows the regression coefficients for MRR. *Figure 10* shows the interaction plot for MRR. *Table 9* shows the response optimization for MRR parameter components. *Table 10* shows the response optimization of MRR.

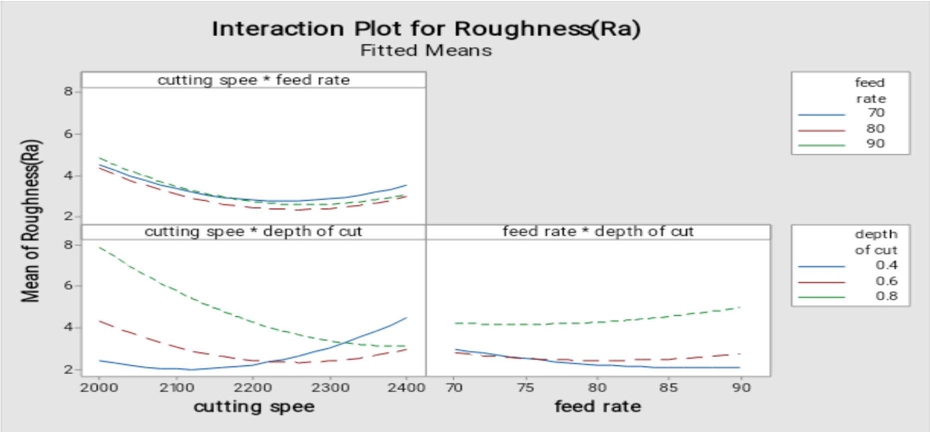

Figure 7 Interaction plot for roughness (R_a)

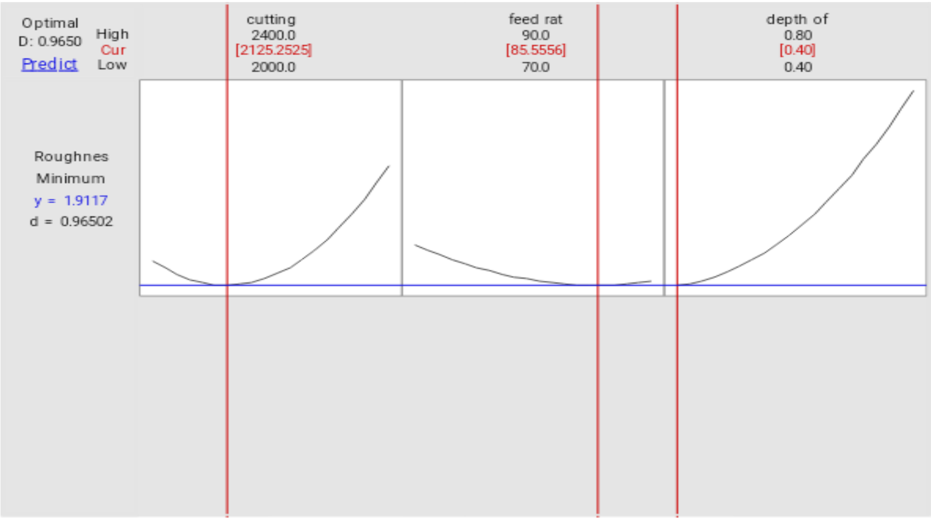

Figure 8 Optimization plot of surface roughness (R_a)

Table 7 Response optimization solution for R_a

Solution	Cutting speed	Feed rate	Depth of cut	Surface roughness (Ra) Fit
1	2125.25	85.5556	0.4	1.91172

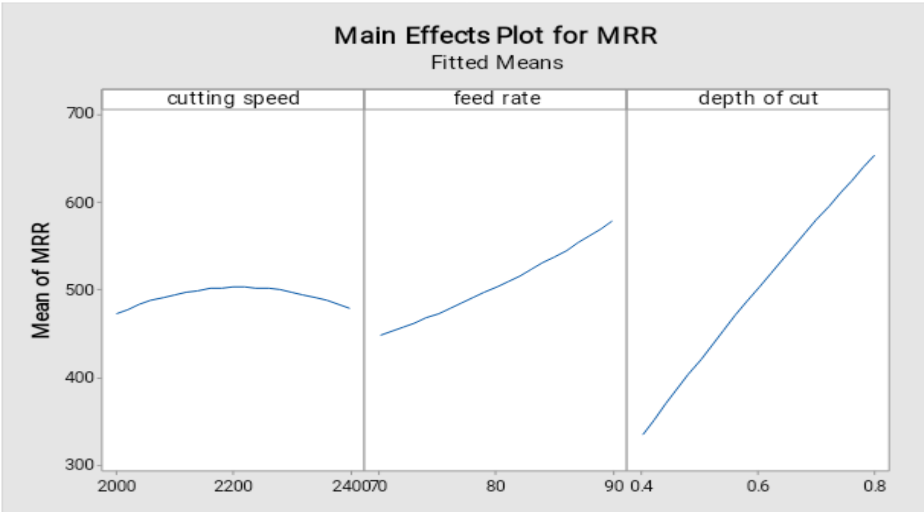

Figure 9 Main effect plot of MRR

Table 8 Regression coefficients for MRR

Term	**Effect**	**Coef SE**	**Coef**	**T-Value**	**P-Value**	**VIF**
Constant		503.5	10.9	46.26	0.000	
Cutting speed	5.94	2.97	6.67	0.45	0.674	1.00
Feed rate	129.64	64.82	6.67	9.73	0.000	1.00
Depth of cut	320.10	160.05	6.67	24.01	0.000	1.00
Cutting speed*Cutting speed	-55.33	-27.67	9.81	-2.82	0.037	1.01
Feed rate*feed rate	20.54	10.27	9.81	1.05	0.343	1.01
Depth of cut*depth of cut	-17.44	-8.72	9.81	-0.89	0.415	1.01
Cutting speed*feed rate	13.02	6.51	9.43	0.69	0.520	1.00
Cutting speed*depth of cut	-18.61	-9.31	9.43	-0.99	0.369	1.00
Feed rate*depth of cut	36.36	18.18	9.43	1.93	0.112	1.00

Regression Equation in Uncoded Units

MRR=−2594+ 2.94 cutting speed− 22.6 feed rate + 846 depth of cut − 0.000692 cutting speed × cutting speed + 0.1027 feed rate × feed rate − 218 depth of cut × depth of cut + 0.00326 cutting speed × feed rate−0. 233 cutting speed × depth of cut + 9.09 feed rate × depth of cut

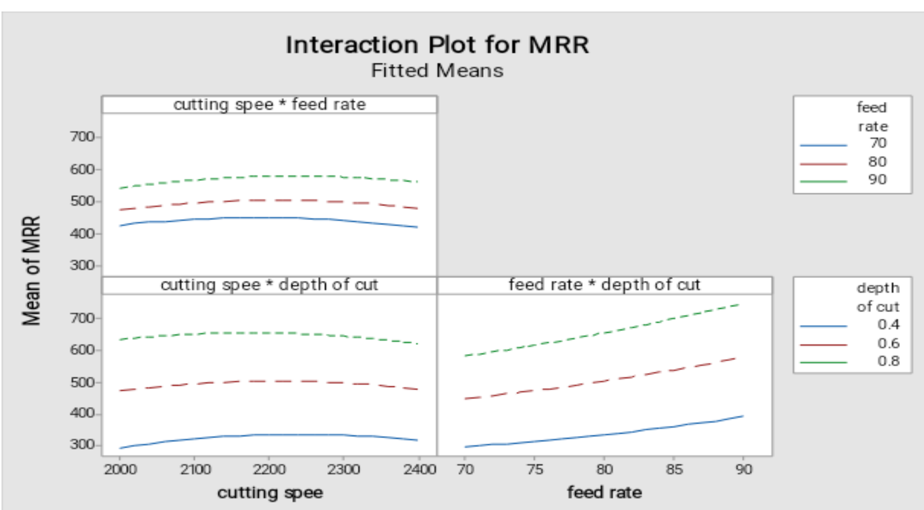

Figure 10 Interaction plot for MRR

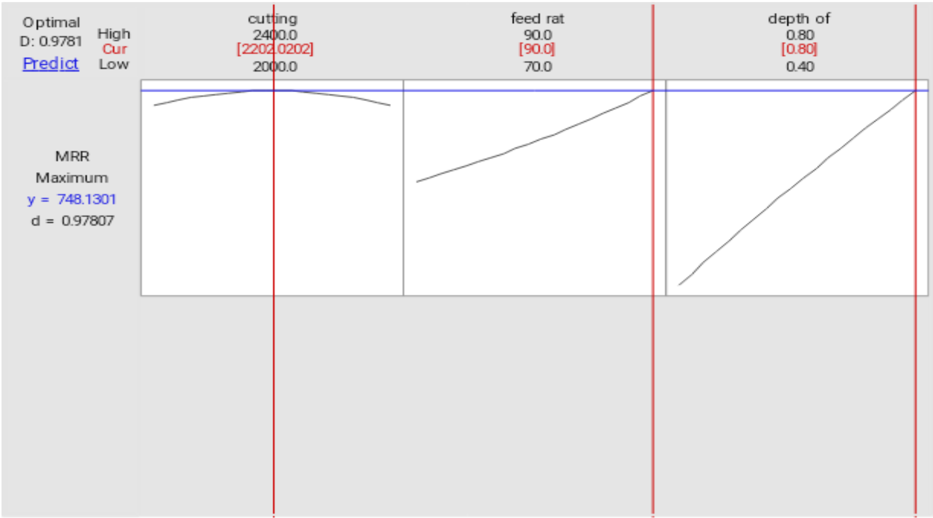

Figure 11 Optimization plot of MRR

Table 9 Response optimization for MRR parameter components

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Maximum	288.079	758.445		1	1

Table 10 Response optimization of MRR

Solution	Cutting speed	Feed rate	Depth of cut	MRR FIT	Composite desirability
1	2202.02	90	0.8	748.130	0.978071

Optimization plot

A Minitab response optimizer tool shows how different experimental setting affects the predicted response for factorial, response surface and material removal rate. Minitab calculates an optimum solution serves as the starting point of the plot [6].

The optimization plot for surface roughness, as shown in *Figure 8*, indicated that the minimum.

Surface roughness is 1.911μm obtained at cutting speed=2125.25 RPM, feed rate=85.56 mm/min, and depth of cut=0.4mm.

The optimization plot for MRR as shown in *Figure 11* shows that the maximum MRR is 748.13 mm^3/min obtained when cutting speed=2202.02rpm, feed rate=90 mm/min & depth of cut=0.8 mm.

4.Conclusion and future scope

In this document, CNC milling parameters were determined for multiple performance characteristics (surface roughness and MRR) by response surface modeling and optimization based on convenience. Based on the results, the following conclusions can be drawn:

1. RSM is used for the modeling of CNC milling parameters in the machining of Al 6063 / SiC composites. The results indicate that the models are effective in predicting multiple responses in the milling compound.
2. The optimization of multiple responses was performed using the response surface methodology. The optimum solution actually reduces the response in the milling of composite. The optimal solution that was obtained was almost optimal and can be improved considering several variables and levels.
3. The optimization result shows that it is necessary to combine the cutting speed, feed rate and cutting depth to minimize surface roughness and maximize the material removal rate.

In the current research the milling machine parameters were optimized by RSM technique.

The following can be considered as the scope for future work:

1. Research can be based on optimizing various machining parameters for different composite material.

2. Research can also be carried on a machine other than milling machine. A better optimization technique may be employed.
3. The results of various optimization techniques for the same material and machine can be compared and studied.
4. A comparative study can be carried out for optimizing machining parameter for different metals or alloys and composite materials.

Acknowledgment
None.

Conflicts of interest
The authors have no conflicts of interest to declare.

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