OPTIMIZATION OF PROCESS PARAMETERS IN CNC TURNING BY COATED & UNCOATED CUTTING TOOL INSERT

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Abstract - *The present work deals with comparative study on cutting performance of (BUSH P-780308A) made up of C-20 plain carbon steel using HSS, TiN Coated HSS cutting tool. The experimented optimal setting ensured minimization of surface roughness, and maximization of MRR (Material Removal Rate). Regression equations, used to get the relation between different response variables (MRR and surface finish) and the input parameters (speed, feed, and depth of cut) were found out using software for statistical analysis. In addition to it, the significance of the model is also analyzed graphically with the diagnostic graphs like Actual v/s Predicted result. Further the individual and combined effects of factors at various levels on the chosen response are discussed with the help of Interaction plots, Perturbation plots and ANOVA technique.*

***Key Words*: Cutting parameters, Surface roughness, Optimize machining time and Material removal rate.**

1.INTRODUCTION

Quality and productivity play significant role in today's competitive manufacturing market. For consumer viewpoint quality is very important.Therefore, every manufacturing or production unit always concerned about the quality of the product. Every manufacturing industry aims at producing many products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. To embrace these two conflicting criteria, it is necessary to balance the quality level & productivity level of the item. Wherever metal is used its sure that it must have reached its final stage through processing with machine tools. In terms of annual expenditure, machining is the most important of the manufacturing processes.

2. MATERIALS AND METHOD

2.1. Work Piece Material

The work piece material used for present work was C20 plain Carbo steel. Table 1 and Table 2 show the chemical composition and mechanical properties of C20 plain Carbo steel.

Table -1: Chemical Composition C20 Plain carbon steel

Mechanical Properties of C20 Plain carbon steel	
Property	**Value**
Carbon (C)	0.15-0.25
Manganese (Mn)	0.60-0.90
Silicon (Si)	0.15-0.35
Phosphorus (P)	0.0-0.06

Table -2: Mechanical Properties of C20 Plain carbon steel

Mechanical Properties of C20 Plain carbon steel	
Property	**Value**
Tensile Strength	425 MPa
Density	7.8 g/cm3
Elongation	0.15%
Machinability	65%

2.2. Cutting Inserts

The cutting tool used for experimentation with the standard specification is TiN Coated HSS.

Table -3: Cutting Tool Detail.

Single Point Cutting Tool	
Material	HSS, TiN Coated HSS
Type	Rhombus 80°,12mm side,4mm thickness
No. of edge	4

Coated HSS tools have shown better performance when compared to the uncoated carbide tools.

2.3. 1 Selection of Control Factors

Modeling and analysis were done by 3k factorial design is the most widely used factorial design having three levels for each of 'k' factors. The three levels of factors are referred to as low

(0), intermediate (1) and high (2). All three levels of these parameters had been decided based on machine tool design handbook and full factorial approach has been employed for experimentation.

Cutting experiments are conducted considering. three cutting parameters: Cutting Speed (m/min), Feed rate (mm/rev), Depth of Cut (mm) and overall, 27 experiments were carried out. All three levels of these parameters had been decided based on machine tool design handbook and full factorial approach has been employed for experimentation. Table 4 shows the values of various parameters used for experiments:

TABLE 4: Levels of control factors

Level	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
-1 (low)	500	0.10	0.4
0 (medium)	1000	0.12	0.8
+1 (high)	1500	0.14	1.2

TABLE 6: Full factorial design with process parameters

Run	Cutting Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	500	0.10	0.4
2	500	0.10	0.8
3	500	0.10	1.2
4	500	0.12	0.4
5	500	0.12	0.8
6	500	0.12	1.2
7	500	0.14	0.4
8	500	0.14	0.8
9	500	0.14	1.2
10	1000	0.10	0.4
11	1000	0.10	0.8
12	1000	0.10	1.2
13	1000	0.12	0.4
14	1000	0.12	0.8
15	1000	0.12	1.2
16	1000	0.14	0.4
17	1000	0.14	0.8
18	1000	0.14	1.2
19	1500	0.10	0.4
20	1500	0.10	0.8
21	1500	0.10	1.2
22	1500	0.12	0.4
23	1500	0.12	0.8
24	1500	0.12	1.2
25	1500	0.14	0.4
26	1500	0.14	0.8
27	1500	0.14	1.2

2.4. EXPERIMENTAL PROCEDURE

2.4.1 Preparation of work piece

To perform the experiments, work pieces from the 25mm diameter cylindrical bars of C-20 material were cut up to required length of 100mm with the help of power saw as shown in the fig: 1.

FIGURE: 1 Cutting of work piece with power saw

2.4.2 Conducting the Turning Operation

Further, the diameter of rough turned work pieces were measured and approximately 30 pieces having in range of outer diameter 25 mm were collected for conducting the experiments. The finished turning operation was carried out on these rough turned work pieces using the different combination of cutting parameters designed by the Design of Experiment on Experimental CNC turning center.

2.4.3 Determination of Material Removal Rate & Surface Finish

The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm3 /min. For each revolution of the work piece, a ring-shaped layer of material is removed.

MRR = ($\pi . D_{avg.} dfN$) in mm^3/ min

where **N**= cutting speed in RPM, **f** = feed in mm/rev,

d = Depth of cut in mm, & $\mathbf{D_{avg}}$ = (Do+Df)/2

2.4.4 Measurement of Surface Finish

The surface roughness was measured by using Mitutoyo SJ-301 Surface Roughness Tester. The surface roughness Ra - can be measured in inches as well as in µm, with diamond point stylus roughness tester at three different places. The measured Ra values in µm were recorded in the table 7. The values of material removal rate and surface roughness obtained from the experiments conducted using different combination of cutting conditions were used for finding the optimum combination of cutting conditions.

TABLE 7: Input And Output Cutting Parameter.

Run	Factor 1 (A) Cutting Speed (rpm)	Factor 2 (B) Feed (mm/rev)	Factor 3 (C) Depth of Cut (mm)	Response 1 Material Removal Rate (mm^3/min)	Response 2 Surface Roughness Ra (µm)
1	500	0.10	0.4	1507.2	2.24
2	500	0.10	0.8	2863.68	2.49
3	500	0.10	1.2	3918.72	2.69
4	500	0.12	0.4	1808.64	3.01
5	500	0.12	0.8	3436.416	2.53
6	500	0.12	1.2	4702.464	2.77
7	500	0.14	0.4	2110.08	2.86
8	500	0.14	0.8	4009.152	3.5
9	500	0.14	1.2	5486.208	3.72
10	1000	0.10	0.4	3014.4	2.95
11	1000	0.10	0.8	5727.36	3.25
12	1000	0.10	1.2	7837.44	3.39
13	1000	0.12	0.4	3617.28	3.61
14	1000	0.12	0.8	6872.832	3.78
15	1000	0.12	1.2	9404.928	3.88
16	1000	0.14	0.4	4220.16	4.34
17	1000	0.14	0.8	8018.304	4.59
18	1000	0.14	1.2	10972.42	4.73
19	1500	0.10	0.4	4521.6	2.28
20	1500	0.10	0.8	8591.04	2.83
21	1500	0.10	1.2	11756.16	3.98
22	1500	0.12	0.4	5425.92	2.74
23	1500	0.12	0.8	10309.25	3.27
24	1500	0.12	1.2	14107.39	3.87
25	1500	0.14	0.4	6330.24	3.7
26	1500	0.14	0.8	12027.46	4.58
27	1500	0.14	1.2	16458.62	4.64

2.5. RESULT & ANALYSIS

A 3*3 full factorial design was used to get the output data uniformly distributed all over the ranges of the input parameters. In this way 27 experiments were carried out with different combinations of the levels of the input parameters. Regression equations, to get the relation between different response variables (metal removal rate and surface finish) and the input parameters (speed, feed, and depth of cut) were found out using software for statistical analysis. The software required the cutting conditions and responses from the experiments, and developed the statistical design summary, signal to noise ratio, Analysis of variance, to verify the significance of the model obtained through Regression Equations for material removal rate (MRR) and surface roughness (Ra). In addition to the significance of the model is also analyzed graphically with the diagnostic graphs like Actual v/s Predicted and Box-Cox transformation plot. Further the individual and combined effects of factors at various levels on the chosen response are discussed with the help of Interaction plots, Perturbation plots and 3-D graphs of Response Surface methodology (RSM).

2.5.1 Analysis of Response: material Removal rate (MRR)

After entering all the process parameters and responses in the designed input table given by the software, the Transform level was checked by software. By selecting MRR as response for analysis, the suggested Transform determined by the software.

The summary table 8 indicates that sequential source of the model is linear, 2 Factorial Interaction and Quadratic but the software suggests that the desirability of model is Quadratic. The Detailed Summary table is shown below.

(a) The Sequential Model Sum of Squares

TABLE 8: Sequential model sum of squares [type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Desirability
Mean vs Total	1.187E+009	1	1.187E+009			
Linear vs Mean	3.706E+008	3	1.235E+008	86.17	< 0.0001	
2FI vs Linear	3.158E+007	3	1.053E+007	150.58	< 0.0001	
Quadratic vs 2FI	**7.851E+005**	**3**	**2.617E+005**	**7.26**	**0.0024**	**Suggested**
Cubic vs Quadratic	6.106E+005	7	87231.43	360.00	< 0.0001	Aliased
Residual	2423.10	10	242.31			
Total	1.591E+009	27	5.893E+007			

From Sequential Model Sum of Squares, it is depicted that highest order polynomial is selected where additional terms are significant, and the model is not aliased. This table again indicates that the model is suggested to analyze with Quadratic process order because of lowest value of F = 7.26 with p-value 0.0024 is indicated in front of Quadratic vs 2FI as a source of process shown in Table 8.

(b) Model Summary Statistics: This summary focus on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared" values and it is tabulated in the

Table 9. Model summary statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	1197.41	0.9183	0.9076	0.8769	4.967E+007	
2FI	264.40	0.9965	0.9955	0.9920	3.210E+006	
Quadratic	**189.90**	**0.9985**	**0.9977**	**0.9943**	**2.319E+006**	**Suggested**
Cubic	15.57	1.0000	1.0000	0.9999	31589.53	Aliased

This was again suggested to proceed further analysis with Quadratic, as a process order After selecting the Quadratic source as a type of model, the analysis of variance (ANOVA) was calculated along with the statistic terms such as degree of freedom (DF), sum of squares (SS), mean square (MS), F value and P values for MRR as a response.

The fundamental technique is a partitioning of the total sum of squares SS into components related to the effects used in the model. For example, the model for a simplified ANOVA with one type of treatment at different levels is

$SS_{Total} = SS_{Error} + SS_{Treatments}$

The number of degrees of freedom DF can be partitioned in a similar way. One of these components (that for error) specify a chi-squared distribution which describes the associated sum of squares, while the same is true for "treatments" if there is no treatment effect.

$DF_{Total} = DF_{Error} + DF_{Treatments}$

The F-test is used for comparison of the components of the total deviation. For example, in one-way or single-factor ANOVA, statistical significance is tested for by comparing the F-test statistic.

$$F = \frac{Varience\ Between\ Measurment}{Varience\ Between\ Treatments}$$

$$F = \frac{MS_{Treatments}}{MS_{Erroe}} = \frac{\frac{SS_{Treatments}}{I-1}}{\frac{SS_{Erroe}}{nT-I}}$$

Where MS is mean square, I = number of treatments and n_T = total number of cases to the F-distribution with I-1, nT-I degree of freedom. ANOVA for Response Surface for Quadratic Model is given in Table 10.

Table 9. Analysis of variance [partial sum of squares – type iii]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	**402995882.6**	**7**	**57570840.37**	**1784.29**	**< 0.0001**	**significant**
A-Cutting	197906308.3	1	197906308.3	6133.69	< 0.0001	
B-Feed	21989589.81	1	21989589.81	681.52	< 0.0001	
C-DOC	150735912.2	1	150735912.2	4671.75	< 0.0001	
AB	3664931.635	1	3664931.635	113.59	< 0.0001	
AC	25122652.03	1	25122652.03	778.62	< 0.0001	
BC	2791405.781	1	2791405.781	86.51	< 0.0001	
C^2	785082.8759	1	785082.8759	24.33	< 0.0001	
Residual	613043.1099	19	32265.42684			
Cor Total	403608925.7	26				

The Model F-value of 1784.29 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, C2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

The "Pred R-Squared" of 0.9950 is in reasonable agreement with the "Adj R-Squared" of 0.9979.

Std. Dev.	179.63	R-Squared	0.9985
Mean	6631.68	Adj R-Squared	0.9979
C.V. %	2.71	Pred R-Squared	0.9950
PRESS	2001668.82	Adeq Precision	149.63

2.5.1.2 Regression Analysis Model

Moreover, the regression analysis has also been provided by Design Expert by giving the Regression Equation for MRR in coded and actual values. The equation in both forms are given below.

(i) Final Equation in Terms of Coded Factors:

MRR = +6872.83+3315.84*A+1105.28* B+2893.82* C+552.64*A*B+1446.91*A*C

+482.30 * B*C-361.73 *C2

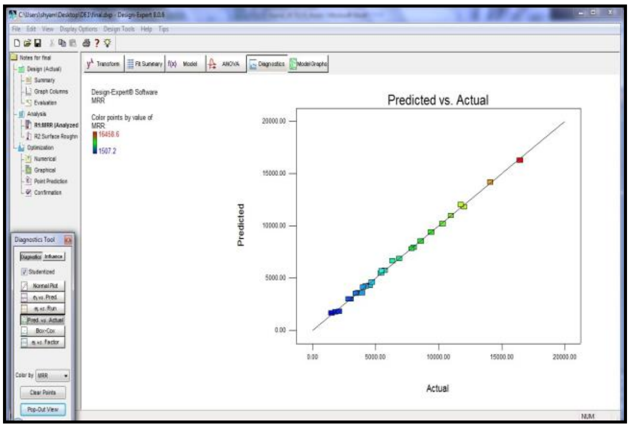
(ii) Final Equation in Terms of Actual Factors:

MRR = +4581.89-5.79 * CS-48230.40 * Feed-3617.28*DOC+55.26*CS*Feed+7.24*CS*DOC

+60288.00*Feed*DOC-2260.80*DOC2

This regression equation for MRR gives the predicted values within the range of input process parameters. The actual and predicted values of MRR are further compared graphically (Figure 2) are placed on X-axis and Y-axis respectively.

FIGURE: 2 Actual and predicted values of MRR



Graph, showing the relationship between MRR and input parameters for both the prediction methods and for the experimental values show that the trend shown by these graphs for both the prediction techniques and the experimental values is increasing. These graphs can help in indirect measurement of the MRR. Lower, middle and higher

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values are displayed with blue, green and red color respectively.

2.5.1.3 Main Effects of Input Parameter on MRR

A main effect test will merely look at whether overall there is something about a particular factor that is making a difference. Main effects are essentially the overall effect of a factor. All The main effect plots shows that there is increase in value of MRR with increase in value of cutting speed, feed and depth of cut individually. The interaction effects of Cutting Speed and Feed, Feed and Depth of cut and Cutting Speed and Depth of cut on surface roughness value were analyzed.

Figure 3: MRR and Cutting Speed

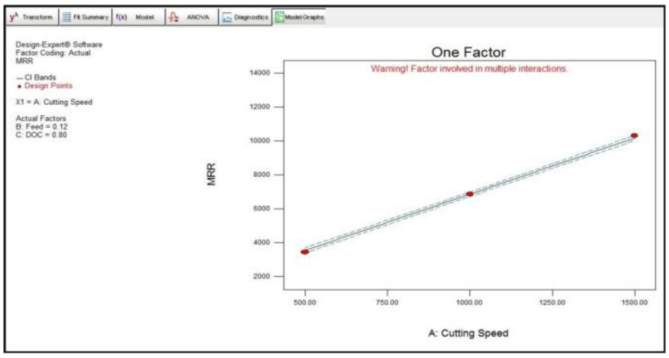


Figure 4: MRR and FEED

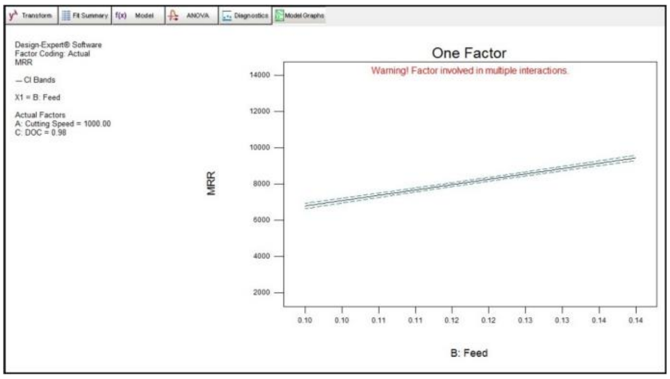


Figure 5: MRR VS DOC

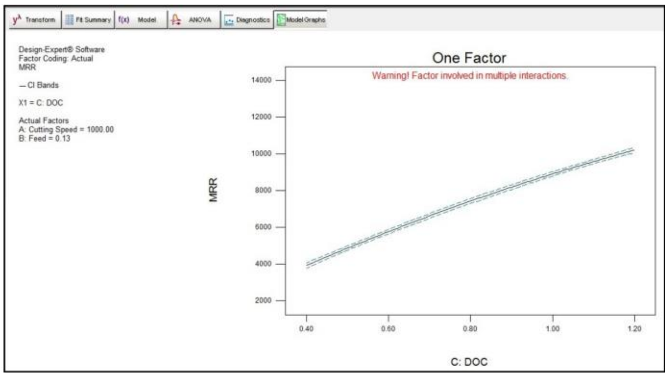
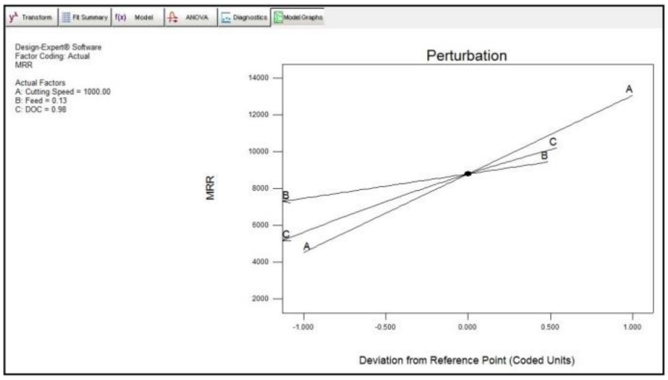


Figure 6: Perturbation graph of cutting parameters verses MRR



2.5.1.4 Interaction Plot Effects

The combined effect of feed and cutting speed has been plotted for response MRR by the software as shown in the Figure 7. The graph indicates the increasing trend of MRR by increasing cutting speed A: cutting speed (CS) on X1 axis ranges from 500 rpm to 1500 rpm along with increasing value of B: feed rate (FR) on X2 axis ranges from 0.10 mm/rev to 0.14 mm/rev.

Figure 7: Interaction graph of cutting speed, feed vs MRR

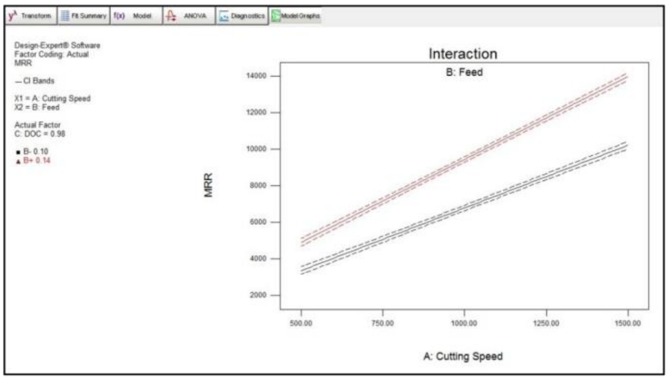
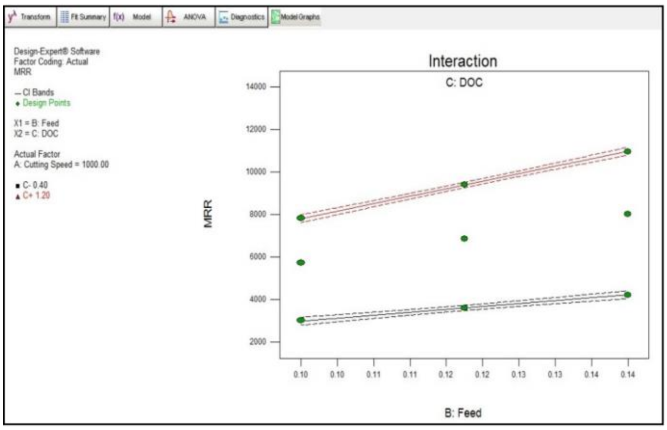


Figure 8: The interaction graph of feed and depth of cut



The interaction graph (figure 8) has been plotted between 2 input parameters DOC (X2) and Feed (X1) and MRR. This graph shows significant increase in values of MRR as DOC changes from its minimum level 0.4 mm to maximum level of 1.2 mm, as CS 1000 rpm, whereas feed rate has less effect on MRR.

2.5.2: Analysis of Response: Surface Roughness

Above same process followed for Surface roughness optimization. The Input and Output process parameters and responses are taken from table 7.

2.5.2.1: Analysis of Variance (ANOVA)

In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. Doing multiple two sample t-tests would result in an increased chance of commuting a type I error. For this reason, ANOVA are useful in comparing two, three or more means. In this case the, ANOVA was calculated and the related terms were tabulated in the

Table 9: ANOVA [partial sum of squares – type iii]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Desirability
Model	**13.60**	**9**	**1.51**	**23.28**	**< 0.0001**	**significant**
A-Cutting Speed	2.05	1	2.05	31.64	< 0.0001	
B-Feed	6.20	1	6.20	95.45	< 0.0001	
C-DOC	1.96	1	1.96	30.20	< 0.0001	
AB	0.11	1	0.11	1.76	0.2025	
AC	0.61	1	0.61	9.36	0.0071	
BC	0.01	1	0.01	0.21	0.6561	
A^2	2.38	1	2.38	36.69	< 0.0001	
B^2	0.27	1	0.27	4.21	0.0560	
C^2	0.00	1	0.00	0.02	0.8995	
Residual	1.10	17	0.06			
Cor Total	14.70	26				

Table 10: Standard deviation and adjusted values

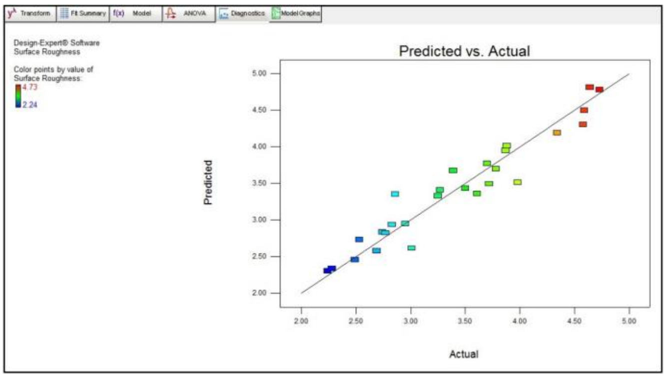
Std. Dev.	0.25	R-Squared	0.92
Mean	3.42	Adj R-Squared	0.89
C.V. %	7.46	Pred R-Squared	0.76
PRESS	3.51	Adeq Precision	16.18

The "Pred R-Squared" of 0.76 is in reasonable agreement with the "Adj R-Squared" of 0.89

2.5.2.2 Regression Analysis Equation for Ra value

The results obtained by this method were formed as Regression Analysis Equation for Ra value equation by the same software similar with above done for MRR findings.

Figure 9: Actual Vs Predicated value of Ra



The graph between actual and predicted values is shown in Figure 9. The plot shows scattered points a little bit deviated from fitted line. The low range values of Surface roughness are shown in blue color points and high range values in red color. It indicates that lowest value of Ra i.e. 2.24(blue) and the value 4.73 (red) are most deviated experimental values.

2.5.2.3 Main-Effect Plots

Figure 10: Cutting speed vs Ra

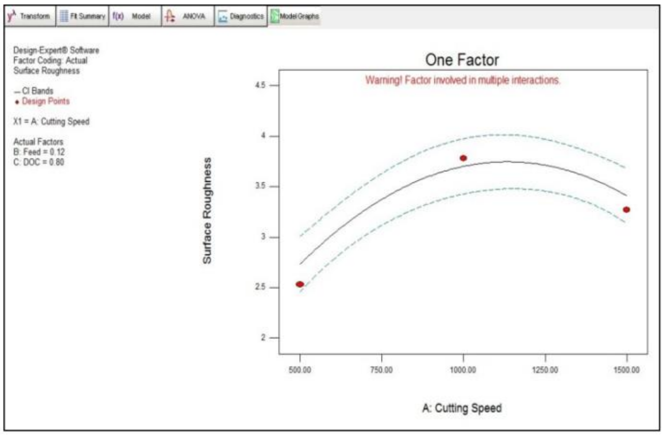


Figure 11: DOC **vs** Ra

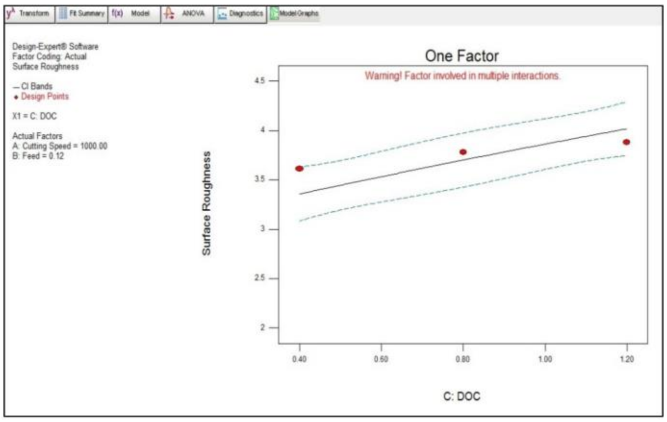
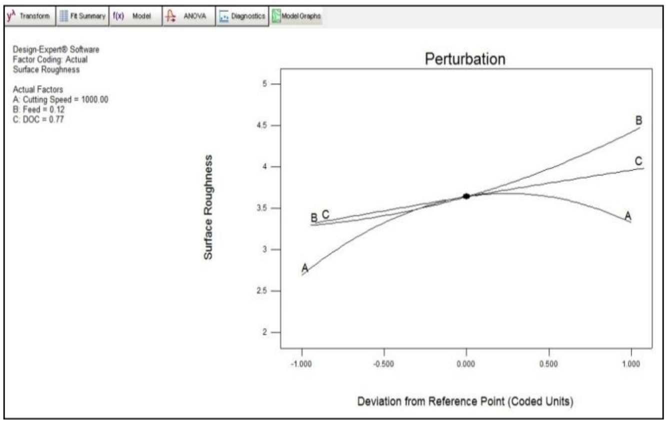


Figure 12: perturbation graph of cutting parameters vs Ra



2.5.2.3 Interaction Plots

Figure 13: The interaction graph of cutting speed, feed vs Ra

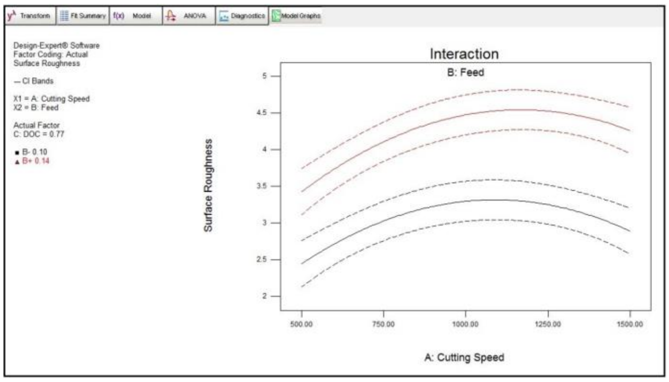
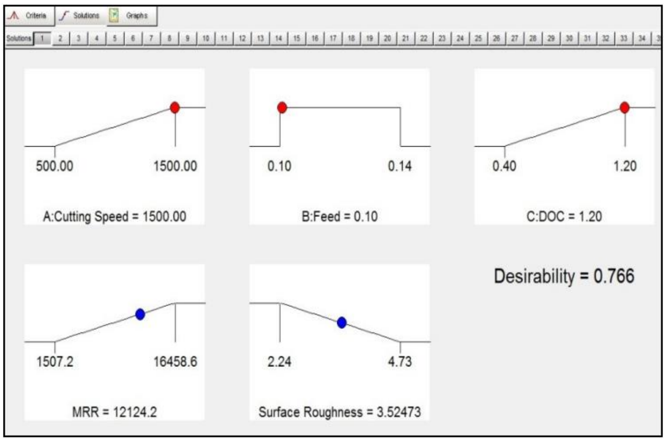


Figure 14: The interaction graph of cutting speed and depth of cut verses Ra.

2.5.3 Optimized Result

After making discussions and analysis the optimization process was carried out with assigning the values of constraints in the prescribed space provided by the software. After analyzing the result, the number of solutions were obtained by the software, along with the selected optimum cutting parameters are as shown in fig14

Figure 12: Graph of constraints for optimization



the solution number one with highest desirability value of 0.766 was selected as the set of optimum cutting parameters. Therefore, the suggested Optimum Cutting Parameters given in Table 11

Table 10: Suggested optimum cutting parameters.

Cutting Speed	Feed	DOC	MRR	Surface Roughness
1500.00	0.10	1.20	12126.5	3.52

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