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Experimental Investigation Of Surface Roughness and MRR in Turning on EN 18 Steel Using Response Surface Methodology

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***Abstract*— in industries increasing the quality and the productivity of the machined parts under process are the main challenges faced today; there has been increased interest in monitoring all the machining techniques and developing new methods to improve productivity. The turning operation is gaining much importance in the present industrial age. Turning is one of the most common process used in manufacturing sector to produce smooth finished cylindrical workpieces. The main purpose of this research is to study the surface roughness(Ra) and material removal rate(MRR) in turning on EN 18 Steel workpiece by using three input parameters i.e. spindle speed, feed rate and depth of cut. The turning was done using a CNC Lathe machine and surface roughness was measured with the help of portable Mitotoyo Surftest-4 tester. In this research Response surface methodology was used to find the optimum machining parameters resulting in minimum surface roughness and maximum material removal rate in turning process.**

***Index Terms*— CNC lathe, EN 18 steel, Material removal rate, Response surface methodology, Surface roughness.**

I. INTRODUCTION

Since ages the lathe machine has been widely used in the industrial sector. Within that time frame there have been many improvements in the lathe. This improvement ranges from making lathe a easy component for use, as well as increasing the range of materials possible to machine on lathe. But with the time the demand of manufacturing complicated components with high accuracy in large quantity has also increased. Now, these machines have been attached with a computer to generate highly accurate results and in very short span of time. And these machines are now known as CNC machines. CNC means Computer Numerical Control machines. The design and construction of these sophisticated machines are somewhat different form conventional machines. Turning is a commonly used process in production industries for manufacturing many products. With the help of CNC lathe now it has become possible to make complex products with quite ease. And due to this CNC's find wide application in industries now. On the other side, EN-18 is an alloyed medium carbon steel which is used for manufacturing of shafts, stressed pins, studs, keys etc. All these components are manufactured by most useful and easy process i.e. turning. Minimum surface roughness and maximum MRR of the turned part is of great importance in industries. Therefore, optimization of input process parameters for CNC lathe machine are necessary to full fill the increasing demands related to minimum surface roughness and maximum material removal rate.

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II. EXPERIMENTAL PROCEDURE

In this experimental work Design Expert 7.0.0 (dx7) software with Central Composite Design (CCD) approach was used to develop the experimental plan for multi response optimization. Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. RSM was introduced by G.E.P.BOX and K.B.WILSON in 1951. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). The experiment was conducted on a HMT Stallion CNC lathe machine and surface roughness was measured using a portable Mitotoyo Suftest-4 tester. This experiment consist of three process parameters to be varied in three discrete levels consisting of 15 combinations of spindle speed, longitudinal feed rate and depth of cut. The same software was also used to analyse the collected Result data. And Desirability was found with help of numerical optimization. The Desirability ranges from zero to one (least to most desirable respectively). Lastly predicted results were then validated by comparing with experimentally obtained results.

A. Flow Process Chart

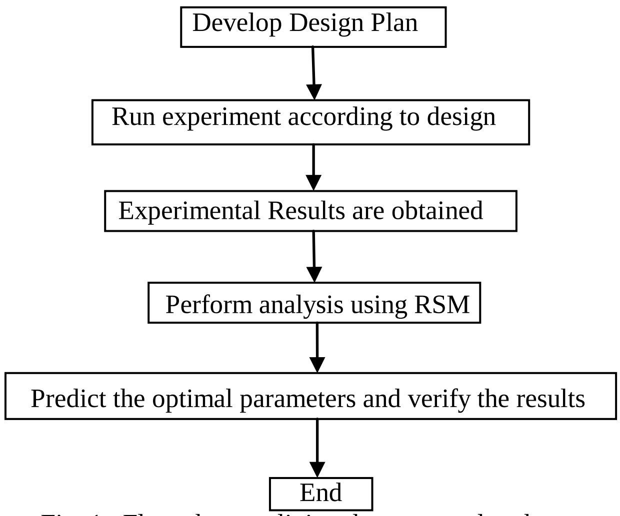


Fig. 1. Flow chart outlining the steps undertaken

B. Workpiece Material

In present study, EN-18 alloyed medium carbon steel is used which offers more strength and toughness than mild steel. It is suitable for use in shafts, couplings, pins, rolls, spindles, torsion bars, gears, axles, keys, damper, shafts, studs, cold headed keys parts.

Table 1: Chemical Composition of EN-18

ELEMENT	PERCENTAGE
C	.35 - .45
Mn	.60 - .95
Si	.10 - .35
S	.050
P	.050
Cr	.85 -1.15

Fig. 2. Turned EN-18 Workpiece

C. Process variables and their levels

The working ranges of parameters for subsequent design of experiment based on Response Surface Methodology have been selected. In the present experimental study spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 2

Table 2: Process Variables

Factors	Units	Level1	Level2	Level3
Spindle speed(N)	rpm	1500	2500	3500
Feed (F)	mm/min	0.05	0.20	0.50
Depth of cut (DOC)	mm	0.30	1.25	2.50

D. Experimental Result for Surface Roughness and Material Removal Rate.

The results of experiments obtained for average Surface Roughness and Material Removal Rate are given in Table 3. Here input parameters or factors are Speed, Feed and DOC (depth of cut) and Response variables are Surface Roughness (Ra) and Material Removal Rate (MRR).

Table 3: Results of main experiments for average R_a And MRR

	Factors			Responses	
	1	2	3	1	2
Std	Speed	Feed	DOC	Ra µm	MRR mm^3/sec
1	3500.00	0.50	0.30	1.78	1269.76
2	3500.00	0.05	2.50	1.70	1001.31
3	1500.00	0.50	2.50	1.58	1048.1
4	1500.00	0.05	0.30	3.05	969.3
5	1085.79	0.28	1.40	1.58	217.94
6	3914.21	0.28	1.40	2.39	1465.2
7	2500.00	0.04	1.40	1.68	1097.1
8	2500.00	0.59	1.40	2.40	1143.9
9	2500.00	0.28	0.26	2.40	1372.01
10	2500.00	0.28	2.96	2.01	1474.3
11	2500.00	0.28	1.40	1.99	1258.5
12	2500.00	0.28	1.40	0.98	1268.2
13	2500.00	0.28	1.40	1.86	1257.3
14	2500.00	0.28	1.40	0.30	1261.3
15	2500.00	0.28	1.40	2.45	1247.2

III. RESULTS ANALYSIS AND DISCUSSIONS

A. ANOVA tables for Surface Roughness and Material Removal Rate

Table 4: ANOVA for Ra

Source	Sum of Squares	DF	Mean Square	F Value	P-value	Remarks
Model	5.54	7	0.79	10.09	0.0034	Significant
A	0.100	1	0.100	1.27	0.2963	
B	0.18	1	0.18	2.29	0.1736	
C	0.013	1	0.013	0.16	0.6983	
A^2	0.55	1	0.55	7.05	0.0327	
B^2	0.65	1	0.65	8.27	0.0238	
AB	0.66	1	0.66	8.47	0.0226	
AC	2.28	1	2.28	29.03	0.0010	
Residual	0.55	7	0.078			
Lack of	0.13	3	0.044	0.43	0.7445	Insignificant
Pure	0.42	4	0.10			
Cor Total	6.09	14				
Std. Dev	0.28	C.V.%	14.93			
R-Squared	0.9099	Pred R-Squared	0.6689			
Mean	1.88	PRESS	2.02			
Adj R-Squared	0.8197	Adeq Precision	13.444			

Table 5: ANOVA for MRR

Source	Sum of Squares	DF	Mean Square	F Value	P- value Prob> F	Remarks
Model	1.263E+ 006	9	1.403E+ 005	2035.97	<0.0001	Significant
A	7.778E+ 005	1	7.778E+ 005	11285.46	<0.0001	
B	1095.12	1	1095.12	15.89	0.0105	
C	5231.62	1	5231.62	75.91	0.0003	
AB	13970.39	1	13970.39	202.70	<0.0001	
AC	9874.68	1	9874.68	143.27	<0.0001	
BC	2.851E+ 005	1	2.851E+ 005	4136.44	<0.0001	
A^2	3.280E+ 005	1	3.280E+ 005	4758.69	<0.0001	
B^2	34351.08	1	34351.08	498.40	<0.0001	
C^2	55208.87	1	55208.87	801.02	<0.0001	
Residual	344.62	5	68.92			
Lack of Fit	113.56	1	113.56	1.97	0.2335	Insignificant
Pure Error	231.06	4	57.76			
Cor Total	1.263E+ 006	14				
Std. Dev.	8.30	C.V.%	0.72			
R-Squared	0.9997	Pred R-Squared	0.9900			
Mean	1156.76	PRESS	12624.70			
Adj R-Squared	0.9992	Adeq Precision	185.343			

The ANOVA i.e. Analysis of Variance table is commonly used to summarize the performed test. ANOVA table shows the significance of model. If the "Prob.> F" is less than 0.05, this indicates the model is significant which is desirable as it also indicates that the model have a significant effect on the responses. The lack of fit test in the ANOVA table shows that the model is ready to fit or not. Insignificant lack of fit is desirable as we want the model to fit. The terms which are not significant are removed to improve the model. Table 4 shows the ANOVA table for Surface Roughness and Table 5 show the ANOVA table for Material Removal Rate. And it's clearly visible that both tables have Prob.> F less than 0.05, which indicates the model is significant and have Lack of fit value insignificant which shows that model fits well.

In both tables R squared value was high and close to one, which is desirable. The predicted R squared value is in reasonable agreement with Adj. R squared value. In this experimental work, the experimental results were used to develop the mathematical models using response surface methodology (RSM) on Design expert 7.0.0 software (dx7).

B. Response Surface Diagrams and Normal Plot of Residuals.

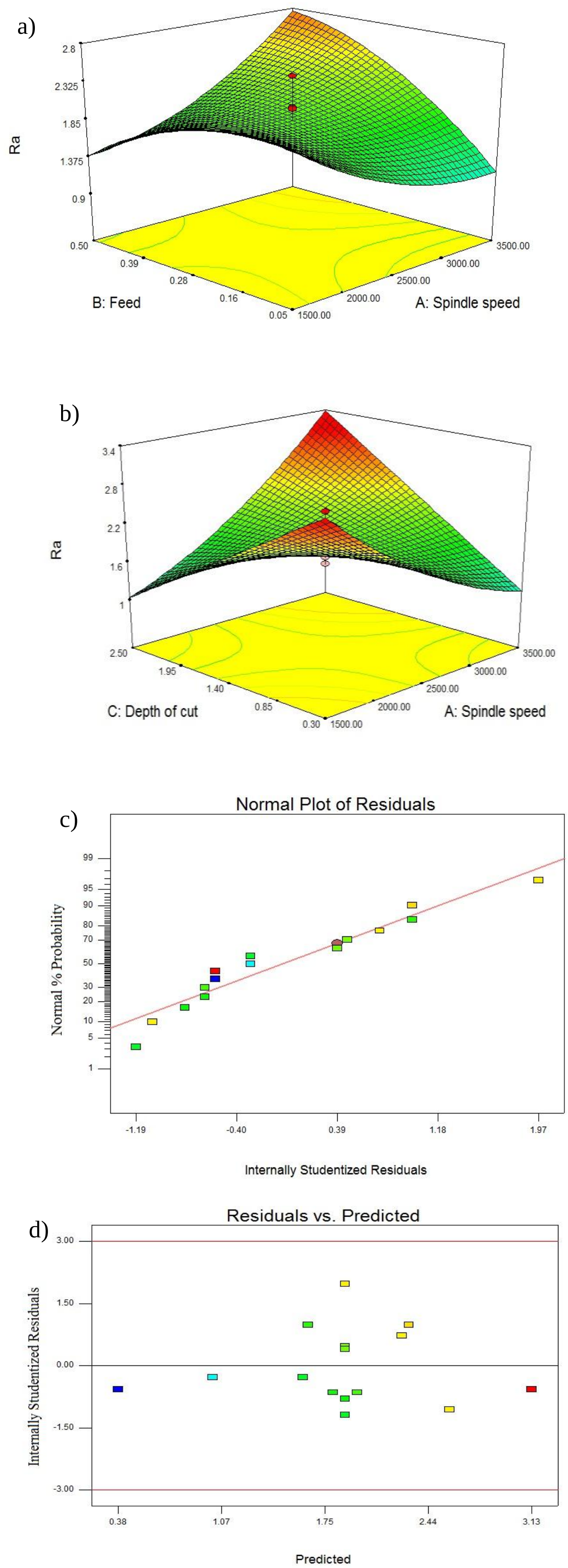
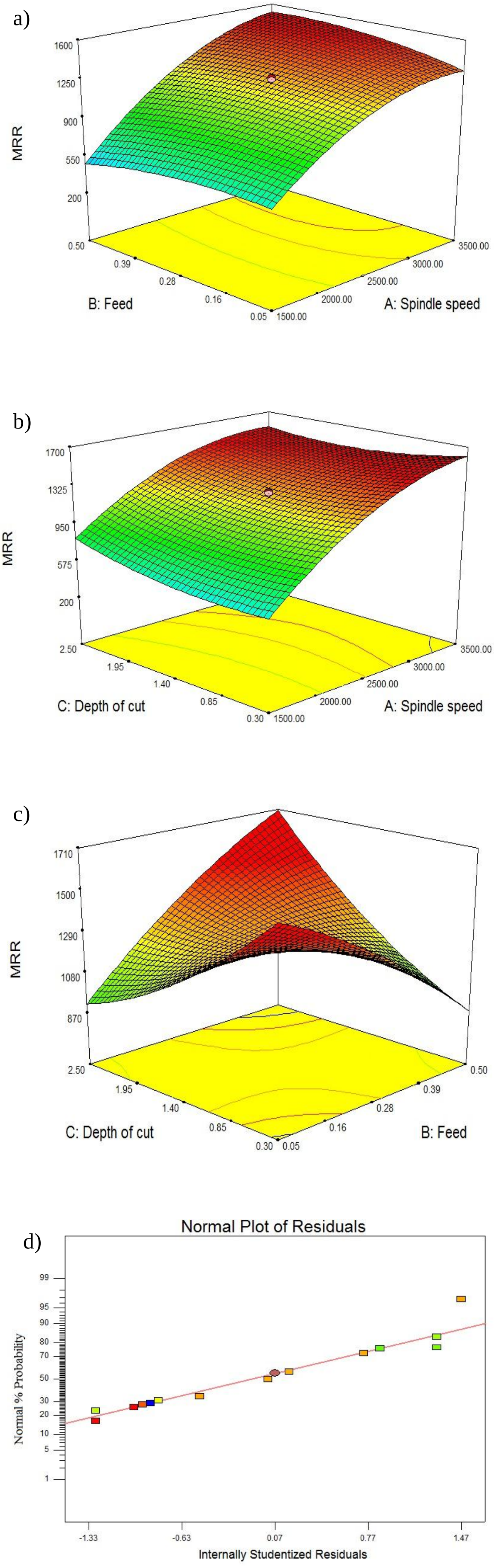


Fig. 3. (a,b) Response surface diagrams c) Normal plot of residuals and d) Residuals Vs Predicted for Surface Roughness (Ra).



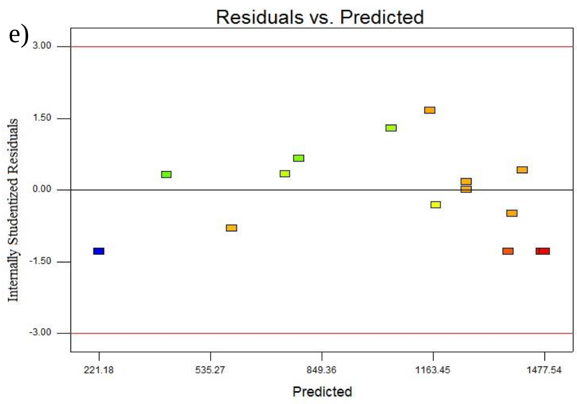


Fig. 4. (a,b,c) Response surface diagrams d) Normal plot of residuals e) Residuals Vs Predicted for Material Removal Rate (MRR).

The response surface diagrams for Ra are shown in Fig. 3 (a,b) which reveals that Ra decreases with increased value of Speed and DOC, whereas Ra shows a considerable increase with increased value of Feed. On the other hand response surface diagrams for MRR are shown in Fig. 4 (a,b,c) which reveals that MRR decreases with increased value of Feed and DOC and shows a considerable increase with increased value of Spindle speed. And adequacy was examined using residual plots. If the model is adequate, the points on the normal probability plots of the residuals will form a straight line. On the other hand the plots of the residuals versus the predicted response should be structure less, that is, they should contain no obvious pattern but all points lie between the red lines. The normal probability plots of the residuals and the plots of the residuals versus the predicted response for the surface roughness and MRR are given in Fig. 3(c,d) & Fig. 4(d,e) respectively. It can be clearly seen that proposed model is adequate and fits well

C. Regression Equations for Surface Roughness and Material Removal Rate

The regression equations are given below in both coded and actual factors. The insignificant coefficients are omitted from the equations. The developed statistical model for Surface roughness and Material removal rate are

Surface Roughness = $1.89 + 0.11 * A + 0.21 * B + 0.057 * C + 0.58 * A * B + 1.07 * A * C + 0.27 * A^2 - 0.29 * B^2$

Surface Roughness = $1.89 + 0.11 * speed + 0.21 * feed + 0.057 * depth\ of\ cut + 0.58 * speed * feed + 1.07 * speed * depth\ of\ cut + 0.27 * speed^2 - 0.29 * feed^2$.

Material Removal Rate = $1257.20 + 440.97 * A + 16.55 * B + 36.16 * C + 83.58 * A * B - 70.27 * A * C + 377.56 * B * C - 206.20 * A^2 - 66.73 * B^2 + 84.60 * C^2$

Material Removal Rate = $1257.20 + 440.97 * speed + 16.55 * feed + 36.16 * depth\ of\ cut + 83.58 * speed * feed - 70.27 * speed * depth\ of\ cut + 377.56 * feed * depth\ of\ cut - 206.20 * speed^2 - 66.73 * feed^2 + 84.60 * depth\ of\ cut^2$

D. Multiresponse Optimization for maximum MRR and Minimum Ra.

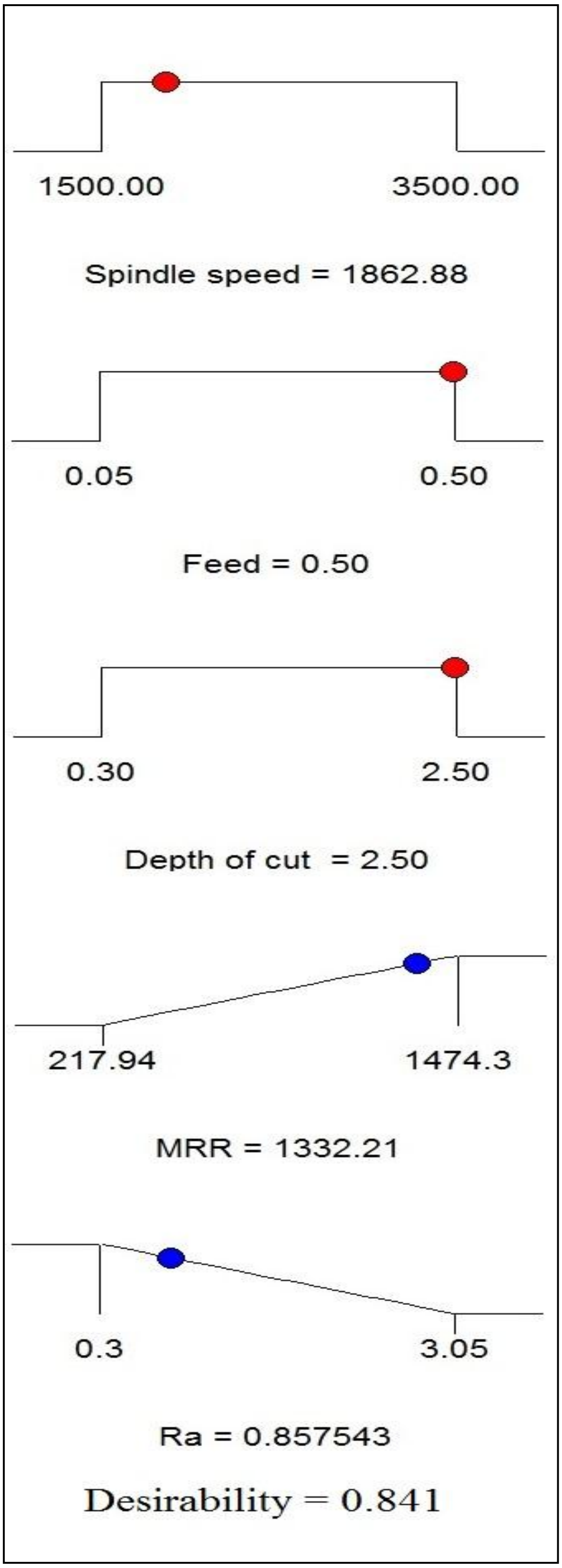


Fig. 5. Multi Response optimization diagrams

Table 6: Optimal parameters for Ra and MRR

Parameters	Units	Optimal parameters
Speed	RPM	1862.88
Feed	mm/min	0.50
Depth of cut	mm	2.50

Here, Fig. 5. Shows Multi Response optimization diagrams where Desirability value comes to be 0.841. And Table 6. Shows that the current optimum process parameter setting is spindle speed 1862.88 RPM, feed rate 0.50 mm/min. and depth of cut 2.50 mm.

E. Validation of experiment

Table 7: Experimental validations of developed models with optimal parameter settings

Responses	Predicted	Experimental	Error
Surface roughness	0.857543	0.904666	5.50 %
MRR	1332.21	1364.81	2.45 %

In order to validate the results obtained during experimentation work next step is to perform confirmation experiments for each of the response characteristics (MRR, SR) at optimal levels of the process variables. The average values of the characteristics were obtained and compared with the predicted values. The results are given in Table 7. This clearly shows that predicated results are in acceptable zone with respect to the experimental results of MRR and Surface roughness. This confirms that the developed model proves to be satisfactory.

IV. CONCLUSIONS

In this study, the surface roughness and MRR in the surface finishing process of EN-18 steel were modeled and analyzed through RSM. Spindle speed, feed and depth of cut have been employed to carry out the experimental study. Summarizing the main features, the following conclusion can be drawn:-

1. When analysed with ANOVA for both the response parameters, the "Pred R-Squared" is in reasonable agreement with the "Adj R-Squared" which shows absence of any problem with the data or the model.
2. When analysed with ANOVA for both the response parameters, the Lack of Fit value is insignificant which shows that the model fits the data well.
3. Adequacy of model with the normal probability plots of the residuals and the plots of the residuals versus the predicted response for the surface roughness and MRR revealed that the residuals generally fall on a straight line implying that the errors are distributed normally. And also that they have no obvious pattern and lie between red lines. Which implies that the model proposed is adequate and fits well.
4. From the multi response optimization, the optimal

combination of parameter settings are speed of 1862.88RPM, feed rate 0.50 mm/min. and depth of cut 2.50 mm for achieving the required minimum surface roughness and maximum MRR.

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