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Optimization of Cutting Parameters in Turning of Aluminium7075 Alloy using RSM

K. Gopalakrishnan[1], M. Rajamani[2], M. Ramesh[3], S. Dinesh[4], V. Gowtham[5]
Department of Mechanical Engineering
KSR Institute for Engineering and Technology, Tiruchengode, Tamilnadu, India

Abstract:
The project is to investigate the effect of cutting parameters on the surface roughness and metal removal rate in aluminium 7075 alloy turning. Aluminium is the lightest material which has the density of 2.8 g/mm^3. The results and material of this experiment can be applicable in the manufacture of aircraft and aerospace industry. This experiment can be done using the Computer Numerical Controlled (CNC) turning Machine with ceramic insert. The parameter like speed, feed rate and depth of cut will be changed for each experiment. For this Minitab 18 Statistical software is used and the results will be determined using Response Surface Methodology (RSM). The developed RSM model was tested using Analysis of Variance (ANOVA).

Keywords: Aluminium alloy 7075, CNC milling machine, end milling, carbide tool, surface roughness, Response surface methodology.

1.INTRODUCTION

Generally manufacturing processes are developed to achieve either maximum productivity or minimum cost. A CNC machine plays the major role in industries during the manufacturing process they also follow this type of traditional manufacturing. Turning is the most common process in manufacturing setups it is a process of removing material by positioning a tool against a revolving job, and this tool is referred as a turning tool. The tool has sharp edges to remove material present it makes it a fast method of machining. Expanding the profitability and the nature of the machined parts are the primary difficulties of metal-based industry: there has been expanded enthusiasm for checking all parts of the machining procedure. Surface completion is an imperative parameter in assembling designing. It is a trademark that could impact the execution of mechanical parts and the generation costs. Machining operations have been the centre of the assembling business since the modern insurgency and the current improvement inquiries about for Computer Numerical Controlled (CNC) turning. [1]. The application of the fuzzy logic integrated with taguchi method for minimizing the surface roughness and maximizing the material removal rate simultaneously, in CNC end milling of AL7075 T6 aerospace Aluminium alloy. The input parameters taken into consideration are speed, feed, depth of cut and nose radius. AL7075 T6 is one of the highest strength Aluminium alloy in 7000 series family [2]. The work piece material was Aluminium 7075- T6 material was chosen in this study is usually employed in the aerospace industry to manufacture components that demand: lighter, harder, stronger, tougher, stiffer, more corrosion- and erosion-resistant properties [3]. The trained ANN is able to predict the Ra values with reasonable accuracy. Taguchi S/N ratio analysis and ANN are useful to find the optimum combination of parameters for getting a good surface finish [4]. S/N noise ratio and Analysis of Variance (ANOVA) approve that parameter more significant affect the surface roughness is feed rate follow by cutting speed and depth of cut. Almost the correlation between dependent variable with independent variable very close and strong, which is approval by using multiple regression analysis. The value experiment with calculated almost closed. It means the Taguchi method have produced more accurate prediction value [5]. Tool life of ball nose end mill depending on up-copying and down-copying. The aim was to determine and compare the wear of ball nose end mill for different types of copy milling operations for various tool materials. Moreover, surface roughness in up-copying and down-copying was also measured and compared [6]. The experiment to find the surface roughness through feed cutting forces. They have used finite element modelling (FEM). It is considered a famous method belonging to the numerical simulation methods [7]. The parameter optimization of end milling operation for Inconel 718 super alloy with multi-response criteria based on the taguchi orthogonal array with the grey relational analysis. Nine experimental runs based on an L9 orthogonal array of Taguchi method were performed [8]. The effect of machining parameters spindle speed, feed and depth of cut were investigated during Face Milling of Wrought Cast Steed grade B(WCB).23 full factorial design with four centre points is selected to perform the reliable experiments. Here the response parameters selected are surface roughness and flatness. To achieve the desire value of flatness and surface roughness machining parameters need to be controlled [9]. The study of Taguchi optimization method for low surface roughness value in terms of cutting parameters when face milling of the cobalt-based alloy (stellite 6) material. The milling parameters evaluated are feed rate, cutting speed and depth of cut, a series of milling experiments are performed to measure the surface roughness data [10]. The process has been analysed using a Response Surface Method in order to obtain a model fit for the fine tuning of the process parameters. The present study analyses the effect of simultaneous variations of four cutting parameters (cutting speed, feed rate, and radial and axial depth of cut) on energy consumption. For this purpose, the Response Surface Method (RSM) is utilized [11]. An experimental study related to the optimization of cutting parameters in roughing turning of AISI 6061 T6 aluminium. Energy consumption and surface roughness were minimized, while the material removal rate of the process was maximized [12]. The predictive models of these three energy components are developed for orthogonal cutting mode, and the influences of cutting speed, undeformed chip thickness and tool rake angle on the cutting energy consumption are revealed [13]. Feed rates, cutting speeds and depth of cut were investigated to determine the effect of machining parameters on the surface roughness and the cutting force. The full factorial experimental cutting parameters with three factors and four levels involve 54 experimental results [14]. The effect of machined surface inclination angle, axial depth of cut, spindle speed and feed rate for better surface integrity in inclined end milling process utilizing titanium coated carbide ball end mill [15].

1.1ALUMINIUM 7075

7075 aluminium alloy's composition roughly includes 5.6-6.1% zinc, 2.1-2.5% magnesium, 1.2-1.6% copper, and less than a half percent of silicon, iron, manganese, titanium, chromium, and other metals. It is produced in many tempers, some of which are 7075-0,7075-T6, 7075-T651.The first 7075 was developed in secret by a Japanese company, Sumitomo Metal, in 1943. 7075 was eventually used for airframe production in the imperial Japanese Navy.

1.2 MECHANICAL PROPERTIES

Tensile strength	83.000 psi
Yield point	74.000 psi
Brinell hardness	150
Elongation at break	10%
Shear strength	48000 psi
Thermal conductivity	130 W/m-K
Strength to weight ratio	196 kN-m/kg

1.3 CUTTING PARAMETERS

- Speed
- Feed
- Depth of cut

1.4 RESPONSE SURFACE METHODOLOGY (RSM)

It explores the relationships between several explanatory variables and one or more response variables. The method was introduced by George E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but they use it because such a model is easy to estimate and apply, even when little is known about the process.

1.5 ANOVA

Since there are a large number of variables controlling the process, some mathematical models are required to represent the process. However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response.

1.6 Minitab 18

It is a popular & powerful statistical software package that provides a wide range of data analysis capabilities. Minitab allows the user to create, manipulate and restructure data, produce a variety of graphs from simple charts to detailed diagrams and perform comprehensive statistical analysis. Minitab Inc is the provider of software and services for quality improvement and statistic education. Minitab is statistical data analysis software that provides a broad range of basic and advanced data analysis techniques. It includes regression techniques (general and logistic), analysis of variance, experimental design, control charts and quality tools, survival analysis, multivariate analyses (principal components, cluster and discriminate), time series, descriptive and non-parametric statistics, exploratory data analysis, power and sample-size calculations statistics package that permits Mac users to use a spread software.

2.EXPERIMENTAL DETAILS

2.1 DESIGN OF EXPERIMENTS

The design of experiments technique is an important tool, which permits us to carry out the modelling and analysis of the influence of process variables on these variables. The response variable is an unknown function of the process variables, which are known as design factors. In the present study, 15 numbers of experiments based on a three level- three factors Box-Behnken design in RSM were performed to obtain surface roughness values measured from aluminium7075 alloy under wet conditions. The machining parameters such as spindle speed, depth of cut and feed rate are considered as design factors.

Table 2.1: Chemical composition of aluminium 7075 alloy (wt, %)

Si	Fe	Cu	Mn	Mg	Zn	Cr	Pb	Ni	Sn	Ti	Al
0.075	0.13	1.53	0.008	2.51	5.56	0.18	0.004	0.003	0.002	0.09	89.9

Table 2.2: Process parameters and levels used in the experimentation

Parameters	Code	Unit	Level-1	Level-2	Level-3
Spindle speed	S	Rpm	2000	2500	-
Feed rate	F	mm/min	200	250	300
Depth of cut	D	mm	0.25	0.4	0.5

2.2MEASUREMENT OF SURFACE ROUGHNESS:
Surface roughness is an important measure of the technological quality of a product and a factor that greatly influences manufacturing cost. In the present study, 18experiments were conducted and 18 Ra values were measured from the machined area. And then, the average of these values was recorded by a TRI10 Surface roughness tester instrument. Surface roughness measurement in the material by using TRI10 Surface Roughness Tester instrument

Table 2.3: Experimental results for surface roughness and MRR

Run order	Blocks	Spindle speed, S, (rpm)	Feed rate, F, (mm/min)	Depth of cut, D, (mm)	Surface roughness, Ra, (µm)	MRR (mm^3/min)
1	1	2000	200	0.25	1.56	2500
2	1	2000	200	0.40	1.01	4000
3	1	2000	200	0.50	1.46	5000
4	1	2000	250	0.25	2.17	3125
5	1	2000	250	0.40	2.15	5000
6	1	2000	250	0.50	2.23	6250
7	1	2000	300	0.25	3.10	3750
8	1	2000	300	0.40	2.87	6000
9	1	2000	300	0.50	2.85	7500
10	1	2500	200	0.25	0.99	2500
11	1	2500	200	0.40	1.03	4000
12	1	2500	200	0.50	1.60	5000
13	1	2500	250	0.25	2.06	3125
14	1	2500	250	0.40	1.95	5000
15	1	2500	250	0.50	2.11	6250
16	1	2500	300	0.25	2.88	3750
17	1	2500	300	0.40	3.47	6000
18	1	2500	300	0.50	2.77	7500

Formula for Calculation of Ra:
Ra = -1.989 - 0.000109 Spindle speed + 0.01707 Feed rate + 0.236 Depth of cut

Table 2.4: Estimated Regression Coefficients for surface roughness

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1.989	0.658	-3.02	0.009	
Spindle speed	-0.000109	0.000228	-0.48	0.640	1.00
Feed rate	0.01707	0.00140	12.23	0.000	1.00
Depth of cut	0.236	0.554	0.43	0.677	1.00

Table 2.5: Estimated Regression Coefficients for average surface roughness

S	R-Sq	R-Sq(adj)	R-Sq(pred)
0.241648	91.47%	89.64%	85.48%

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Table 2.6: Analysis of Variance for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	8.76205	2.92068	50.02	0.000
Spindle speed	1	0.01334	0.01334	0.23	0.640
Feed rate	1	8.73813	8.73813	149.64	0.000
Depth of cut	1	0.01058	0.01058	0.18	0.677
Error	14	0.81751	0.05839		
Total	17	9.57956			

2.4 RESPONSE SURFACE REGRESSION:(Metal Removal Rate versus Spindle speed, Feed rate, Depth of cut)
The material removal rate, MRR. can be defined as the volume of material which removed divided by the machining time. Another way to define MRR is to imagine an " Instantaneous " material removal rate as there is at which the cross-section area of material being removed moves through the work piece.
Formula:
MRR= Depth of cut (mm)* Width of cut (mm) * Feed rate (mm/min).

The results from the machining trails were input into the MINITAB 16 software for the further analysis. A quadratic polynomial regression model was created by employing the MRR values to illustrate the fitness of experimental measurements. In Table, R2 value is 99.69% and adjusted R2 value is 99.55%, which is desirable. When adjusted R2 value close to 100%, the multiple regression models match very well with experimental measurements. Adjusted R2 value 99.55% also agrees with the multiple regression models and provides a very good relationship between machining parameters such as spindle speed, feed rate and depth of cut and surface roughness.

Formula for calculation of MRR

MRR	=	-4792 + 0.000 S + 19.17 F + 12500 D

Table 2.7:Estimated Regression Coefficients for MRR

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-4792	647	-7.40	0.000	
Spindle speed	0.000	0.224	0.00	1.000	1.00
Feed rate	19.17	1.37	13.96	0.000	1.00
Depth of cut	12500	546	22.91	0.000	1.00

Table 2.8:Estimated Regression Coefficients for average MRR

S	R-Sq	R-Sq(adj)	R-Sq(pred)
237.797	98.09%	97.68%	96.34%

Table 2.9: Analysis of variance for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	40708333	13569444	239.96	0.000
Spindle speed	1	0	0	0.00	1.000
Feed rate	1	11020833	11020833	194.89	0.000
Depth of cut	1	29687500	29687500	525.00	0.000
Error	14	791667	56548		
Total	17	41500000			

3. RESULT AND DISCUSSION

A confirmation experiment was an important process for to validate the predicted optimal values after experimental trails. In the present work confirmation experiment was conducted for the optimal machining parameters such as spindle speed 0 mm/min and depth of cut 0.25 mm. The surface roughness (R) value was repeated at least two times and then, the average surface roughness value was recorded by TRII0 Surface Roughness Tester instrument. The measured 3000, surface roughness value (0.99) was very close to the minimum surface roughness (0.99) in the table

3.1 RESIDUAL PLOTS FOR Ra:

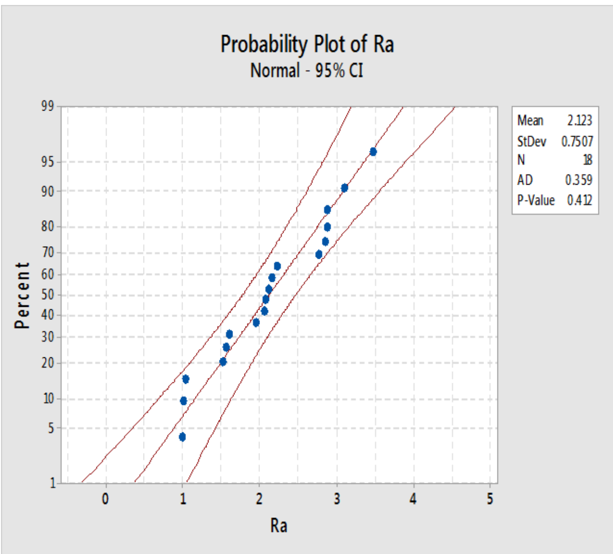

Figure.3.1: Residual plots of Surface Roughness (Ra)

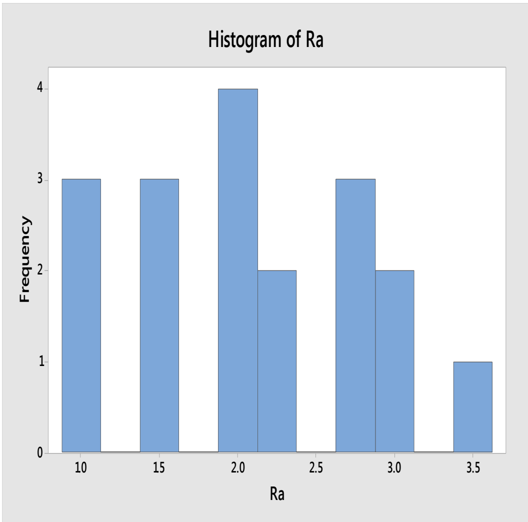

Figure.3.2: Histogram of Surface Roughness (Ra)

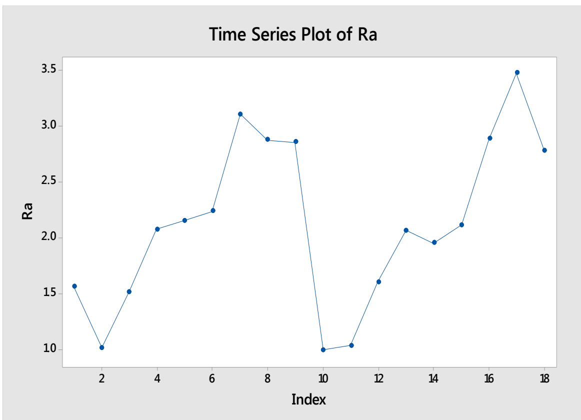

Figure.3.3: Time Series Plot of Surface Roughness (Ra)

3.2 SURFACE PLOTS FOR Ra:

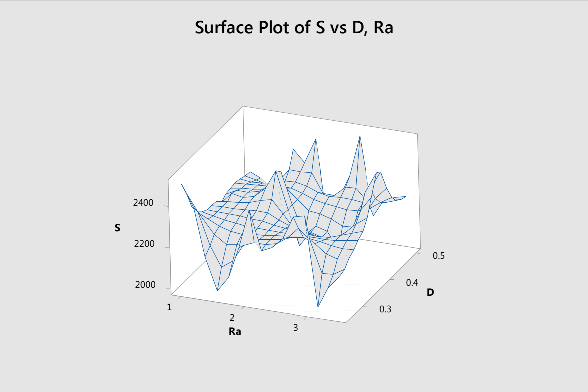

Figure.3.5: Speed vs Depth of cut in Surface plot for Ra

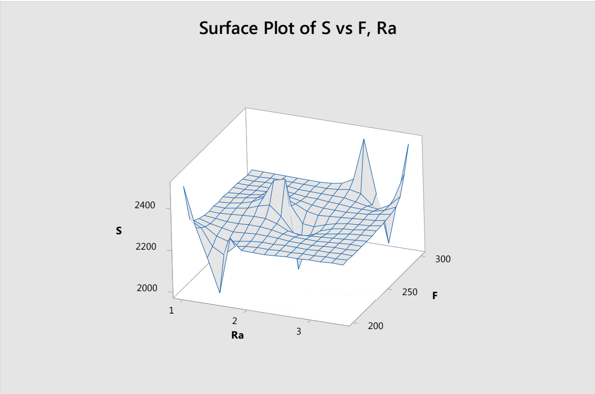

Figure.3.7: Spindle speed vs Feed rate for Surface Roughness (Ra)

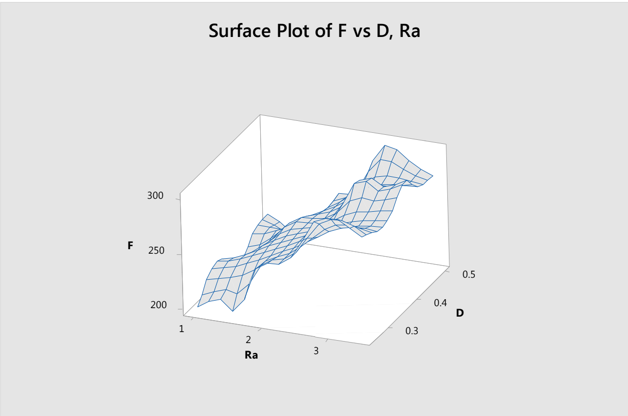

Figure..4: Feed rate vs Depth of cut in Surface plot for Ra

3.3 RESIDUAL PLOTS FOR MRR:

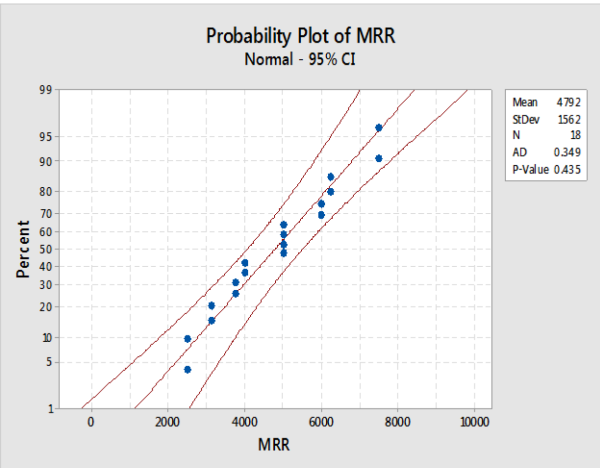

Figure.3.6: Residual Plot for Metal Removal Rate (MRR)

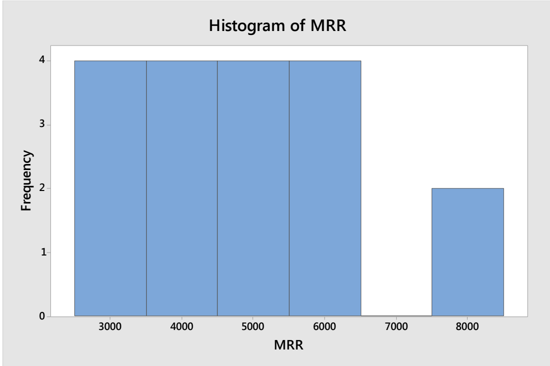

Figure. 3.8: Histogram of Metal Removal Rate (MRR)

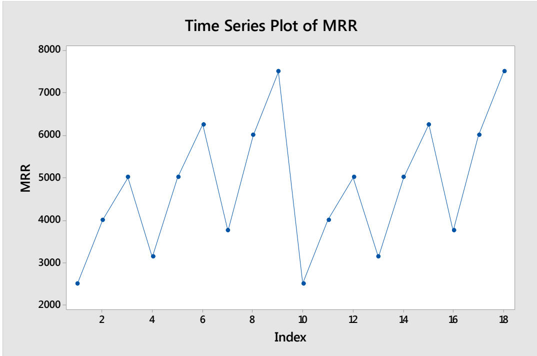

Figure.3.9: Time series plot of Metal Removal Rate (MRR)

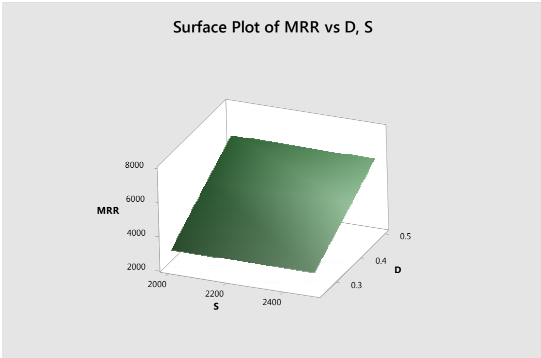

Figure. 3.11: Metal Removal Rate vs Depth of cut for MRR

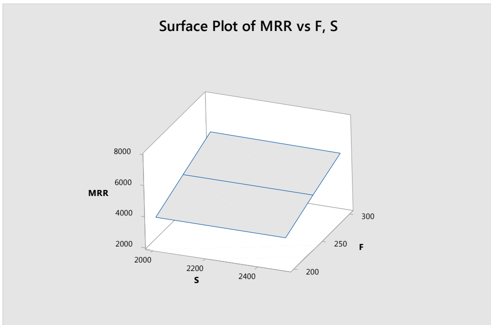

Figure. 3.10: Metal Removal Rate vs Feed rate for MRR

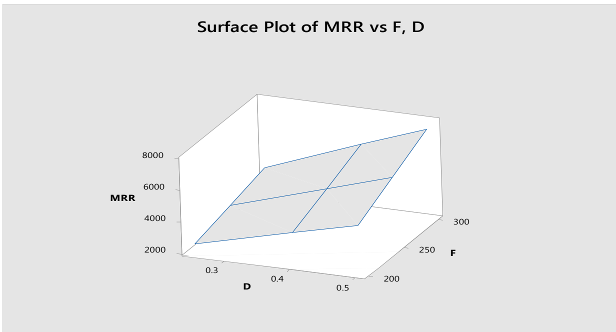

Figure. 3.12: Metal Removal rate vs Feed rate for MRR

In the present study, the better combinations of machining param selected to provide the lower surface roughness and higher metal removal rate in the milling of the aluminium 7075 alloy under wet condition Quadratic polynomial regression model was developed based on RSM using Box-Behnken design. The developed RSM model was tested through ANOVA. An ANOVA analysis was performed to indicate the influence of three machining parameters on the surface roughness and MRR. The following least two times and then, the average surface roughness value was recorded by TRI10 Surface Roughness Tester instrument. The measured surface roughness value (0.12) w roughness (0.12) in the Table 3.3. Therefore, the confirmation experiment i indicated that the selection of the optimal levels for the all the machining parameters produced the low surface roughness.

3.4 OPTIMAL VALUE FOR THE MILLING OF ALUMINIUM 7075 ALLOY:

Table 3.1: Optimal value's

Spindle speed	Feed rate	Depth of cut
3000 rpm	200 mm/min	0.25 mm

4.CONCLUSION

Conclusions were summarized from the results and discussion, from the regression analysis, R2 was found to be 96.12% and adjusted R2 was 91.24% Therefore, the surface roughness (Ra) values are adequate to construct the prediction model for surface roughness. From ANOVA results, the feed rate was found to be most significant factor effects surface roughness of milled surface. Depth of cut and spindle speed were other machining parameters affecting the surface roughness. Surface plots clearly show the surface roughness increases rapidly with the eases in feed rate and depth of cut. So, it is recommended to employ smaller feed rate and depth of cut to achieve low surface roughness. From the regression analysis, R2 was found to be 99.69% and adjusted R2 was 9955% Therefore, the surface roughness (R.) values are adequate to construct the prediction model for surface roughness. Surface plots clearly show the metal removal rate increases rapidly with the increases in feed rate and depth of cut. So, it is recommended to employ higher feed rate and depth of cut to achieve high metal removal rate.

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