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OPTIMIZATION OF PROCESS PARAMETERS DURING DRY TURNING OF AISI O-1 DIE STEELWITH CVD COATED TOOL FOR BETTER SURFACE FINISH AND IMPROVED PRODUCTIVITY

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Abstract

Surface roughness and Material Removal Rate are the main quality functions in high speed turning of high carbon cold work steel in dry conditions. This research presents the optimization of surface roughness & material removal rate in dry turning of AISI O-1 DIE steel. CVD coated carbide inserts were used for machining of AISI O-1 to study effects of process parameters. These models can be effectively used to predict the surface roughness (R_a) & material removal rate of the work piece. The big challenge of the Micro, small& medium industries in India for achieving high quality products with increased productivity. This paper presents work of an investigation of turning process parameters on AISI O-1 material, for optimization of surface roughness only and surface roughness as well as material removal rate. The experiment is carried out by considering three controllable input variables namely spindle speed (**N**), feed rate (**f**), and depth of cut (**a_p**). The design of experiments is carried out by Response Surface Methodology (Central Composite Rotatable Method) and optimization of surface roughness as well as influence of turning process parameters is carried out by ANOVA.

Keywords: Dry Turning, CVD Coated Tool, Die Steel, Surface Roughness, RSM, CCRD, ANOVA, MRR, AISI O-1

1. INTRODUCTION

Lathe is the oldest machine tool and it is also known as the Mother of all any other machine tools. It is used to remove material from a cylindrical shaped work piece by the use of a single point cutting tool where cutting tool does longitudinal and transverse motion for fed and the material removes in the form of chips (continuous or discontinuous). The tool employed for the machining process should be made of harder material than the work piece material and both the tool and work piece should be hold rigidly by tool post and chuck.

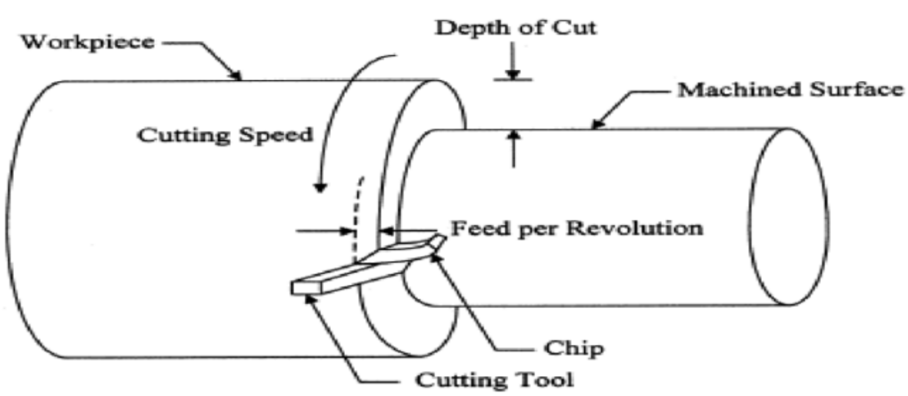

Figure 1: Working Principle of Lathe

2. RESEARCH GAP

As it is understood after literature review that turning is machining process which is commonly used in almost every manufacturing industry i.e. automobile, aviation, ancillary parts, machine tool manufacturer etc. From the literature review, we found that a lot of work is done on turning of stainless steel and EN series steel by using different optimization techniques but few work is done on the turning of materials like aluminium alloys, titanium alloys, die steels, composites etc.

According to the literature review, effect of process parameters and their optimization for improved surface

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finish and maximum productivity (MRR) while turning of AISI O-1 die steel using RSM (response surface methodology) and ANOVA (analysis of variance) will be quite useful.

3. OBJECTIVE

- Experimental study of the effect of spindle speed (N), feed rate (ƒ), depth of cut (a_P) on productivity and surface finish.
- Development of mathematical models for both surface finish and material removal rate.
- Optimization of the turning parameters for only better surface finishes (min. R_a).
- Optimization of the turning parameters for better surface finishes (min. R_a) as well as improved productivity (max. MRR).

4. EXPERIMETAL SETUP

All the experimental work is performed on CNC Turning Centre model PUSHKAR-200 Turret Lathe which is manufacture by HMT. It is a flexible machine with high power, speed & accuracy and excellent performance. The reason we selected this machine for our experimental work is to maintain the accuracy during the operations. A cutting tool insert plays the most important role in cutting operations and in our experimental works, the cutting insert we used is TNMG 16 04 08 MP KU30T CVD (Chemical Vapor Deposition) Coated Carbide insert which is coated with the layers of Tin, TiCN & TiC. Multilayered CVD Coatings are used for composition of this insert by subtracted with tough cobalt.

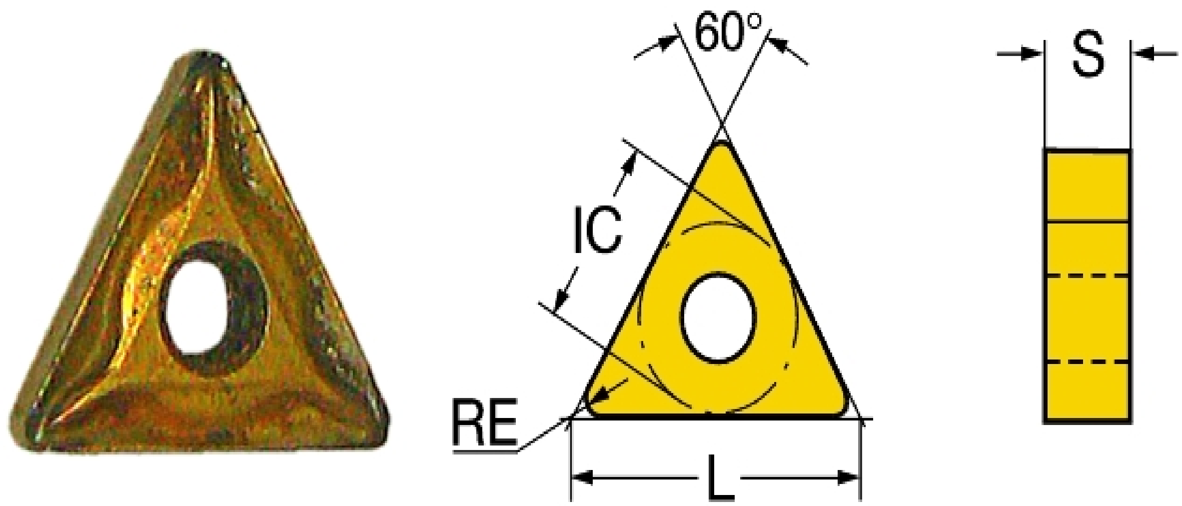


Figure 2 CVD Coated Carbide Insert and Geometric Details

Figure 3 showing the actual picture of the used CVD coated carbide insert. Coated inserts have lives 10 times greater than uncoated inserts. It is recommended by the industries for the machining of die steels, cast irons and stainless steels. Here are the summarized specification details of the insert below and it includes the geometric details shown in figure 2.

Table 1 Specifications of Insert

Insert Seat Size Code (SSCM)	16
Operation Type (CTPT)	Medium
Cutting Edge Length (L)	16.4987 mm
Cutting Edge Effective Length (LE)	15.7978 mm
Insert Thickness (S)	4.7635 mm
Inscribed Circle Diameter (IC)	9.535 mm
Corner Radius (RE)	0.8 mm
Fixing Hole Diameter (D1)	3.84 mm

In order to research the optimum surface finish and material removal rate, AISI O-1 Die Steel has been chosen. It is a type high carbon cold-work steel which is better known by OHNS (Oil Hardening Non Shrinkable) Die Steel. It is economical and widely used steel in industries for several purposes.

Table 2 Chemical Composition of AISI O-1

Element	C	Mn	Si	Cr	Ni	W	V	Cu	P	S
Content (%)	0.85-1.00	1.00-1.4	0.50	0.40-0.60	0.03	0.40-0.60	0.30	0.25	0.03	0.03

Table 3 Mechanical Properties of AISI O-1

Properties	Max. Stress	Yield Stress	Proof Stress	Elongation	Impact Stress	Brielle Hardness
Values	963 N/mm^2	452 N/mm^2	488 N/mm^2	9.5%	24 j	285 Bhn

5. DESIGN OF EXPERIMENTS

5.1 Response Surface Methodology

There are so many researchers presented the investigations in previous year employed the RSM to find out the optimum values of performance parameters in order to minimize the responses. Response Surface Methodology is a collection of statistical techniques and mathematical skills use for solving the problem in which the response parameters are influenced by some controllable variables in order to optimize the response.

While focusing on optimization of experiments related to machining operations, Response Surface Methodology is used widely. RSM minimizes the number of experiments to be conducted in order to reduce the cost as well as time. Moreover, this methodology enables the experimenter to choose the factor's levels accurately. RSM improves the optimization process because it represent the better picture of variations in response variables with respect to the process variables by graphical approach like curves, 3D space, contour plots.

❖ **Central Composite Rotatable Design (CCRD)**

All the second-order models are considered as very flexible tool in most optimization process. There are many standard second-order design provided by RSM. In this research, we will study the turning process with one of the best efficient standard RSM design of second-order model called central composite design. Some variable in this design must be specified i.e. the distance α (1.68 in our case) from axial points to center points and the number of total center points n_c. Runs for center points having same values of input parameters on every point in order to maintain the accuracy and they are recommended in between three to six. CCRD involves 2^N factorial runs, 2N axial runs and n_c N is the number of process variables. In our research CCRD was for three process variables i.e. Spindle Speed, Feed Rate, Depth Of Cut and these are the following runs for our case : -

- **No. of Factorial Points (n_f) = (2^N) = 2^3 = 8**
- **No. of Axial Points (n_a) = (2N) = (2×3) = 6**
- **No. of Center Points = 6 Runs (3 to 6 are recommended)**
- **No. of Center Points = 6 Runs (3 to 6 are recommended)**

Thus, we had total 20 runs or experiments and the all are performed on a CNC turning center as described in previous headings and then, Analysis & Optimization part was performed on Design-Experts® software.

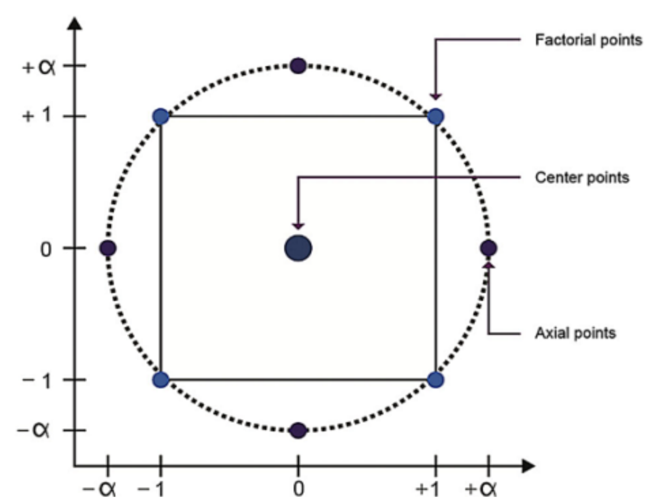


Figure 3: Central Composite Rotatable Design

5.2 SELECTED PROCESS PARAMETERS AND THEIR LEVELS

Table 4: Range Of Process Parameters

Levels	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth Of Cut (mm)
-1.68	829.55	0.02	0.16
-1.00	1000	0.03	0.5
0	1250	0.05	1.0
1.00	1500	0.07	1.5
1.68	1670.45	0.08	1.84

5.3 DESIGN MATRIX WITH FOR MRR AND R_a

Table 5 Design Matrix for MRR and R_a

Std	Run	Coded Values			Real Values			MRR (mm^3/s)	R_a (µm)
		N (rpm)	f (mm/rev)	a_p (mm)	N (rpm)	f (mm/rev)	a_p (mm)		
1	6	-1	-1	-1	1000	0.03	0.50	**031.173**	**3.200**
2	1	1	-1	-1	1500	0.03	0.50	**040.052**	**2.327**
3	3	-1	1	-1	1000	0.07	0.50	**072.513**	**4.270**
4	8	1	1	-1	1500	0.07	0.50	**106.396**	**3.100**
5	19	-1	-1	1	1000	0.03	1.50	**085.785**	**2.920**
6	15	1	-1	1	1500	0.03	1.50	**129.291**	**1.665**
7	13	-1	1	1	1000	0.07	1.50	**199.452**	**3.624**
8	2	1	1	1	1500	0.07	1.50	**298.706**	**1.388**
9	4	**-1.68**	0	0	**829.55**	0.05	1.00	**085.029**	**3.750**
10	11	**1.68**	0	0	**1670.45**	0.05	1.00	**170.934**	**1.337**
11	12	0	**-1.68**	0	1250	**0.02**	1.00	**048.529**	**2.727**
12	10	0	**1.68**	0	1250	**0.08**	1.00	**205.828**	**3.951**
13	17	0	0	**-1.68**	1250	0.05	**0.16**	**021.454**	**3.557**
14	20	0	0	**1.68**	1250	0.05	**1.84**	**212.768**	**1.820**
15	7	0	0	0	1250	0.05	1.00	**123.123**	**3.330**
16	5	0	0	0	1250	0.05	1.00	**120.733**	**2.999**
17	14	0	0	0	1250	0.05	1.00	**125.611**	**2.950**
18	9	0	0	0	1250	0.05	1.00	**126.893**	**2.982**
19	8	0	0	0	1250	0.05	1.00	**119.480**	**2.911**
20	16	0	0	0	1250	0.05	1.00	**130.728**	**3.001**

5.4 EXPERIMENTAL PROCEDURE

First of all, a rod of material AISI O-1 was purchased having dimensions (7 feet. long and 40 mm) diameter. The rod was divided into 20 equal pieces with 100 mm length and 40 mm diameter each as shown in figure 4. The machine was set to its minimum level. The work piece were given a finishing cut (0.5 mm depth if cut) reducing its diameter from 40 mm to 39 mm in order to make them uniform. The purpose was to perform 20 rums with different spindle speed, depth of cut and feed rate. That was performed using CVD coated carbide cutting tool of nose radius 0.8mm in dry conditions. For this, tool was held in the turret and work piece was held into power chuck during machining as shown in figure 4.

Next step was to machine the work piece up to 50 mm of length. Total 20 runs were performed at different levels of process parameters according to design matrix made by Design-Expert® software.

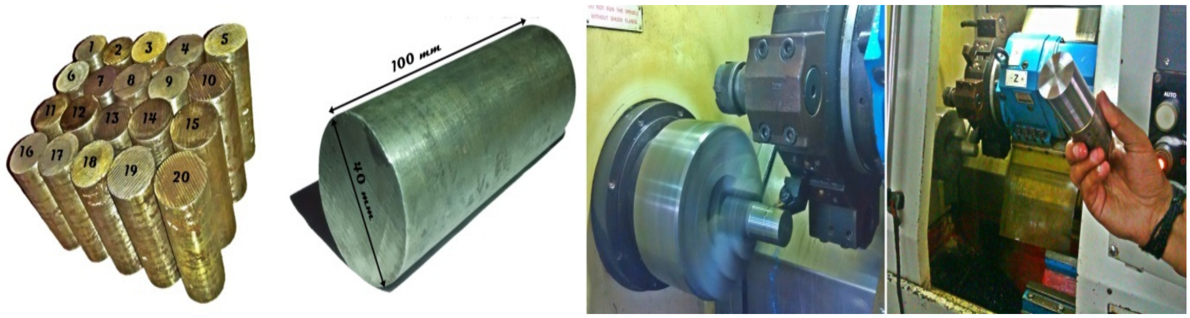


Figure 4 Total Number & Dimensions of and Work-Piece Setup for Machining

5.5 ANOVA TABLE FOR MRR

The mathematical model suggested for this response is Two Factor Interaction (2FI). From the ANOVA table (Table 4.2) of MRR, we found that the value of Lack of Fit is 0.1469 which is Not Significant hence the collected data fit to the model and suggested model is good for further analysis. The value of Adjusted R-Squared is 0.9950, Predicted R-Squared is 0.9926 which is too close to 1 and the difference of these two values is less than 0.2 hence the suggested model is Significant. The Adequate Precision Ratio should be greater than 4 and in our case it 77.030 which is correct and good for the model.

Table 4.2 ANOVA Table for MRR

Response 1 : MRR						
ANOVA for Response Surface 2FI Model						
Analysis Of Variance Table [Partial sum of square - Type-Ш]						
Source	**Sum Of Square**	**df**	**Mean Square**	**F-Value**	**P-Value Prob. > F**	
Model	90433.79	6	15072.30	426.89	< 0.0001	**Significant**
A (N)	7973.89	1	7973.89	225.84	< 0.0001	**Significant**
B (f)	31444.50	1	31444.50	890.60	< 0.0001	**Significant**
C (a_p)	45104.73	1	45104.73	1277.50	< 0.0001	**Significant**
AB	815.09	1	815.09	23.09	0.0003	**Significant**
AC	1249.98	1	1249.98	35.40	< 0.0001	**Significant**
BC	3845.60	1	3845.60	108.92	< 0.0001	**Significant**
Residual	458.99	13	35.31			
Lack Of Fit	371.99	8	46.50	2.67	0.1469	**Not Significant**
Pure Error	87.00	5	17.40			
Cor Total	90892.78	19				

Std. Dev.	5.94	**R-Squared**	0.9950
Mean	122.72	**Adj. R-Squared**	0.9926
C.V. %	4.84	**Pred. R-Squared**	0.9799
PRESS	1830.08	**Adeq. Precision**	77.030

For further analysis, we need better model and R-Squared values but for this response our model is at its best possible R-Squared values and the model is good enough for further analysis hence there is no need to apply any elimination step for improved ANOVA.

5.6 ANOVA TABLE FOR R_a

The mathematical model suggested for this response is Quadratic. From the ANOVA table of R_a (Table 4.3), we found that the value of Lack Of Fit is 0.4751 which is Not Significant hence the collected data fit to the model and suggested model is good for further analysis.

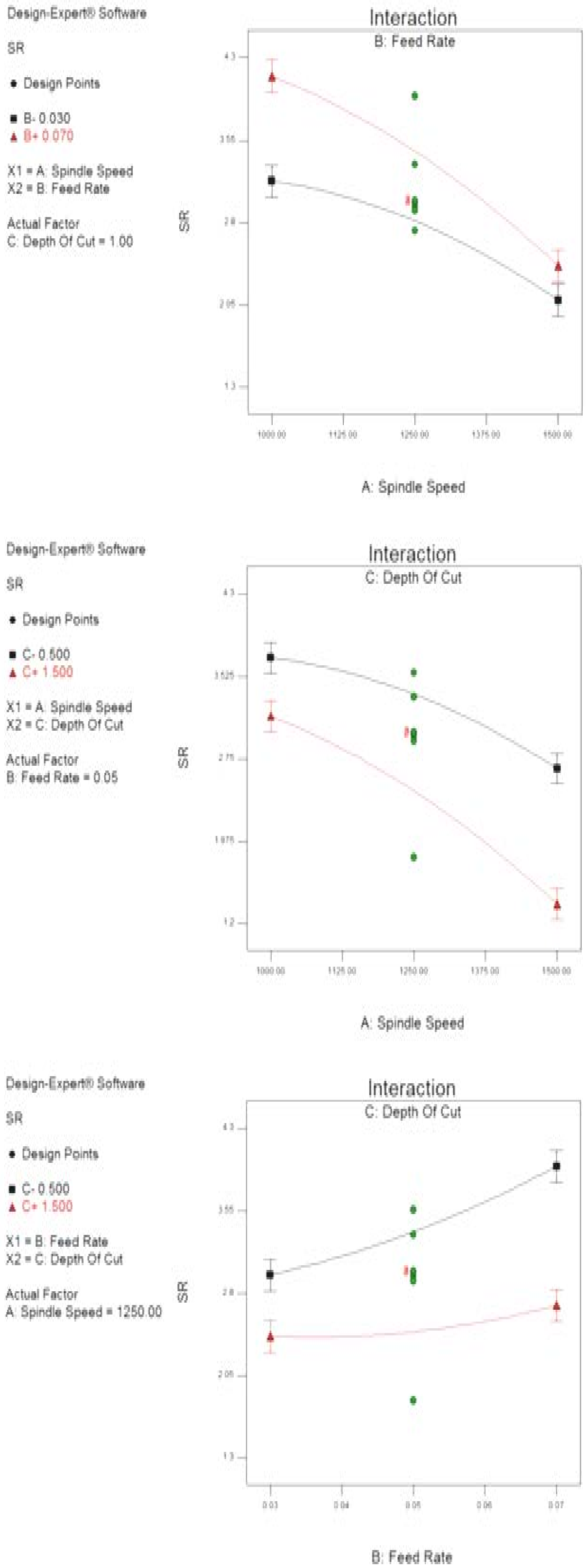
Table 4.3 ANOVA Table for R_a

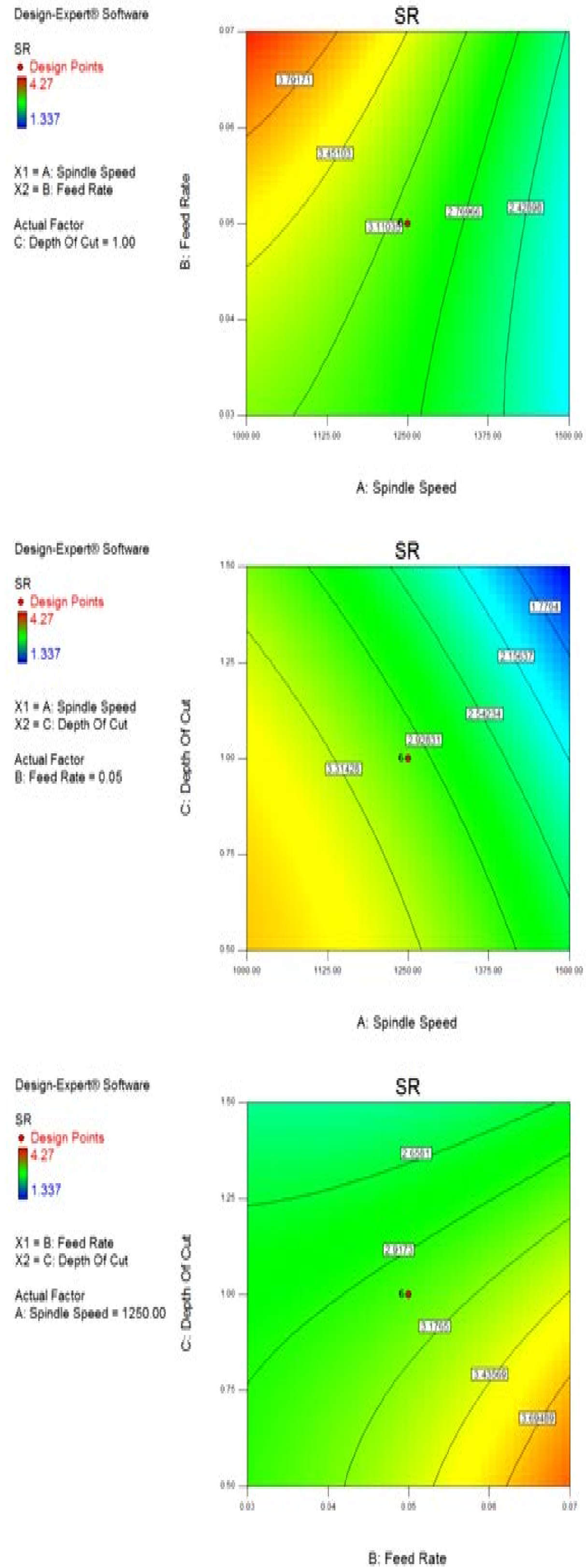
Response 1 : R_a						
ANOVA for Response Surface Quadratic Model						
Analysis Of Variance Table [Partial sum of square - Type-Ш]						
Source	**Sum Of Square**	**df**	**Mean Square**	**F-Value**	**P-Value Prob. > F**	
Model	12.55	9	1.39	59.00	< 0.0001	**Significant**
A (N)	6.74	1	6.74	285.16	< 0.0001	**Significant**
B (ƒ)	1.37	1	1.37	58.07	< 0.0001	**Significant**
C (a_p)	2.83	1	2.83	119.95	< 0.0001	**Significant**
AB	0.20	1	0.20	8.64	0.0148	**Significant**
AC	0.26	1	0.26	11.09	0.0076	**Significant**
BC	0.25	1	0.25	10.61	< 0.0001	**Significant**
A^2	0.46	1	0.46	19.53	0.0013	**Significant**
B^2	0.15	1	0.15	6.38	0.0300	**Significant**
C^2	0.23	1	0.23	9.94	0.0103	**Significant**
Residual	0.24	10	0.024			
Lack Of Fit	0.12	5	0.024	1.06	0.4751	**Not Significant**
Pure Error	0.11	5	0.023			
Cor Total	12.78	15				

Std. Dev.	0.15	**R-Squared**	0.9815
Mean	2.89	**Adj. R-Squared**	0.9649
C.V. %	5.32	**Pred. R-Squared**	0.9076
PRESS	1.18	**Adeq. Precision**	28.648

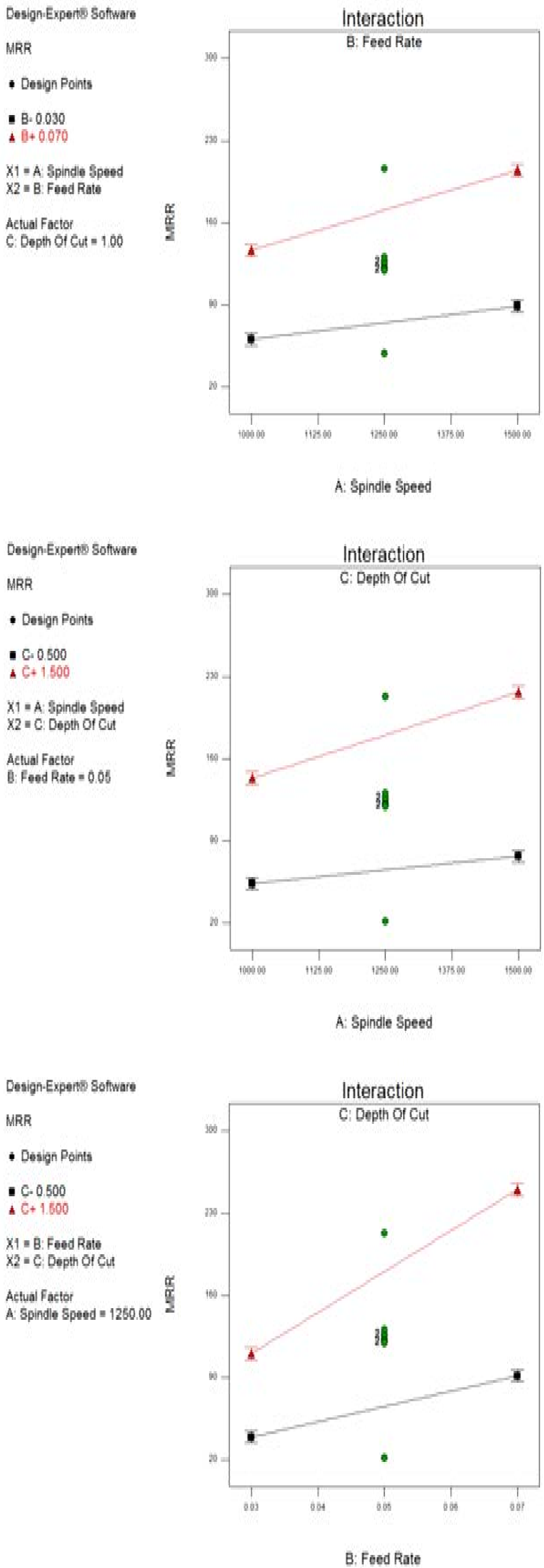
The value of Adjusted R-Squared is 0.9649, Predicted R-Squared is 0.9076 which is too close to 1 and the difference of these two values is less than 0.2 hence the suggested model is Significant. The Adequate Precision Ratio should be greater than 4 and in our case it 28.648 which is correct and good for the model. For further analysis, we need better model and R-Squared values but for this response our model is at its best possible R-Squared values and the model is good enough for further analysis hence there is no need to apply any elimination step for improved ANOVA.

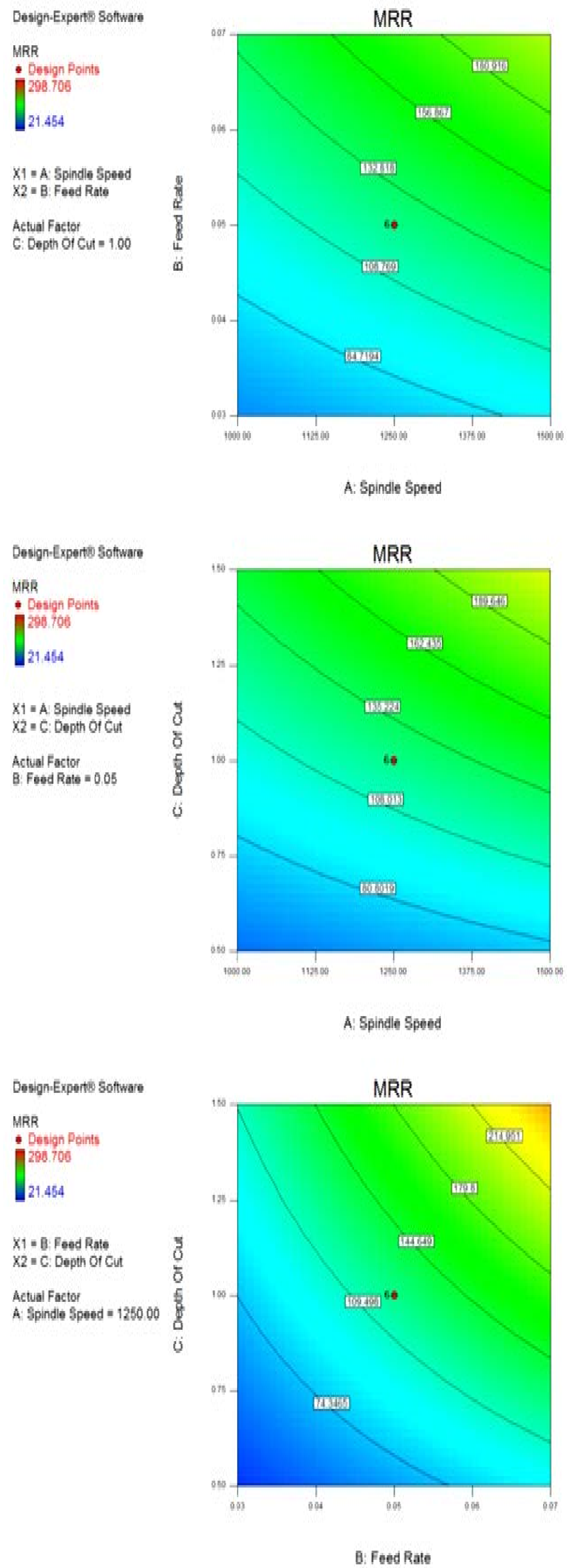
6. RESULTS & DISCUSSIONS





6.1 INTERACTION PLOTS FOR R_a **6.2 CONTOUR CURVES FOR R_a**





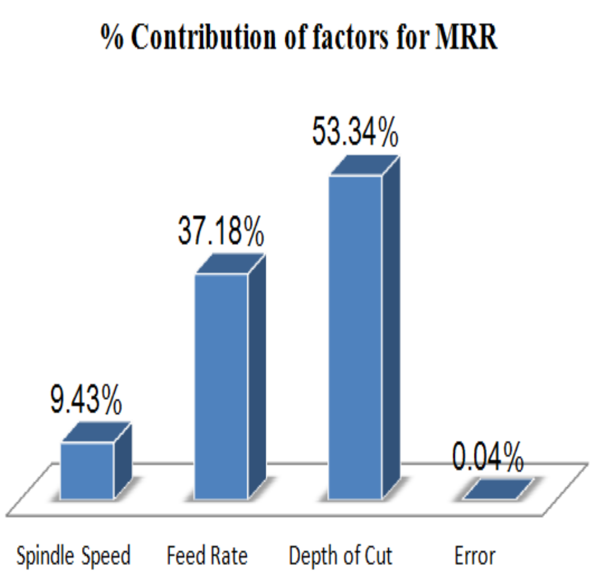
6.3 INTERACTION PLOTS FOR MRR

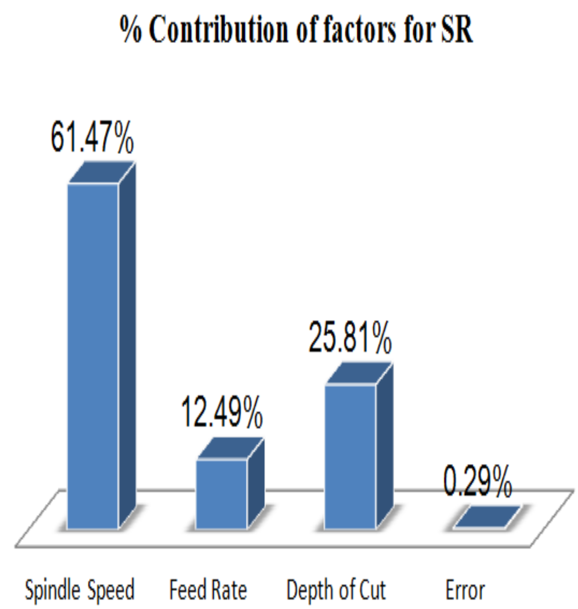
6.4 CONTOUR CURVES FOR MRR

6.6 CONCLUSIONS

- Spindle speed is most effective factor and R_a decreases non-linearly for every increased value of spindle speed so the chuck should rotate at high rpm.
- R_a decreased non-linearly when we increased the depth of cut within the range which is quite awkward but for the CVD coated carbide cutting tool plus the range of depth of cut that we choose, it could happen.
- We can't take the previous conclusion as a universal truth because the higher value of depth of cut may causes of formation of built up edges resulting in worst surface finish.
- R_a increases proportionally with feed rate so it should be at low value for better surface finish.
- MRR increases with the higher value of spindle speed, so the chuck should rotate at high rpm.
- We analyzed that feed rate is more effective than spindle speed when higher material removal rate is primary retirement.
- MRR is proportional to all of three factors that we employed in our experimental study but depth of cut is the most effective parameter from all of them. Small change in depth of cut resulting in great change in material removal rate.

As we know that feed rate and depth of cut are the most effective factors for our second response and for every increased value of these factors, material removal rate increases effectively but higher values (out of the range that we selected) of these factors may resulting in tool failure, tool wear, increased tool life and unexpected hazard.





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