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Optimization of Machining Parameters during CNC Turning on Surface Roughness by using Response Surface Methodology

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Abstract—*In the present study the effects of various machining parameters such as cutting speed, feed rate, and depth of cut on surface roughness were experimentally observed. EN47 alloy steel is machined using tungsten carbide insert. Response Surface Methodology is used to design the experiment and for optimization of the input parameters. Surface plots and contour plots were generated by using response surface methodology to check the interaction of input parameters on the surface roughness of the component. From the analysis of the experimental result it is found that feed rate has maximum effect on surface roughness followed by cutting speed and depth of cut. The ranges of the machining parameters are feed rate (0.1 – 0.2 mm/rev), cutting speed (900 – 1300 rpm) and depth of cut (0.5 – 1 mm). The contribution of the effect of machining parameters on surface roughness is obtained by ANOVA analysis.*

1. INTRODUCTION

Turning and Facing is one of the most important metal cutting operations in industries. The process of turning is influenced by many factors such as spindle speed, feed rate, depth of cut, geometry of cutting tool, cutting conditions etc. The finished product with desired attributes of size, shape, surface roughness and cutting forces developed are functions of this input parameters. Properties like wear resistance, fatigue strength, coefficient of friction, lubrication, wear rate and corrosion resistance of the machined parts are generally influenced by surface roughness. And to get better surface finish many other processes are required like grinding, buffing and polishing. But due to their high cost and time consumption we try to get the best surface finish possible from basic turning and facing operation.

Jasvir et al. [1] outlined an experimental study to optimize the effects of cutting parameters on surface finish of Aluminium6061 work material with CNMG EN-TM (H20TI) on CNC lathe by employing RSM techniques. Three parameters were chosen as process variables: speed, feed, depth of cut. RSM full factorial technique and Minitab 16 statistical software is used. Optimal cutting parameters for, minimum surface roughness (SR) were obtained. K. Siva et al. [2] has experimentally optimized the process parameters of CNC End Milling for Aluminium6082. Experiments are done on the CNC milling machine and the optimization technique used is RSM. Machining parameters speed, feed rate and depth of cut are optimized for better surface finish of the product. Ihan et al. [3] has done an experimental study for the optimization of parameters affecting Surface roughness of Co28Cr6Mo medical material during CNC lathe machining by using the Taguchi and RSM methods. Input parameters that are considered are speed, feed rate, depth of cut and tool tip radius and was found that the most effective parameter is the tool tip radius followed by feed rate. Bikash et al. [4] has studied the effect on cutting forces and surface roughness during machining of Inconel 718 alloy using Minimum quantity lubrication technique. And found that with change in feed both the force and the surface roughness decreased appreciably under Minimum quantity lubrication environment compared to those under dry and wet environments. This experiment established that the overall machining performance of the Inconel alloy improved under MQL condition. Manish et al. [5] has determined the effect of process parameters on surface finish in CNC turning of 16MnCr5H steel. And this analysis proved that feed rate and cutting speed are the most influencing parameters on Surface finish while depth of cut is least significant as compared to feed rate and cutting speed.

Many work has been done in this field on different materials but not on EN47 alloy steel. And as En47 alloy steel has wide application in the motor vehicle industry and many general engineering applications like crankshafts, steering knuckles, gears, spindles and pumps. So in this study optimization of speed, feed and depth of cut has been done using Response Surface Methodology to get the best surface finish.

2. DESIGN OF EXPERIMENT

In this study, the experiment was designed using CCD method of Response Surface Methodology using Minitab software. Speed, feed rate and depth of cut are selected as design factors while other parameters have been assumed to be constant over

the experimental domain. The range of the machining parameters are 0.1 – 0.2 mm/rev, 900 – 1300 rpm and 0.5 – 1 mm for feed rate, cutting speed and depth of cut respectively. And after putting the value of ranges for different factors in Minitab software following table is obtained.

Table 1: Experimental table generated in Minitab using RSM

Experiment No.	Spindle Speed (rpm)	Feed (mm/rev)	Depth of Cut(mm)
1	1100	0.15	0.75
2	763.64	0.15	0.75
3	1100	0.23409	0.75
4	1100	0.15	0.75
5	1100	0.15	0.329552
6	1300	0.1	1
7	1100	0.15	0.75
8	1300	0.2	1
9	1100	0.06591	0.75
10	900	0.1	1
11	110	0.15	0.75
12	1300	0.2	0.5
13	1100	0.15	0.75
14	1100	0.15	1.170448
15	900	0.1	0.5
16	900	0.2	0.5
17	1100	0.15	0.75
18	900	0.2	1
19	1436.4	0.15	0.75
20	1300	0.1	0.5

3. EXPERIMENTAL WORK

Turning and facing operation was performed using MAXTURN PLUS, CNC Lathe machine tool of MTAB. Operations was performed on EN47 alloy steel bar of Φ34 × 150 mm using tungsten carbide insert of VNMG160408.

Fig. 1: MAXTURN + CNC lathe front view

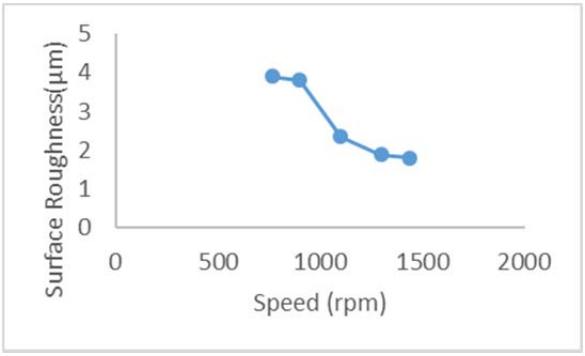
4. RESULT AND DISCUSSION

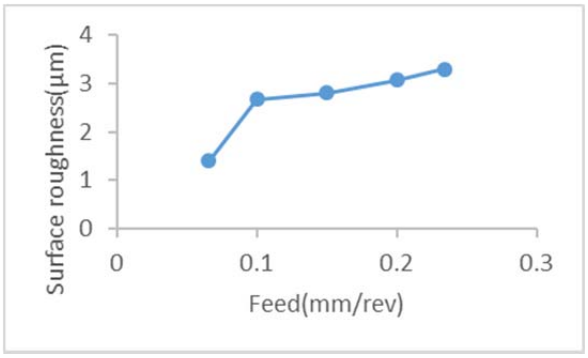
Surface roughness is measured for turned and faced surfaces after performing the experiments using the portable Handy Surf (E- 35 A, Tokyo Seimitsu) surface texture measuring instrument with 0.8 mm as cut- off length and stylus radius as 2 µm. Average surface roughness values are taken for analysis and following table showing the result obtained.

Table 2: Experimental values of surface roughness

Experiment No.	Spindle Speed	Feed	Depth of Cut	Ra Turning	Ra Facing
1	1100	0.15	0.75	2.36	2.4
2	763.64	0.15	0.75	3.90	4
3	1100	0.234	0.75	3.30	3.50
4	1100	0.15	0.75	2.21	2.26
5	1100	0.15	0.33	2	2.11
6	1300	0.1	1	1.8	1.87
7	1100	0.15	0.75	2.32	2.39
8	1300	0.2	1	2.1	2.11
9	1100	0.066	0.75	1.4	1.49
10	900	0.1	1	3.8	3.13
11	110	0.15	0.75	2.35	2.4
12	1300	0.2	0.5	2	2.11
13	1100	0.15	0.75	2.3	2.37
14	1100	0.15	1.17	3	3.06
15	900	0.1	0.5	3.5	3.61
16	900	0.2	0.5	4	4.13
17	1100	0.15	0.75	2.25	2.29
18	900	0.2	1	4.2	4.26
19	1436.4	0.15	0.75	1.9	1.87
20	1300	0.1	0.5	1.6	1.67

The data is further analyzed with the help of main effect plots. The plots show the variation of individual response with the three machining parameters spindle speed, feed rate and depth of cut separately.





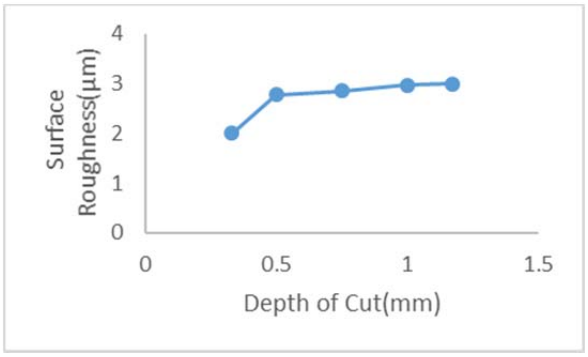
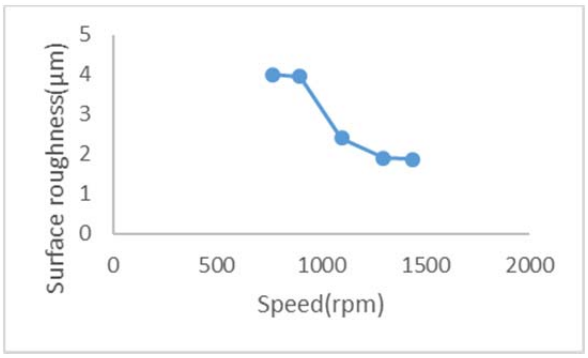
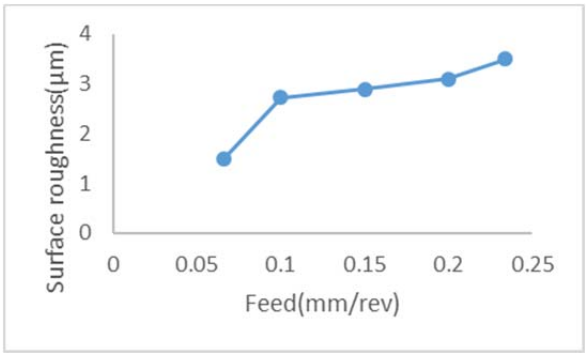


Fig. 2: Main effect plots for Ra turning vs speed, feed and depth of cut.





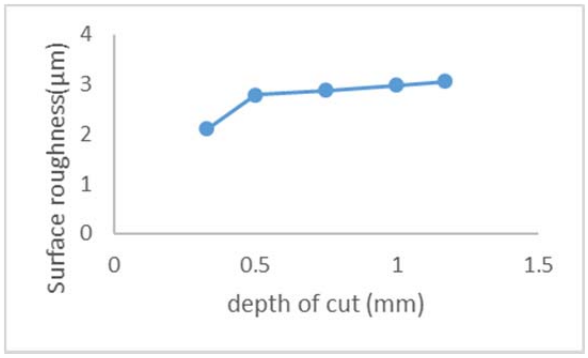


Fig. 3: Main effect plots for Ra facing vs speed, feed and depth of cut

Analysis of Variance (ANOVA) is used to study the effect of the input parameters speed, feed rate and depth of cut on the response variable that is surface roughness. Which shows the effect of individual parameters, their squares and their interactions on the response variable.

Estimated Regression Coefficients for roughness

Term	Coef	SE Coef	T	P
Constant	2.28947	0.15108	15.154	0.000
speed	-0.83208	0.10024	-8.301	0.006
feed	0.35114	0.10024	3.503	0.001
doc	0.18173	0.10024	1.813	0.100
speed*speed	0.27062	0.09758	2.773	0.020
feed*feed	0.07617	0.09758	0.781	0.453
doc*doc	0.12920	0.09758	1.324	0.215
speed*feed	-0.02500	0.13097	-0.191	0.852
speed*doc	-0.02500	0.13097	-0.191	0.852
feed*doc	-0.02500	0.13097	-0.191	0.852

S = 0.370442 PRESS = 10.3077
R-Sq = 90.34% R-Sq(pred) = 27.46% R-Sq(adj) = 81.65%

Analysis of Variance for roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	12.8366	12.8366	1.42629	10.39	0.001
Linear	3	11.5902	11.5902	3.86342	28.15	0.000
Square	3	1.2314	1.2314	0.41046	2.99	0.082
Interaction	3	0.0150	0.0150	0.00500	0.04	0.990
Residual Error	10	1.3723	1.3723	0.13723		
Lack-of-Fit	5	1.3552	1.3552	0.27104	79.33	0.000
Pure Error	5	0.0171	0.0171	0.00342		
Total	19	14.2089				

Fig. 4: ANOVA for turning operation

The effect on response variable of individual parameters and their interactions is inversely proportional to the p value corresponding to it. Lower the p value higher the effect on the surface roughness and vice versa. In this minimum p value is 0.001 which is corresponding to the feed rate, it means feed rate shows maximum effect on the surface finish. Maximum value of p is corresponding to the depth of cut it means depth

of cut has minimum effect on the surface roughness when operation is performed on the material.

Response Surface Regression: roughness versus speed, feed, DOC

The analysis was done using coded units.

Estimated Regression Coefficients for roughness

Term	Coef	SE Coef	T	P
Constant	2.34335	0.15067	15.553	0.000
speed	-0.85321	0.09997	-8.535	0.004
feed	0.36688	0.09997	3.670	0.000
DOC	0.15726	0.09997	1.573	0.147
speed*speed	0.26061	0.09731	2.678	0.023
feed*feed	0.10505	0.09731	1.080	0.306
DOC*DOC	0.13687	0.09731	1.406	0.190
speed*feed	-0.03375	0.13061	-0.258	0.801
speed*DOC	-0.01875	0.13061	-0.144	0.889
feed*DOC	-0.03625	0.13061	-0.278	0.787

S = 0.369423 PRESS = 10.2444
R-Sq = 90.74% R-Sq(pred) = 30.47% R-Sq(adj) = 82.40%

Analysis of Variance for roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	13.3685	13.3685	1.48539	10.88	0.000
Linear	3	12.1178	12.1178	4.03927	29.60	0.000
Square	3	1.2283	1.2283	0.40943	3.00	0.082
Interaction	3	0.0224	0.0224	0.00748	0.05	0.982
Residual Error	10	1.3647	1.3647	0.13647		
Lack-of-Fit	5	1.3461	1.3461	0.26921	72.05	0.000
Pure Error	5	0.0187	0.0187	0.00374		
Total	19	14.7333				

Fig. 5: ANOVA for turning operation

In this also minimum p value is 0.00 which is corresponding to the feed rate, it means feed rate shows maximum effect on the surface finish.

By using MINITAB surface and contour plots are generated that shows how interactions of two factors affect the surface roughness in 3D and 2D graphs. Surface graphs are 2D graphs and contour graphs are 3D graphs. Contour and surface plots for different interactions are discussed below.

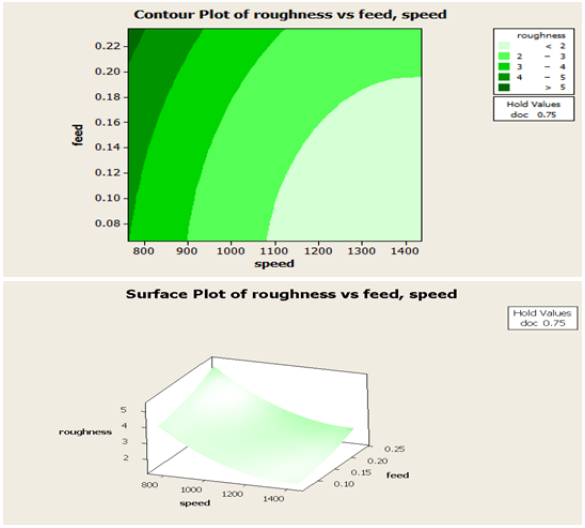


Fig. 6: Contour and Surface plots of Ra Turning(µm) vs feed, speed

These plots shows that surface roughness is minimum when the cutting speed is maximum and feed rate is minimum. Most significant parameter is feed rate. Surface roughness is maximum when feed rate is maximum and cutting speed is minimum.

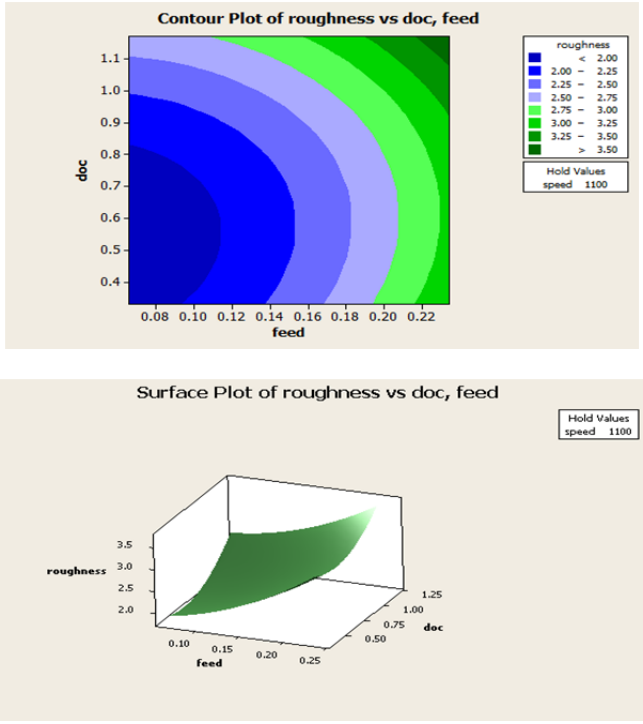
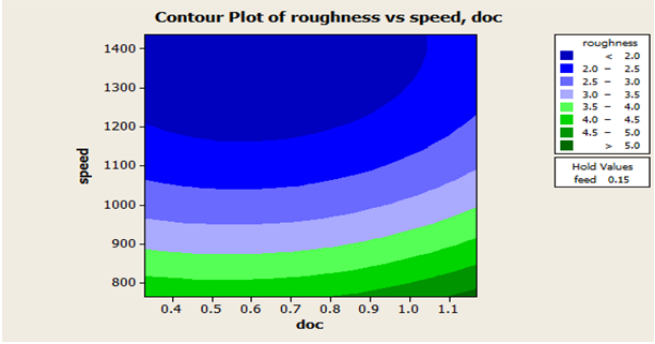


Fig. 7: Contour and Surface plots of Ra Turning(µm) vs feed, doc

These plots shows that surface roughness is minimum when the depth of cut minimum and feed rate is minimum. Most significant parameter is feed rate. Surface roughness is maximum when feed rate is maximum and depth of cut is maximum.



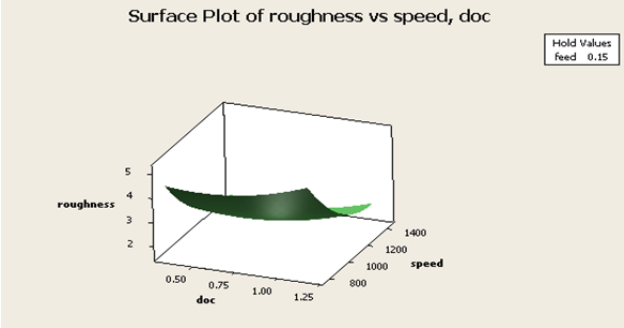
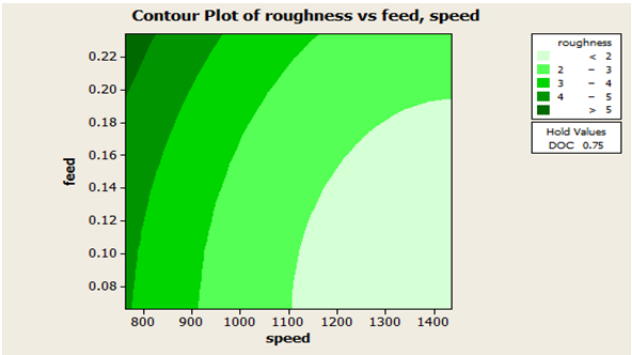


Fig. 8: Contour and Surface plots of Ra Turning(µm) vs speed, doc

These plots shows that surface roughness is minimum when the depth of cut minimum and speed is maximum. Most significant parameter is speed. Surface roughness is maximum when speed is minimum and depth of cut is maximum.



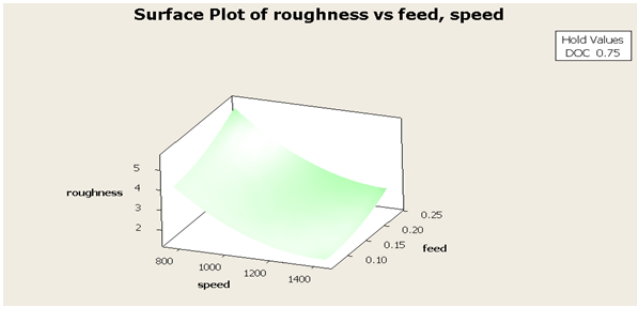
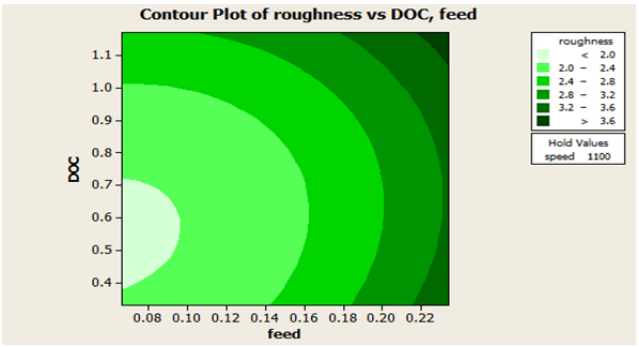


Fig. 9: Contour and Surface plots of Ra Facing(µm) vs feed, speed

These plots shows that surface roughness is minimum when the cutting speed is maximum and feed rate is minimum. Most significant parameter is feed rate. Surface roughness is maximum when feed rate is maximum and cutting speed is minimum.



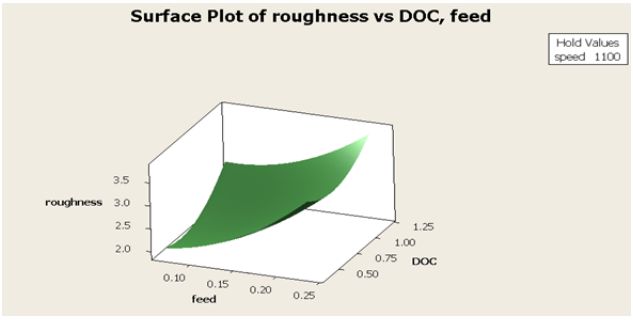
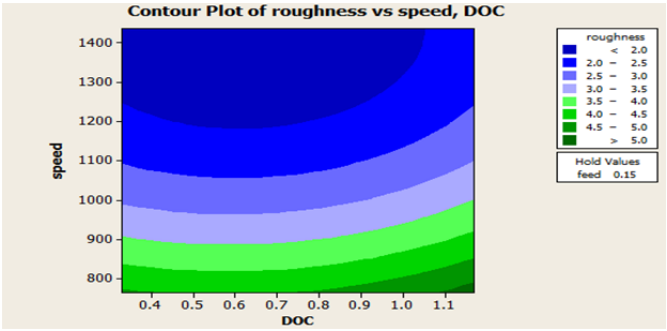


Fig. 10: Contour and Surface plots of Ra Facing(µm) vs feed, doc

These plots shows that surface roughness is minimum when the depth of cut minimum and feed rate is minimum. Most significant parameter is feed rate. Surface roughness is maximum when feed rate is maximum and depth of cut is maximum.



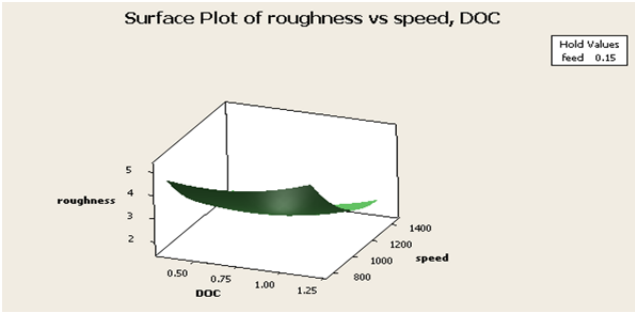


Fig. 11: Contour and Surface plots of Ra Facing(µm) vs speed, doc

These plots shows that surface roughness is minimum when the depth of cut minimum and speed is maximum. Most significant parameter is speed. Surface roughness is maximum when speed is minimum and depth of cut is maximum.

5. CONCLUSION

In this study, Response Surface Methodology was used to see the influence of the input parameters on the surface roughness of the EN47 alloy steel during turning and facing operation and to optimize the process. The main conclusions drawn are below:

i. Most significant factor for surface roughness is feed rate. While cutting speed and depth of cut has lesser significant on surface roughness.
ii. Surface and contour plots are generated that shows how interactions of two factors affect the surface roughness and then optimal conditions are obtained.
iii. The optimal values by Response Surface Methodology for the lowest surface roughness that is better surface finish are 1100 rpm, 0.065910 mm/rev, 0.75 mm for cutting speed, feed rate and depth of cut respectively.

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