Investigating the Effect of Cutting Parameters on Average Surface Roughness and Material Removal Rate during Turning of Metal Matrix Composite Using Response Surface Methodology

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Abstract-This research work investigate the effect of cutting parameters on average surface roughness and material removal rate during turning of Metal Matrix Composite using response surface methodology. The experimental studies are carried out under changing machining parameters like cutting speed, feed and depth of cut during turning of metal matrix composite. Response surface methodology based on the Face centered design technique has been used for the development of mathematical models to predict average surface roughness and metal removal rate. The conclusions revealed that the feed is the most influential machining parameter on the average surface roughness followed by depth of cut and the cutting speed. The depth of cut has significant for both the average surface roughness and metal removal rate for the MMC steel.

Keywords- *Response Surface Methodology, Metal Matrix Composite, Metal removal rate, surface roughness, Cutting Speed, Feed Rate*

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I. INTRODUCTION

Machining parameters such as feed, speed and depth of cut play a crucial role during machining. These have a major effect on production size, production cost and rate of production. These selected machining parameters should produce desired finish on the machined surface while using the cutting resources like cutting tool and machine tool to the full limit possible. So it can be achieved by establish empirical relationship between machining condition and surface roughness indicators using design of experiments (DOE). The proposed work will be employed for investigating the effect of turning parameters on surface roughness and metal removal rate in turning of Metal Matrix Composite steel. Metal matrix composites are prepared by mixing a reinforcing material into a metal matrix. The reinforcement area can be coated to avoid reaction with the matrix. Carbon fibers are normally used in aluminum(Al) matrix to manufacture composites which indicate high strength and low density. Carbon reacts with aluminum(Al) to create a water-soluble (Al_4C_3) and brittle compound on the surface of the fiber.

II. TECHNIQUES AND EQUIPMENTS

A. Response Surface Methodology

Response surface methodology is a statistical method that uses quantitative data from appropriate experiment to determine and simultaneously solve the multivariate equation. This method is used to determine the optimum contribution of factors that yield a desired response and describes the response near the optimum. It also exhibits how a specific response is affected by changes in the level of factors over the specified level of interest. RSM consists of a group of empirical techniques used to the evaluation of relations existing between a collection of controlled experimental factors and measured responses, according to selected criteria. If the model contains coefficients for main effects, coefficients for quadratic effects and coefficients for two factor interactions, a full factorial design with all the factors at three levels would provide estimation of all the necessary regression parameters. However, these full factorial three level designs are costly to run as the number of runs increases with the number of factors. Therefore, special designs are used to help the experiment to fit second order model to the response with the number of runs.

B. The analysis of variance (ANOVA) test for regression

In statistics, ANOVA is a collection of statistical models, and their related procedures, in which the observed variance is divided into components due to different variables. Effect plots visualize the impact of each factor combination and identify which factors are most influential. A statistical hypotheses test is needed in order to determine of any of these effects are significant. Analysis of variance (ANOVA) consists of simultaneous hypothesis tests to determine if any of the effects are significant.

C. Design of experiments

A number of experiments required, mainly depends on design of experiment. Thus, it is important to have a well designed scheme of the experiment, so that number of experiments required can be minimized. In this research, the design suggested by RSM based on face centered design (FCD) has been implemented to analyze the effect of independent process parameters on surface roughness indicators.

TABLE I. PROCESS PARAMETERS AND THEIR LEVELS FOR THE TURNING OF METAL MATRIX COMPOSITE

Factors	Symbol	Levels		
		-1	0	+1
Cutting speed (m/min)	A	100	175	250
Feed (mm/rev)	B	0.10	0.25	0.40
Depth of cut (mm)	C	0.10	0.25	0.40

D. Test specimens

Turning is one of the most commonly employed operations for producing cylindrical parts. In the present research work test specimens in the form of round bar of dimensions Ø24 × 150 mm have been used for the exexperiment.

TABLE II. THE CHEMICAL COMPOSITION OF TEST SAMPLES OBTAINED BY SPECTRAL ANALYSIS

Alloy Element	wt %
B4C	2
Mg	1
Si	0.6
Cu	0.25
Fe	0.2
Cr	0.17
Zn	0.09
Ti	0.01
Mn	0.01
Al	Bal.

E. Machine tool for turning

The CNC becomes very common in factories and are capable to enhance product quality as well as productivity.

Keeping in view the above, all the turning experiments on the Al 6061 alloy have been carried out on HYTECH PUNE MODEL NO: 4-CL T100 lathe. The CNC machining centre equipped with continuously variable spindle speed up to 3000 rpm and 2 HP motor drive was used for experimentation.

TABLE III. TECHNICAL SPECIFICATION OF THE CNC TURNING CENTRE

Model	HYTECH PUNE MODEL NO: 4-CL T100
Rapid Feed Rate X	400 mm/min
Rapid Feed Rate z	400 mm/min
Distance Between Centers	310 mm
Floor Space Provided	1200 x 600 mm
Swing Over Bed:	100 mm
Swing Over Cross Slide:	80 mm
Spindle Speed:	3000 RPM
Spindle Bore:	50 mm
Tool Station :	4
Maximum Machining Diameter	50 mm
Maximum Machining Length (shaft)	350 mm
Main Motor	2 HP

F. Cutting tool for turning

Due to high machinability of metal matrix composite a large number of cutting tools were available as options required for the turning. Single point Tungsten Carbide tool (TCT) was selected as the cutting tool for the experiment.

G. Surface roughness measurement

Surface roughness is considered an index of component quality. It measures the finer irregularities of the surface texture (Tsourveloudis 2010). In this research, a portable surface roughness tester (Model No TR 210 manufactured by Beijing TIME High Technology Ltd. Beijing City, China) has been used to measure surface roughness indicators of finished work pieces. The constants for surface roughness tester for all the measurements of work pieces were standard ISO 97R, 0.8 mm cut-off, least count of 0.001μm. The measurements were repeated at three different locations of the finish work piece in the direction of the tool movement. Finally, the mean of surface roughness values were considered for the particular trial.

III. RESULTS AND DISCUSSION

By the observation of our practical result and average surface roughness value obtained by using the surface measurement device we observed these data for surface roughness and MRR.

Material removal rate can be calculate by using of this formula-

$$\frac{\frac{\pi}{4}(D_i^2 - D_f^2) \times L}{t}$$

Here D_i - Diameter before machining or Initial Diameter

D_f – Diameter after machining or Final Diameter

L- Machining length

t- Time taken in machining for given length

For calculation of material removal rate, time and initial diameter has been already taken for all runs before machining.

TABLE IV. FINAL EXPERIMENTAL DESIGN LAYOUT BY THE TURNING OF METAL MATRIX COMPOSITE STEEL

Std	Run	Factor 1 A:Cutting Speed m/min	Factor 2 B:Feed mm/rev	Factor 3 C: Depth of Cut mm	Response 1 Ra microns	Response 2 MRR mm/min
1	1	100	0.1	0.1	1.26	15263.5
3	2	100	0.4	0.1	1.93	20329.5
4	3	250	0.4	0.1	1.606	28943.2
15	4	175	0.25	0.25	1.712	25982
16	5	175	0.25	0.25	1.692	27341
10	6	250	0.25	0.25	1.52	30880.4
11	7	175	0.1	0.25	1.17	24891
6	8	250	0.1	0.4	1.16	30839
7	9	100	0.4	0.4	2.643	29874.8
20	10	175	0.25	0.25	1.662	26834
14	11	175	0.25	0.4	1.82	30199
8	12	250	0.4	0.4	2.268	35937.3
19	13	175	0.25	0.25	1.712	26693
12	14	175	0.4	0.25	2.021	28732
2	15	250	0.1	0.1	1.06	26013
13	16	175	0.25	0.1	1.48	23983
17	17	175	0.25	0.25	1.727	26893
18	18	175	0.25	0.25	1.694	27112
9	19	100	0.25	0.25	1.932	22787.8
5	20	100	0.1	0.4	1.401	23305.4

The complete results of the 20 experiments carried out as per the experimental plan are shown in Table IV along with the run order selected at random. These outputs were input into the Design Expert 8.0.4.1 software for further analysis of average surface roughness and material removal rate.

Analysis for average surface roughness (R_a)

After the examination of Fit Summary, result indicated that the quadratic model is statistically significant for average surface roughness and therefore it will be utilized for further analysis.

Mathematical model for R_a

The regression model for average surface roughness in terms of coded factors is shown as follows:

$$Ra = +1.69 - 0.16 * A + 0.44 * B + 0.20 * C - 0.032 * A * B - 0.011 * A * C + 0.14 * B * C + 0.060 * A^2 - 0.070 * B^2 - 0.016 * C^2 \quad (4.1)$$

While, the regression model for average surface roughness in terms of actual factors is:

$$Ra = +1.30060 - 4.85590E\text{-}003 * \text{Cutting Speed} + 3.42891 * \text{Feed} + 0.25435 * \text{Depth of Cut} - 2.86667E\text{-}003 * \text{Cutting Speed} * \text{Feed} - 1.02222E\text{-}003 * \text{Cutting Speed} * \text{Depth of Cut} + 6.30000 * \text{Feed} * \text{Depth of Cut} + 1.07394E\text{-}005 * \text{Cutting Speed}^2 - 3.11515 * \text{Feed}^2 - 0.69293 * \text{Depth of Cut}^2$$

ANOVA analysis for R_a

The ANOVA is commonly used to perform test for significance of the regression model, test for significance on individual model coefficients and test for lack-of-fit of model. This analysis was carried out for a significance level of α = 0.05, i.e. for a confidence level of 95%.

The value of "Prob. > F" for model is 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it shows that the terms in the model have a significant influence on the response.

For the Insignificant value we use backward elimination for getting best model and eliminating the not significant term or improver the R-Squared value.

Final mathematical model for R_a

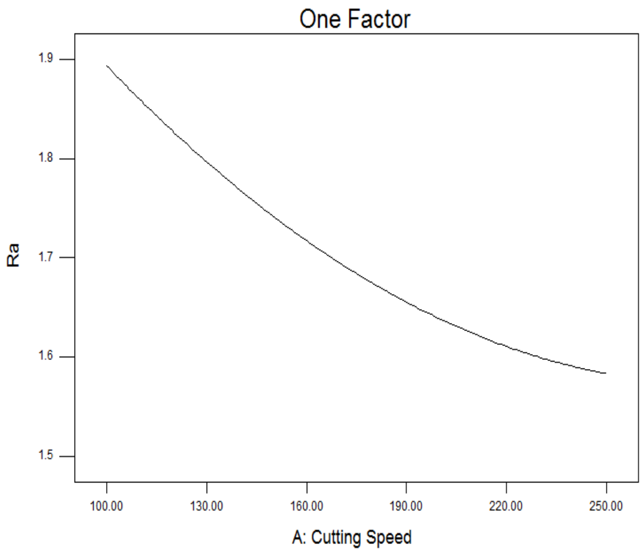
The final regression model for average surface roughness in terms of coded factors is shown as follows:

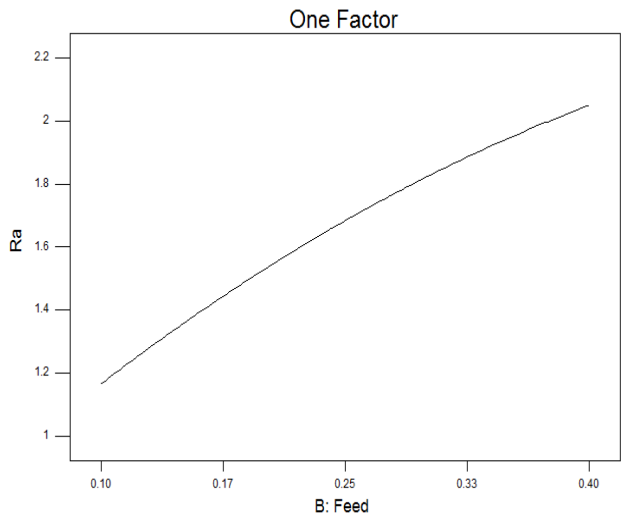
$$Ra = +1.68 - 0.16 * A + 0.44 * B + .20 * C - 0.032 * A * B + 0.14 * B * C + 0.055 * A^2 - 0.076 * B^2 \quad (4.3)$$

While, the regression model for average surface roughness in terms of actual factors is

$$Ra = +1.33861 - 4.74767E\text{-}003 * \text{Cutting Speed} + 3.55883 * \text{Feed} - 0.27100 * \text{Depth of Cut} - 2.86667E\text{-}003 * \text{Cutting Speed} * \text{Feed} + 6.30000 * \text{Feed} * \text{Depth of Cut} + 9.70000E\text{-}006 * \text{Cutting Speed}^2 - 3.37500 * \text{Feed}^2$$

Effect of cutting parameters on average surface roughness. Figure 1 shows as cutting speed increases the average surface roughness decreases. As feed increase the average surface roughness also increases and as depth of cut increases then the average surface roughness slightly increases because higher feed rate traverses the work piece too speedily resulting in deteriorated surface quality and also high feed increase the chatter, which leads to higher surface roughness.





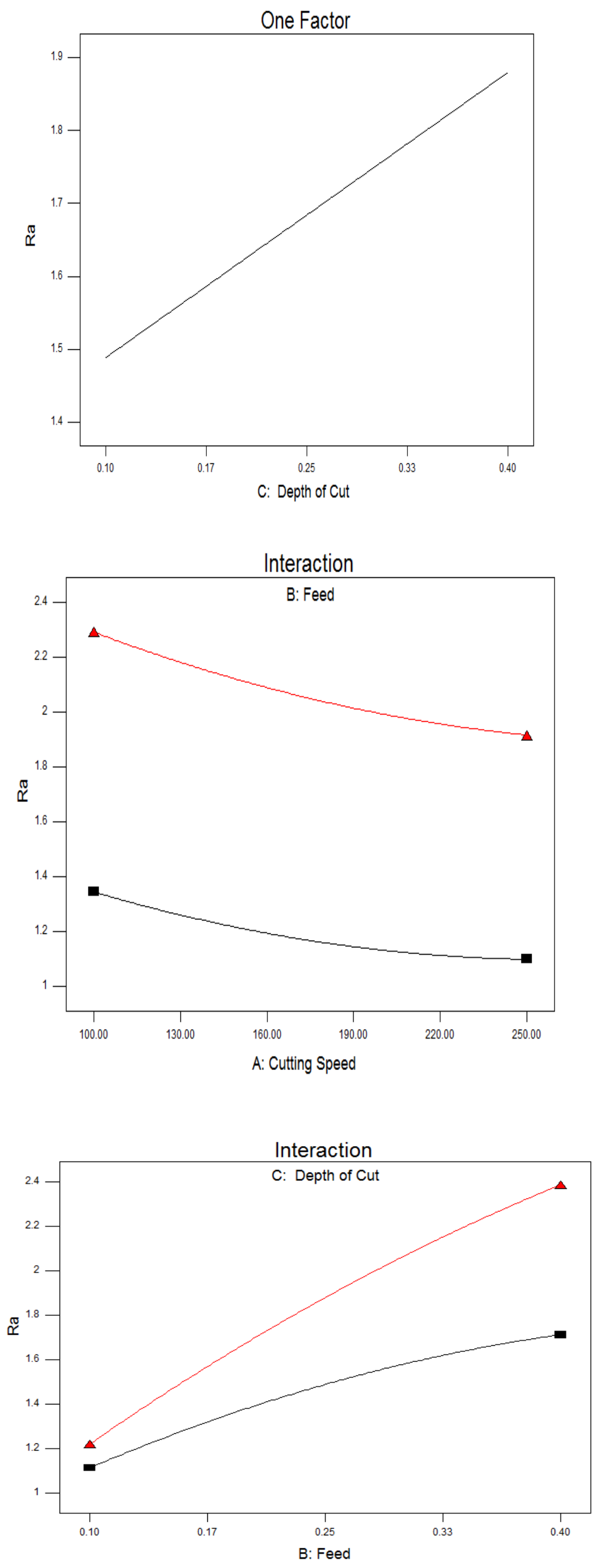


Fig. 1 Response graphs for Ra

Analysis for material removal rate

After the examination of Fit Summary, output indicated that the factorial model is statistically significant for material removal rate and therefore it will be utilized for further analysis.

Mathematical model for MRR

The regression model for material removal rate in terms of coded factors is shown as follows:

MRR = +26641.70 + 4105.19* A + 2350.49 * B + 3562.33 * C - 450.86 * A * B - 720.89

While, the regression model for material removal rate in terms of actual factors is:

MRR = + 3926.23917 + 80.77476 * Cutting Speed + 17584.04444 * Feed + 29863.36667 * Depth of Cut - 40.07667 * Cutting Speed * Feed - 64.07889 * Cutting Speed * Depth of Cut + 20397.22222 * Feed * Depth of Cut

ANOVA analysis for MRR

The ANOVA is commonly used to perform test for significance of the regression model, test for significance on individual model coefficients and test for lack-of-fit of model. This analysis was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%.

The value of "Prob. > F" for model is 0.0001 which is less than 0.05, that indicates the model is significant, which is desirable as it shows that the terms in the model have a significant influence on the response.

For the Insignificant value we use backward elimination for getting best model and eliminating the not significant term or improver the R-Squared value. Here all parameters are significant i.e. cutting speed ,feed and depth of cut and interaction between cutting speed and feed ,feed and depth of cut at last cutting speed and depth of cut all are significant so there is no need to reduce any model because elimination are used for eliminating the insignificant factors.

The equation no 4.5 and 4.6 are the final mathematical model for material removal rate in the terms of actual and coded factors.

Effect of cutting parameters on material removal rate

Fig. 2 shows as cutting speed increases the material removal rate also increases. As feed increase the material removal rate increases and as depth of cut increases then the material removal rate increases because all three are the dominating parameters for the material removal rate.

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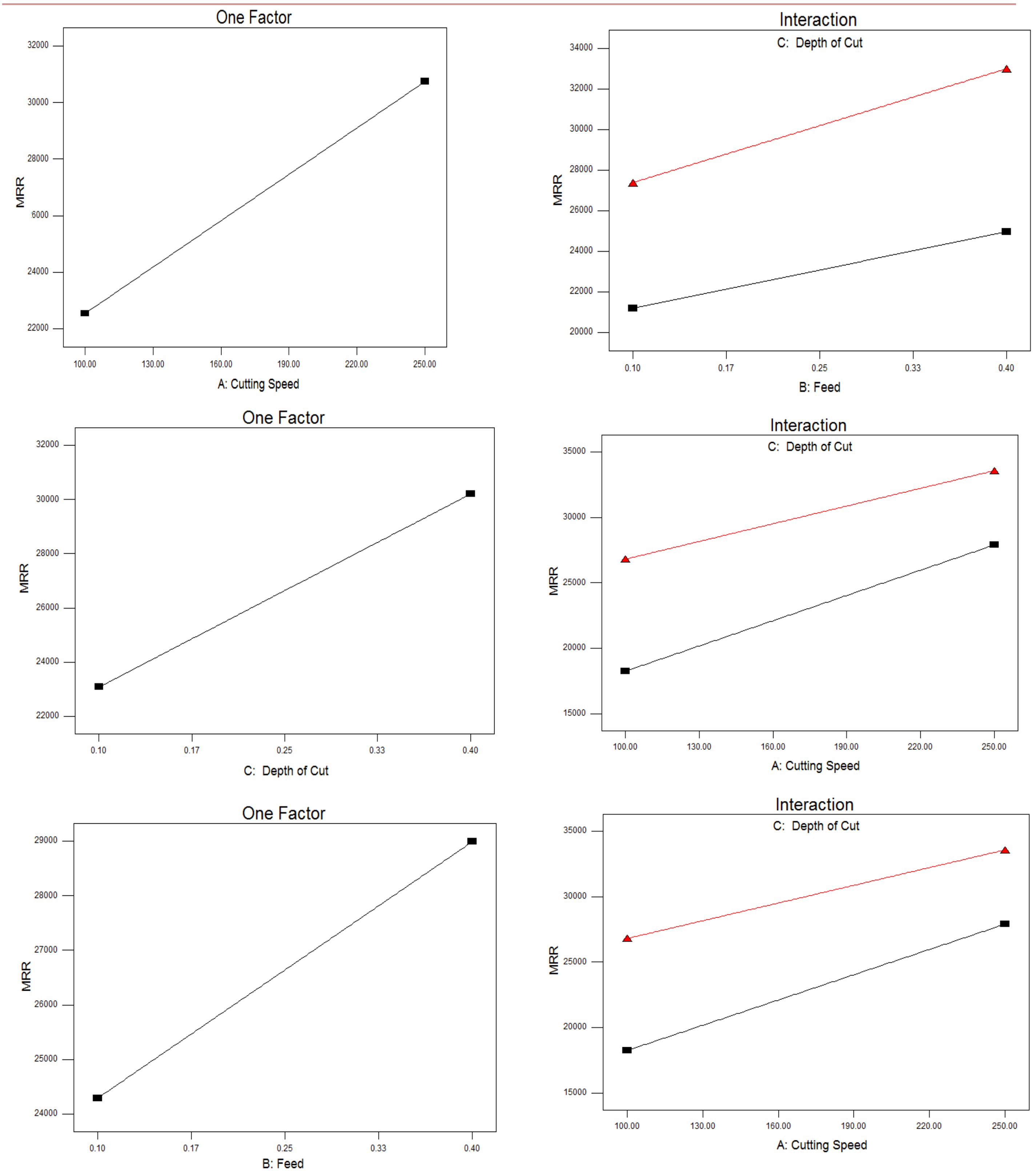

Fig. 2 Response Graphs for MRR

IV. CONCLUSIONS

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

1. Out of three parameters, feed seems to be the most important and influential machining parameter that affect the average surface roughness followed by depth of cut and the cutting speed for metal removal rate.
2. The depth of cut has significant for both the average surface roughness and metal removal rate for the MMC steel.
3. The mathematical models developed clearly show that surface roughness increases with increasing the feed but decreases with increasing the cutting speed.
4. The results of ANOVA and the confirmation runs verify that the developed mathematical models for surface roughness parameters shows excellent fit and provide predicted values of surface roughness that are close to the experimental values, with a 95 per cent confidence level.
5. The model can be used for direct evaluation of Ra and MRR under various combinations of machining parameters during turning of MMC steel.

V. FUTURE SCOPE

In this study, mathematical modeling and optimization has been attempted for average surface roughness and material removal rate. The work can be extended to consider more response variables like cutting forces, tool wear etc. Also, more machining parameters such as coolant concentration, tool angles etc can be introduced to have a better insight in to the process. Response such as tool life, power consumption can be added in this work.

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