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Optimization of Material Removal Rate (MRR) and Surface Roughness (SR) while Turning of Hybrid Aluminium Metal Matrix Composite on CNC Lathe Using Response Surface Methodology (RSM)

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ABSTRACT: In modern era of manufacturing, the Hybrid Metal matrix composites (HMMC) are most advanced material, which are mostly used in today's industries. In this paper we calculate the influence of most prominent parameters of CNC turning machine on material removal rate (MRR) and surface roughness (SR) of the hybrid composite material. Turning process parameters i.e. Feed, Speed and Depth of Cut are considered and have calculated their response in term of MRR and SR. To develop a hybrid metal matrix composite material Aluminium Al6061 as a base material and silicon carbide (10%wt) and graphite (3%wt) particles as reinforcements are used. Stir casting process was used to fabricate the hybrid composite because of easy setup and cheap method of fabrication. To optimize our output parameters, RSM (response surface methodology) is used. We diagnosed the best combination of input parameters for the maximum output (MRR) and minimum (SR). TNMG160408, TNMG2000 and K10 tool inserts are used as cutting tool. The purpose of the present study is to calculate the optimum setting of process parameters for better output results.

Keywords: HMMC (Hybrid metal matrix composite), MRR (Material removal rate), SR (Surface roughness), CNC Turning, RSM (Response surface methodology), design of experiment,

I. INTRODUCTION

Metal matrix composite (MMC) are modern materials. It has number of characteristics as compared to monolithic metals such that higher specific modules and strength, better properties at high temperatures, lower coefficient of thermal expansion, better wear resistance etc.[1]. Generally metal matrixes composite are used in medical industries, automotive parts, and aerospace and electronics industries. There are many engineering applications of such materials in fabrication of bicycles frame; cylinder block and vehicle drive shafts etc. [11].

M.O Bodunrin *et al*. [1] highlighted the huge demands of Al hybrid MMC in engineering application due to their superior set of mechanical properties. The better performance of hybrid MMC is only achieved by adding the right combination of reinforcements into an ethical composition [7]. The conventional processing techniques are better to fabricate a hybrid MMC at lowest cost.

J. Singh *et al*. [2] developed a hybrid MMC at lowest cost with high performance index. Due to the high range of application the hybrid MMC is employed into various sectors. It observed that a low performance of hybrid MMC is arises due to the improper mixing of reinforcements and matrix alloy [7,8]. They concluded that the reliability and flexibility rate is very much high for hybrid MMC.

AAdan. [3] Investigated both conventional and non-conventional machining process to machining the Al6061 MMC. Result showed that the surface roughness quality and hardness of material is directly affected by the machining process and it also overripe the microstructure of material.

Puneet Bansal *et al* [4], carried out the turning on MMC by using different coated and uncoated carbide tool. They observed the effect of different process parameters (speed, feed, depth of cut) on two response variable (SR & MRR). They observed & understand the behaviour of turning parameters for composite material under various operating conditions. Turning Parameters- there are several parameters of turning process. The parameters have been selected by researchers for their work depends upon the work piece material, tool size, tool material and working conditions [8,9]. Major turning parameters that affect the process are

(i) Cutting Speed- It is the difference between the tool insert and the surface of the work piece [11].

(ii) Spindle Speed-It may be defined as the revolutions of the work piece and the rotational speed of the spindle.

(iii) Feed Rate- (Fr = rpm× t× cl)

Fr = feed rate, t = no of teeth on cutter**,** rpm=calculate speed of cutter**,** cl=it is the size of chip which every tooth of the cutter takes.

(iv) Depth of Cut-Volume of the work piece material that can be removed per time unit.

II. MATERIAL PREPARATION

Al6061 has been used as a base material to develop a hybrid Al MMC, where reinforcement graphite particles (3%wt) and silicon carbide particles (10%wt) of 200 mesh size are used. The addition of SiC particle improves the brittleness and wear resistance [1] and the graphite particles worked as solid lubricant which improve the surface quality and reduce the heat generation during machining [8]. In this process the composite was fabricated by stir casting process, because it is the most common and cheap method for casting MMC. Aluminium alloy was melted in an electrical vertical muffle furnace in a range of 750°C. The aluminium was put in a crucible inside the vertical muffle furnace. The preheated reinforcement particles of Silicon carbide and Graphitewere introduced into the vortex of the molten alloy after effective degassing [5]. Mechanical stirring of the molten alloy for a period of 15mins was achieved by using a mechanical graphite stirrer [6]. The speed of the stirrer was adjusted at 600rpm. The melt was poured at 873°K into a cast iron mould [6]. Then the mould was left in air to cool down to room temperature and then after some time our solid MMC sample was ready [6].

Fig. 1. Vertical muffle furnace.

III. EXPERIMENTAL WORK

A series of experiments were performed on Stallion 100HS CNC Lathe machine as shown in Fig. 2.

Fig. 2. CNC Lathe.

A. Calculation of MRR (Metal Removal Rate)

MRR is the difference between weights of work piece (before and after machining) to the machining time [17].

MRR (Mg/sec) = $\frac{Wbm-Wam}{Mt}$

Wbm = workpiece weight before machining (gm)

Wam = workpiece weight after machining (gm)

Mt = total machining time of each trail (sec)

To calculate the weight difference of a work piece we used a weighing machine (shown in figure.3) which has maximum capacity 200gmand least count 0.001gm.

Fig. 3. Weighing Machine.

B. Calculation of Surface Roughness (SR)

Surface roughness is a part of surface texture, and is also referred as simply roughness. It is basically the quantified measure of in the direction of the normal vector to the actual surface [4]. The surface is said to be rough, if these deviations are large but if they are small the surface is said to be smooth [4].

Fig. 4. Surface roughness tester.

It is very important to know the frequency and amplitude of variations to ensure the fit the surface for required use [13]. The surface roughness tester model no ISR-S400 by INSIZE is used in this experimental work.

IV. RESPONSE SURFACE METHODOLOGY (RSM)

Response surface methodology is used to design final design matrix. Through RSM we can find the optimal set of experimental parameters of turning, where the responses (MRR and SR) are instantly affected. In RSM the CCD (central composite design) was selected to conduct the design experiments and calculate the impact of process parameters. It is a combination of statistical and mathematical techniques [13,14], which are used for developing, improving and study the process. The machining parameters and their levels in tables.1

Table 1: Machining parameters and their levels.

Machining parameters	Levels		
	Level 1	**Level 2**	**Level 3**
Speed	1600	1800	2000
Feed	0.1	0.15	0.2
D.O.C	0.15	0.25	0.35
Tool	TNMG160408(-1)	2000 (0)	K10 (1)

RSM makes it possible to represent independent process parametersin quantitative form asto Eq. (1).

$Y = f\,(X_1, X_2, X_3, X_4)$ (1)

Where, Y is the response, f is the response function, and X1, X2, X3, …Xn are independent parameters. Forpredicting the optimal point the quadratic equation model was expressed according to Eq. (2).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum \sum_{i<j} \beta_{ij} x_i x_j + \in \qquad 2)$$

The low and high levels of selected three factors are given in Table 2. To study out the Percentage adsorption we used standard RSM design called Central Composite design (CCD [18]. The design matrix developed by RSM approach and calculated response values are shown in Table 3.

A. Developed mathematical models

The output of the each experiment performed is given in the Table 2. An empirical relationship between the response and the independent variables has been expressed by the following quadratic model:

Material removal rate (MRR) (mg/sec) = +2.05-0.11*A+0.37*B+0.21*C-0.051*D-0.13*AB-0.045*AC+0.40*AD-0.15*BC-0.18*BD-2.013E-00.*CD-0.10*A^ 2-0.10*B^ 2-9.658-004*C^ 2-0.036*D^ 2

Tool wear rate (TWR) (µm) = +2.41-0.13*A-0.16*B-0.097*C-0.11*D-0.41*AB-0.16*AC-0.25*BC-0.093*BD-0.025*CD-0.18*A^ 2-0.060*B^ 2-0.035*C^ 2-0.14*D^ 2

B. Verification of the adequacy of the developed models

Analysis of variance (ANOVA) has been used to analyze the accessibility of the model. The analysis of variance for the response has been encapsulated in Table 3.

Table 2: Design matrix.

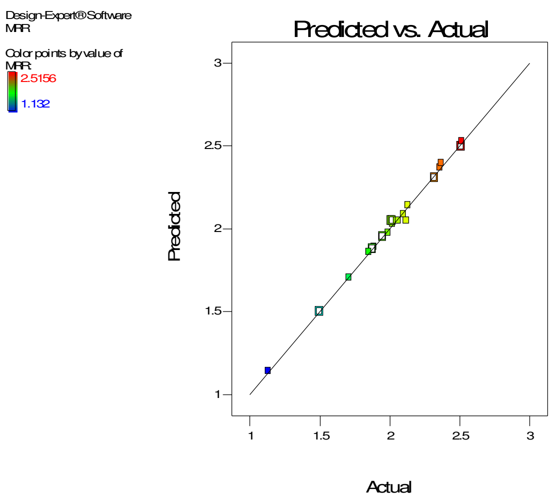
Run	Speed	Feed	D.O.C	Tool	MRR (mg/sec)	SR (μm)
1	2000	0.1	0.15	1	1.8766	2.289
2	1800	0.15	0.25	0	2.0193	2.26
3	1600	0.1	0.15	-1	1.5	1.398
4	1600	0.1	0.35	-1	2.32	2.101
5	2000	0.1	0.35	1	2.5105	2.268
6	2000	0.2	0.15	-1	1.95	2.09
7	1800	0.15	0.25	0	2.01	2.62
8	1800	0.15	0.08	0	1.71	2.51
9	1600	0.2	0.15	1	1.89	2.5
10	2100	0.15	0.25	0	2.13	1.67
11	1400	0.15	0.25	0	2.5156	2.101
12	1800	0.15	0.25	0	2.11975	2.25
13	1800	0.23	0.25	0	2.36	1.974
14	1800	0.15	0.25	0	2.05	2.568
15	1800	0.15	0.41	0	2.37	2.105
16	1800	0.15	0.25	-1	2.02	2.2006
17	1800	0.15	0.25	1	1.85	1.819
18	2000	0.2	0.35	-1	1.99	1.169
19	1600	0.2	0.35	1	2.1	2.1
20	1800	0.15	0.25	0	2.0608	2.35
21	1800	0.06	0.25	0	1.132	2.5

Table 3: ANOVA for MRR.

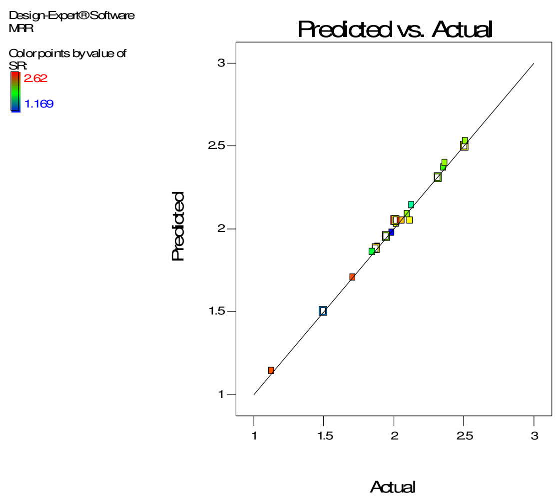
ANOVA for Response Surface Quadratic model											
	MRR					SR					
Source	**SS**	**df**	**MS**	**F-value**	**P-value prob> F**	**SS**	**df**	**MS**	**F-value**	**P-value prob> F**	
Model	2.06	14	0.15	90.68	< 0.0001	2.65	14	0.19	8.99	0.0064	Significant
A-SPEED	0.074	1	0.074	45.75	0.0005	0.093	1	0.093	4.41	0.0804	
B-FEED	0.75	1	0.75	464.04	< 0.0001	0.14	1	0.14	6.58	0.0427	

ANOVA for Response Surface Quadratic model											
	MRR					SR					
Source	**SS**	**df**	**MS**	**F-value**	**P-value prob> F**	**SS**	**df**	**MS**	**F-value**	**P-value prob> F**	
C-D.O.C	0.58	1	0.58	356.82	< 0.0001	0.13	1	0.13	6.07	0.0489	Significant
D-TOOL	0.014	1	0.014	8.89	0.0246	0.073	1	0.073	3.46	0.1122	
AB	0.054	1	0.054	33.25	0.0012	0.57	1	0.57	26.91	0.0020	
AC	0.016	1	0.016	9.76	0.0205	0.19	1	0.19	9.21	0.0230	
AD	0.53	1	0.53	325.85	< 0.0001	0.058	1	0.058	2.73	0.1493	
BC	0.18	1	0.18	111.50	< 0.0001	0.50	1	0.50	23.84	0.0028	
BD	0.11	1	0.11	65.55	0.0002	0.029	1	0.029	1.36	0.2886	
CD	3.240E-005	1	3.240E-005	0.020	0.8923	5.151E-003	1	5.151E-003	0.24	0.6383	
A^2	0.15	1	0.15	93.73	< 0.0001	0.51	1	0.51	24.18	0.0027	
B^2	0.16	1	0.16	97.53	< 0.0001	0.054	1	0.054	2.58	0.1596	
C^2	1.394E-005	1	1.394E-005	8.579E-003	0.9292	0.019	1	0.019	0.89	0.3831	
D^2	0.020	1	0.020	12.02	0.0133	0.30	1	0.30	14.03	0.0096	
Residual	9.749E-003	6	1.625E-003			0.13	6	0.021			
Lack of Fit	2.244E-003	2	1.122E-003	0.60	0.5926	5.475E-003	2	2.737E-003	0.091	0.9151	not significant

Now again to confirm the credibility of developed model matrix, we draw the scatter diagram and the Residual plots graph as shown in Fig. 5a-b and Fig. 6a-b respectively.



(a)



(b)

Fig. 5. Scatter diagram of (a) MRR and (b) SR.

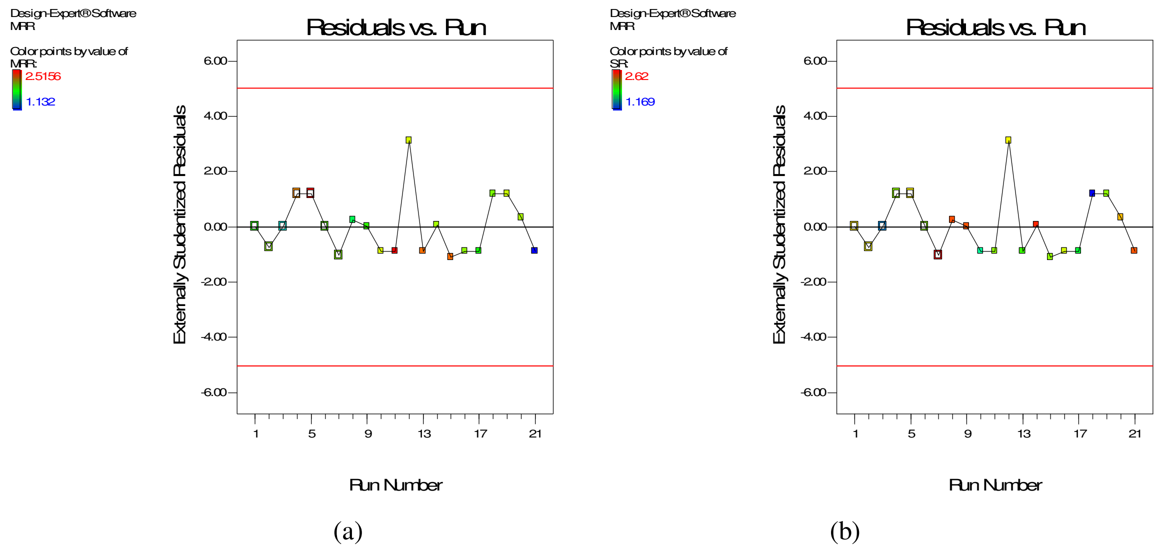


Fig. 6. Residual plots graph of (a) MRR and (b) SR.

V. RESULT AND DISCUSSION

We know that machining is a process, in which the material is removed from the work piece with the help of cutting tool. Turning is a conventional machining method. In this experimental study we consider 4 process parameters i.e. speed, feed, depth of cut and tool material (insert). In RSM we draw the following perturbation graphs to examine that which process parameter mostly affected our response variables (MRR and SR).

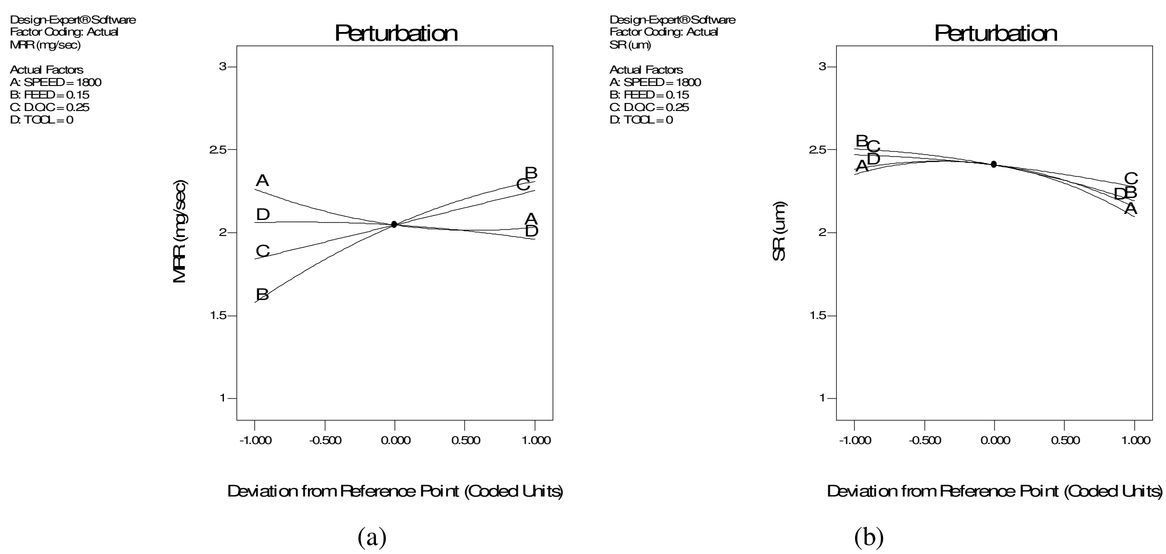
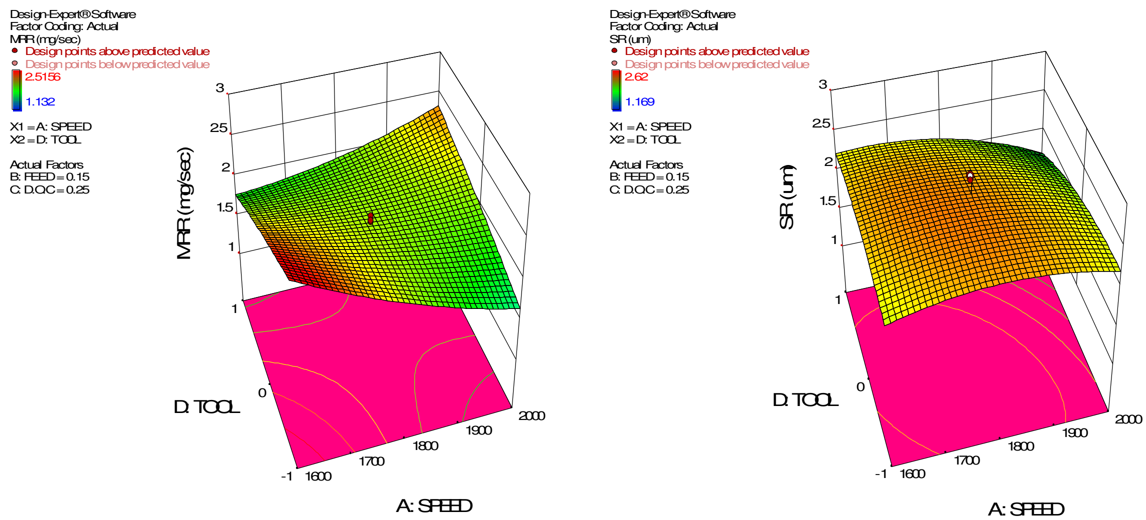


Fig. 7. Perturbation graphs of (a) MRR and (b) SR.

From these on-factor graphs it is confirm that the feed, depth of cut and TNMG2000tool insert directly affected our response variables (MRR and SR). Now for the better understanding that which tool insert has a maximum MRR and minimum SR, we draw 3-d graphs, which show the correlation of process parameters with respect to the response variables.

A. Effect of Speed with tool insert on MRR and SR

From the figure.8a-b, it is identified that the MRR (metal removal rate) and SR (surface roughness) of the composites decreases linearly with increasing the value of speed [1].



(a) (b)

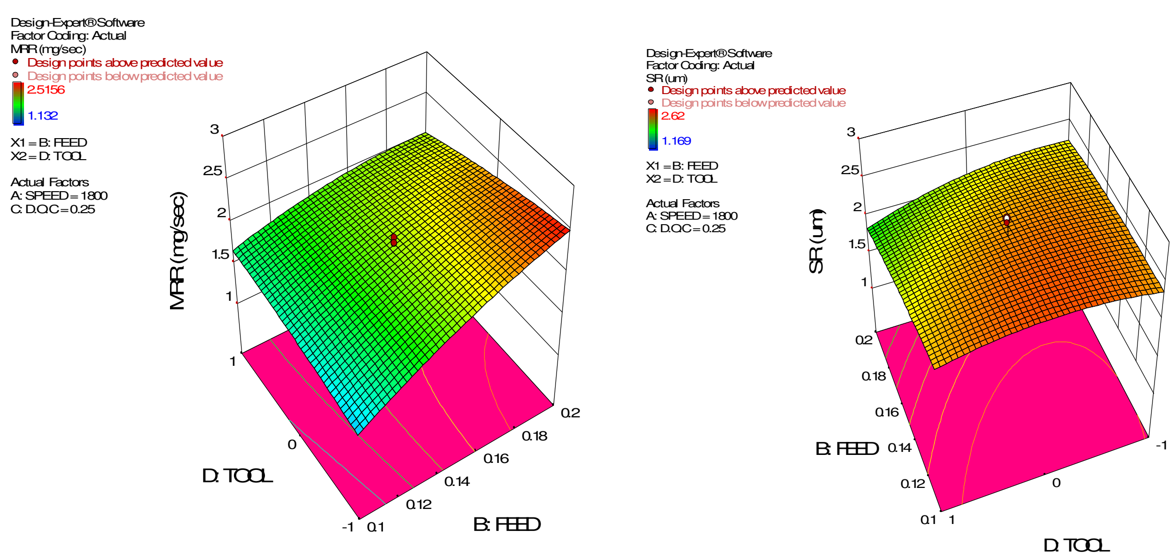
Fig. 8. 3-D graph of (a) MRR and (b) SR.

B. Effect of Feed with tool insert on MRR and SR

From figure.9a-b, it is found that the metal removal rate of the composite increases rapidly as the value of feed increases, on the other hand the value of surface roughness slightly decreasing with increases the value of feed.

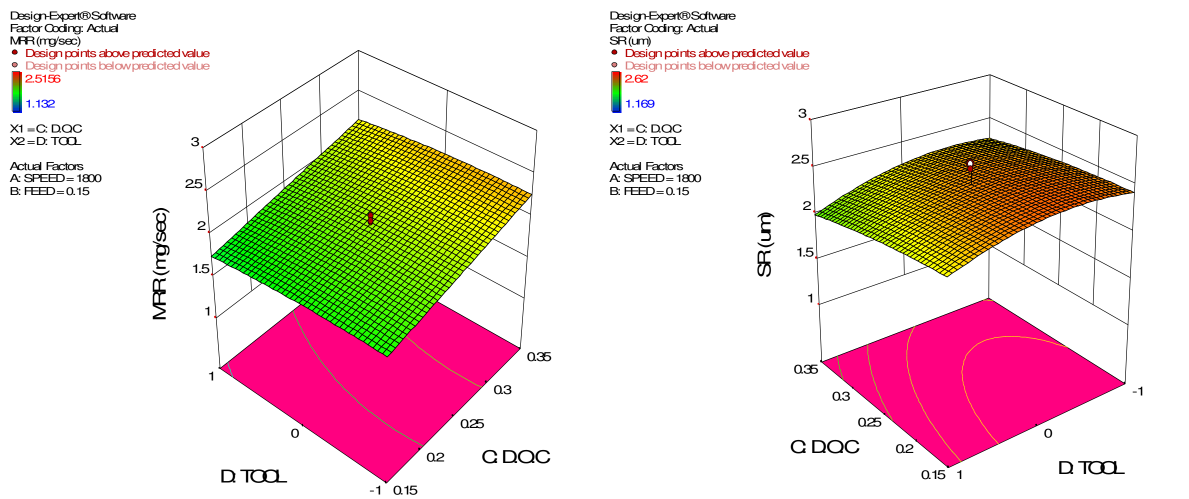
C. Effect of depth of cut with tool insert on MRR and SR

From figure.9a-b, it is investigated that the value of material removal rate is directly proportional to the value of depth of cut. The surface roughness linearly decreasing with increases the value of depth of cut.



(a) (b)

Fig. 9. 3-D graph of (a) MRR and (b) SR.



(a) (b)

Fig. 10. 3-D graph of (a) MRR and (b) SR

From these above 3-D graphs it's also observed that the maximum material removal rate is calculated on TNMG160408 tool insert while the minimum surface roughness is come on TNMG2000 tool insert.

The confirmation test was carried out with the parameters as suggest by the model shown in table.4 to optimize the data as given by numerical modelling under optimization conditions.

VI. CONFIRMATION EXPERIMENT

Table 4: Optimal condition from the model.

Speed	Feed	D.O.C	Tool	Prec.MRR	Exp.MRR	%Variation	Prec.SR	Exp.SR	%Variation
2000	0.15	0.35	K10	2.478	2.512	1.35	1.169	1.162	0.59

VII. CONCLUSION

Here our main focus is to investigate the significant impact of selected parameters and their levels/ranges where our response variable is mostly affected. The desirability approach was employed to calculate the optimization. The 3-D graphs and contour plots were generated for analysing process parameters effects by using the Design expert 9 software. From the analysis, the following conclusion was conducted.

(i) Material removal rate of composite is increasing with the increasing of "Feed" and "Depth of cut" whiles it decreases with increase in "Speed".

(ii) Surface roughness of composite is decreasing with the increasing of "Speed" whiles its decreases with increase in "Feed" and "Depth of cut".

(iii) From three different tool inserts, the TNMG160408 tool insert has highest material removal rate as compare to remaining two, while the minimum surface roughness is observed by TNMG2000 tool insert.

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