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Optimization of Surface Roughness of EN-36 Alloy Steel on CNC Turning Machine using Box Behnken Method under RSM

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Abstract: This project work is mainly focused on the optimization of surface roughness (SR) and Material Removal Rate (MRR), the experiment is carried out as per Box Behnken Design under Response Surface Methodology (RSM)
After that the Design of Experiment (DOE) methodology a Box Behnken Design was used to optimization of Surface Roughness. The experimental study of surface roughness which is perform on CNC machine of EN-36(with hardening and without hardening) material using coated carbide cutting tool by various cutting parameters like feed ,cutting speed and depth of cut and determine optimum cutting parameters of Surface Roughness. After the work piece test on surtronics 3+ tester measuring surface roughness and getting the results those results analyzed in Minitab 16 software and analysis of variance (ANOVA) was carried out for Surface Roughness on EN-36(with hardening and without hardening) material and their constribusation rates was determined, finally experimental observation shows optimum parameters for Surface Roughness.
Keywords: surface roughness, RSM, BBM and Parameters

I. INTRODUCTION

A. Surface Roughness

Surface roughness is used to determine how the real objects interact to its environment. Rough surface comparatively wear very rapidly and also have a high coefficient of friction, when compared to smooth surface. If there is presence of irregularities on to the surface then it is the first sign for the formation of nucleation and cracks on to the surface.

In simple word we can also explain surface roughness, as a measurement on to the texture of the surface. So if the measurement of the surface texture is to be carried out the very first thing we have to do is to compare the deviation in between vertical deviation and idle position of the surface. Now after the measurement of the surface texture, if the deviation made by the vertical surface from its ideal position is large then the surface would be rough or else if the deviation produced is small then the surface would be smooth. Roughness is one of the undesirable factors of manufacturing process which should be controlled in order to get better quality product. Controlling surface roughness involves more machining time and it leads to increase in the manufacturing cost.

B. Surface Texture Parameters

Among the various roughness parameters Ra is most common; this is often for several different historical reasons but not for particular advantages as the early roughness meter can only measure Ra. Some of the most common roughness parameters include Rz, Rq, and Ry which is narrated below:

1) *Ra (Arithmetical mean deviation):* Ra is broadly worldwide recognized, and most frequently implemented, international parameter of surface roughness. In simple word we can interpret it as an arithmetic average of the absolute values of the roughness profile, with in its sampling length.

$$R_a = \frac{1}{L}\int_0^L |z(x)|dx$$

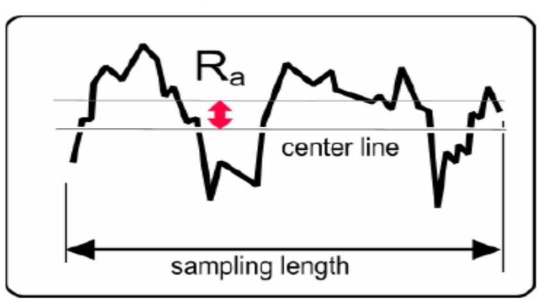

Fig 1.2.1 Graph of Ra within its sampling length

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2) *Rq (Root-mean-square roughness):* In simple word Rq is interpreted as the root mean square of variable which is proportionate to Ra (Arithmetical mean deviation). It is an average of all the heights deviations that is taken in its elevation length and is measured from the mean linear surface.

$$R_q = \sqrt{\frac{1}{L}\int_0^L z^2(x)\,dx}$$

3) *Ry (Maximum peak to valley roughness):* The maximum of all peak to valley values within each cut off length is determined. Vertical distance is taken in between the maximum peak point and deepest valley with in sampling length.

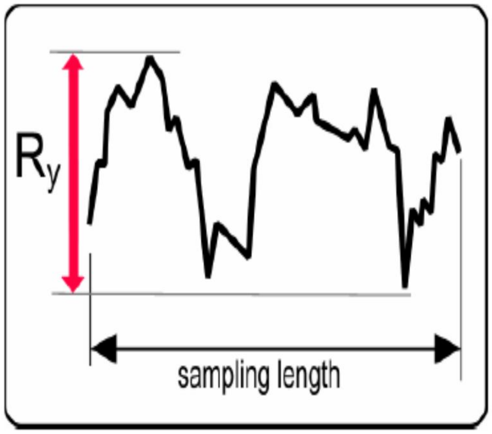

Fig 1.2.2 Graph of Ry within its sampling length

4) *Rz (Ten-point height):* In simple word Rz or Rtm can be interpreted as an average of absolute values of five maximum peaks points and five lowest valleys over an evaluation length.

$$R_z = \frac{(P1+P2.......P5) - (V1+V2........V5)}{5}$$

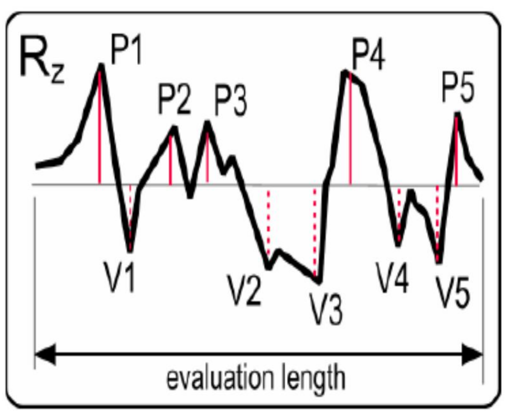

Fig 1.2.3 Graph of Rz within its evaluation length

C. Objectives of Work

The objective of this project work is to obtain optimal Surface Roughness and Material Removal Rate parameters in turning operation using EN-36 steel through experimental investigation and employing design of experiments "Box Behnken Design" technique. The investigation is to be carried out on EN-36 steel with two conditions, with hardening (HRC-30) and without hardening.

II. METHODOLOGY AND EXPERIMENTS

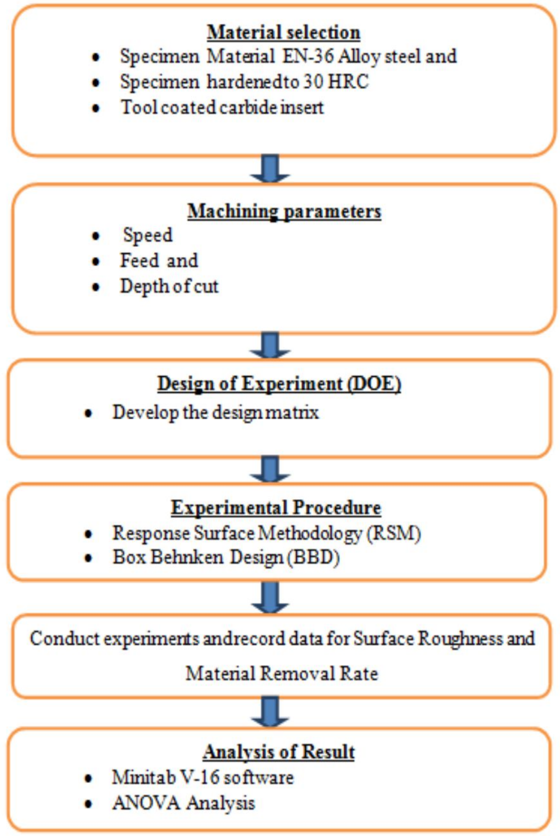

Fig. 2.0 Methodology Flow Chart

A. *Specimen Material*

The material which is used for this investigation process is EN-36 alloy steel. EN-36 is a low carbon and high alloy content steel. It has high toughness due to the presence of nickel in it. It is used for making components which have large cross section and require comparatively high toughness and strength. It has huge application in different manufacturing industries such as gears, crane shafts etc. In aero space application it is used to make heavy duty gear. It is most commonly used metal in manufacturing industries.

Table 2.2 Chemical Composition of EN-36 Steel

Element	Chemical Composition (wt. %)
Carbon-C	0.7
Nickel-Ni	3.2
Chromium-Cr	1.050
Silicon-Si	0.25
Manganese-Mn	0.42
Sulphur-S	0.01
Phosphorus-P	0.012
Molybdenum-Mb	0.140

B. Factors and Levels

The three machining parameters feed, speed and depth of cut are taken as the control factors in this experimental process. Each of the control factors are designed to three levels denoted by level 1, 2 and 3. The experiments are planned using Box Behnken design under RSM process, which helps in reducing the probable number of experiments as the numbers of runs are minimized. The different input parameters and levels with its unit are shown in table 2.3.

Table 2.3 Input parameters with level

Factors/Levels	Level 1(low)	Level 2 (medium)	Level 3 (high)
Speed (rpm)	180	200	220
Feed (mm/rev)	0.10	0.15	0.20
Depth of cut (mm)	0.5	0.7	0.9

C. Design of Experiment

In simple word we can interpret design of experiment as an orderly step by step procedure which is carried out in controlled condition for divergent purposes while carrying out the experimental process. For short experimentation process the Box Behnken design methodology is employed for optimized results.

Depending on different input parameters and its corresponding levels, a design matrix is to be constructed. The design matrix is constructed by employing Minitab V-16 software. Minitab is statistical software which could be employed in order to perform a large variety of tasks, it starts from the construction of graph, and the numerical summation of the set of data, to that of highly complicated statistical procedures and tests. The design matrix is obtained from Minitab V-16 software by following steps:

1) *Step-1:* Starting Minitab V-16 software

To start Minitab, click its shortcut icon present on the monitor of computer. A window is opened.

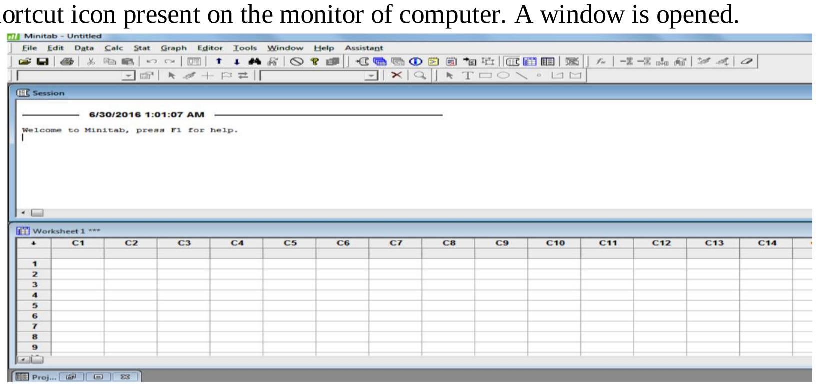

Fig. 2.4.1: Minitab window

2) *Step-2:* Creating the response surface design

Here in this step click the start, select the Design of experiment (DOE) then go to response surface and click on create response surface design. After clicking on create response surface design a dialog box is appeared.

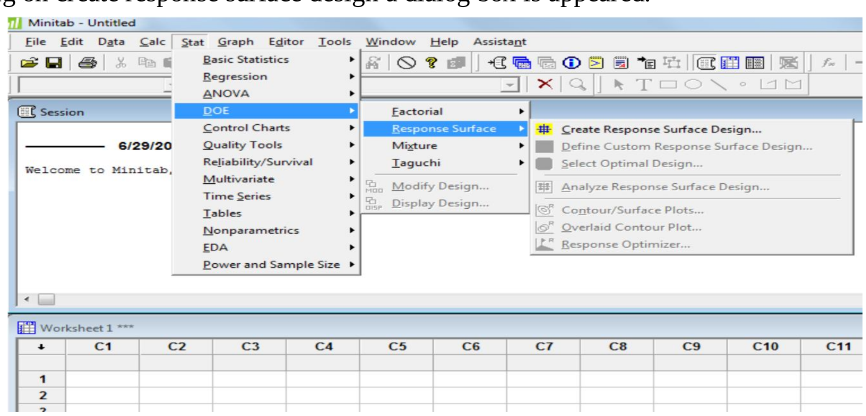

Fig. 2.4.3: Creating response surface design

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3) *Step-3:* Select number of factors and type of design under Response Surface design

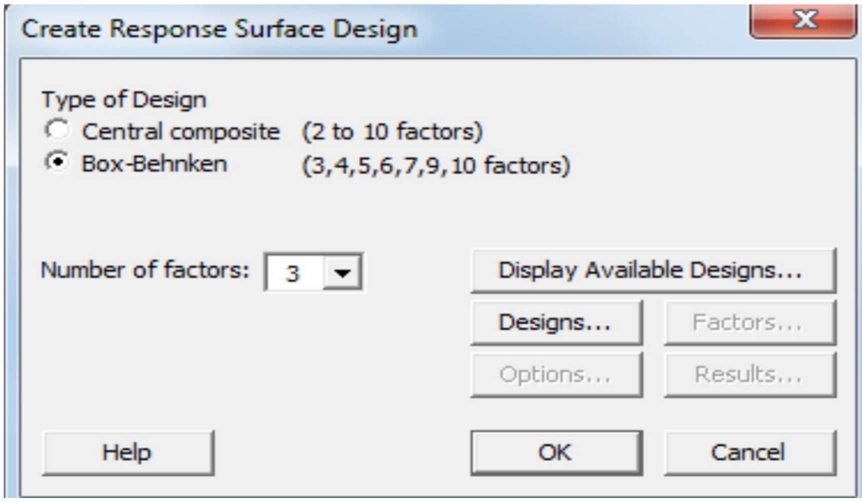
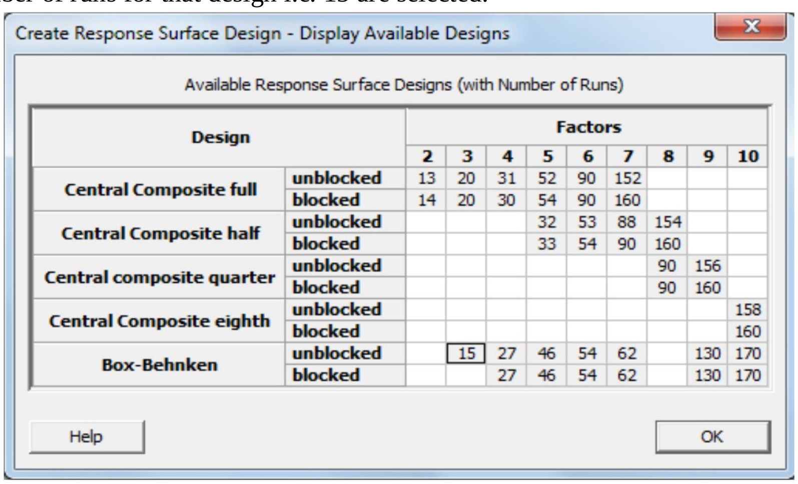


Fig. 2.4.4: Selection of number of factors and type of design

4) *Step-4:* Select the number of runs for the available Response Surface design

After clicking display available designs in step-3 a dialog box is appeared. Here in this step among different design i.e. Box Behnken design and the number of runs for that design i.e. 15 are selected.


Create Response Surface Design - Display Available Designs

Available Response Surface Designs (with Number of Runs)

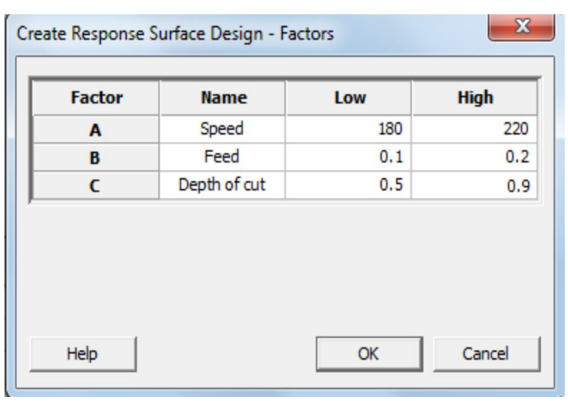
Design		Factors 2	3	4	5	6	7	8	9	10
Central Composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central Composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central Composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

Help OK

Fig. 2.4.5: Display of available designs under Response Surface Design

5) *Step-5:* Create Response Surface design factors

Here three different factors are selected and its low and high values are inserted for EN-36 alloy steel.


Create Response Surface Design - Factors

Factor	Name	Low	High
A	Speed	180	220
B	Feed	0.1	0.2
C	Depth of cut	0.5	0.9

Help OK Cancel

Fig. 2.4.6: Create Response Surface design factors

After clicking ok in step 5, the Box Behnken design in terms of coded variable and design matrix is obtained as shown in table 2.4.1 and 2.4.2 for EN-36 alloy steel.

Table 2.4.1 Box Behnken Design in terms of coded variable

Run order	Factors			Response value
	A	B	C	
1	-1	+1	0	Y1
2	0	-1	-1	Y2
3	0	0	0	Y3
4	0	+1	-1	Y4
5	-1	-1	0	Y5
6	0	-1	+1	Y6
7	+1	0	-1	Y7
8	+1	0	+1	Y8
9	+1	-1	0	Y9
10	+1	+1	0	Y10
11	0	0	0	Y11
12	-1	0	-1	Y12
13	0	+1	+1	Y13
14	-1	0	+1	Y14
15	0	0	0	Y15

Table 2.4.2 Design matrix obtained from Minitab V-16

Std Order	Run order	Pt Type	Blocks	Cutting speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
3	1	2	1	180	0.20	0.7
9	2	2	1	200	0.10	0.5
13	3	2	1	200	0.15	0.7
10	4	2	1	200	0.20	0.5
1	5	2	1	180	0.10	0.7
11	6	2	1	200	0.10	0.9
6	7	2	1	220	0.15	0.5
8	8	2	1	220	0.15	0.9
2	9	2	1	220	0.10	0.7
4	10	2	1	220	0.20	0.7
15	11	2	1	200	0.15	0.7
5	12	2	1	180	0.15	0.5
12	13	2	1	200	0.20	0.9
7	14	2	1	180	0.15	0.9
14	15	0	1	200	0.15	0.7

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D. Response Surface Methodology (RSM)

It is a collection of set of the statical and mathematical techniques which are employed for the development, improvement and optimization of a process. It plays a vital role in the design of new product, improvement of the existing product. It can be used to identify the probable modifications needed for the existing product in developing entirely new product. The major application of Response Surface Methodology (RSM) is in industrial and manufacturing field where various input parameters affects collectively on the performance characteristic and quality aspects of the process.

The objective of RSM process is to get the optimum response, if in a particular situation there is more than one response then in such situation it will be better to find out the compromised optimum, which optimizes only one response. In a certain conditions, if there are constraints on the design data, then the design of experiment should meet the requirements for such constraints.

Under the response surface methodology there are several different methods as:

1) Box Behnken Design (BBD)
2) Central Composite Design (CCD)

a) *Box Behnken Design:* In 1960 George E.P box and Donald Behnken developed this three level design for fitting the response which is now popularly called as Box Behnken design. This design is formulated by combining factorial with that of incomplete block designs. These design purposed is more accurate and efficient particularly on the basic of number of runs that are either rotatable or nearly rotatable. Fig .2.5.1 shows the Box Behnken design for three factors.

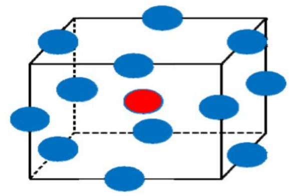

Fig. 2.5.1 Box Behnken Design for three factors

While conducting the experiment through Box Behnken design, no any points that are present on its vertices, of the experimental region is chosen because, on its vertices all the points have peak values. The prime benefit of implementing this process as design of experiment is that, it indicates the definite point where the experimental boundary should be located.

III. EXPERIMENTATION

Now after the design matrix has been developed, and the basic working of CNC machine is studied in detail, the experiments were carried out. The machine used for the experimentation process is Midas 6 Industrial type of CNC Lathe. A series of turning tests were conducted to assess the influence of cutting parameters on the Surface Roughness (SR) during the turning operation on EN-36 steel.

A. Operational Sequence

1) *Turning on Lathe Machine:* In this operation EN-36 alloy steel bar of 30 mm diameter and 32 cm length is used to get the specimens of 26 mm diameter and 18 mm long. The facing operation is carried out on CNC lathe as shown in fig 3.11. Thirty specimens are prepared.

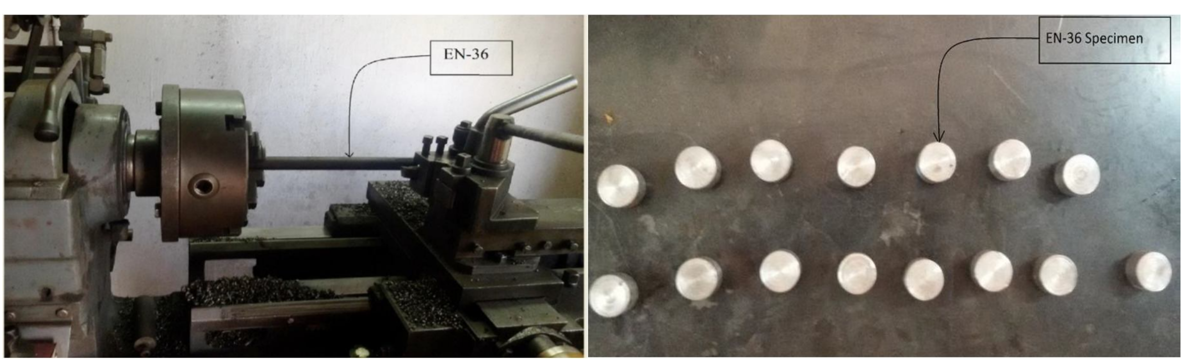

Fig 3.11 Preparation of work piece on lathe and Specimen after cutting on lathe machine

2) *Heat Treatment:* During the heat treatment of EN-36 alloy steel (case hardening) it is heated to a temperature of 620^{0}C for 8 hrs, quenched in furnace oil and then cooled to change the hardness and strong structure. EN-36 steel alloy exhibit a very good stability in heat treatment process. Heat treatment unit is shown in fig 3.1.2 and specimen before heat treatment and after heat treatment is shown in fig 3.1.1

Fig 3.1.2 Heat treatment of specimens on Quenching oil furnace

3) *Turning on CNC:* The machine used in order to carry out this experimental process is Midas 6 Industrial type of CNC lathe.

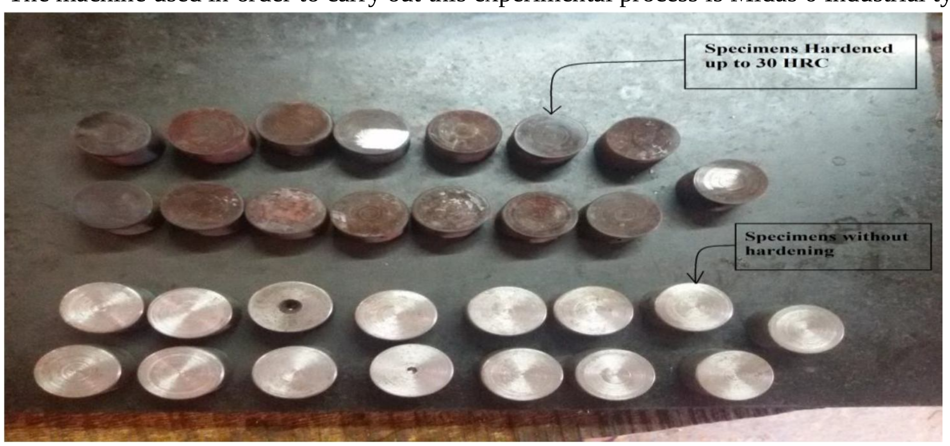

Fig 3.1.3 Specimens ready for machining on CNC

4) *Measurement of Surface Roughness:* The surface roughness of the specimen is obtained using Talysurf Surftronic 3+ profilometer. Figure shows the probe and display screen of Surtronic 3+ tester.

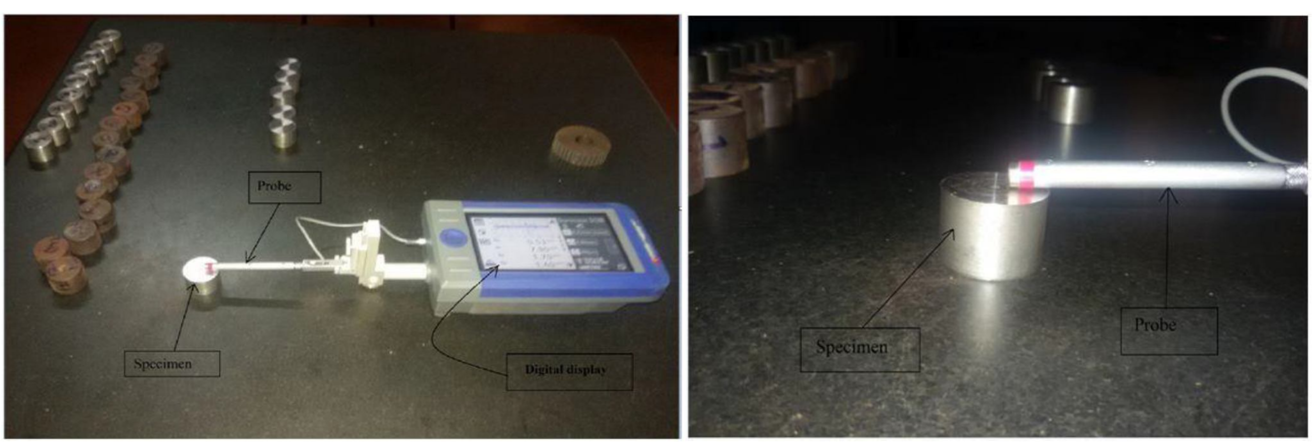

Fig 3.1.4.1 Surtronic 3+ tester measuring surface roughness of specimen

Surface roughness of each single specimen is measured three times at three different sections of the specimen starting from its face along the entire length.

Table 3.1.4.1 Average Surface roughness obtained on hardened specimens of EN-36

Specimen	Trail 1 (µm)	Trail 2 (µm)	Trail 3 (µm)	Average (µm)
1	0.64	0.60	0.65	0.63
2	0.48	0.49	0.46	0.476
3	0.52	0.55	0.61	0.56
4	0.46	0.44	0.45	0.45
5	0.45	0.51	0.47	0.477
6	0.45	0.49	0.41	0.45
7	0.51	0.55	0.57	0.543
8	0.54	0.50	0.57	0.537
9	0.48	0.49	0.47	0.48
10	0.45	0.47	0.48	0.466
11	0.55	0.61	0.57	0.577
12	0.55	0.61	0.60	0.587
13	0.42	0.61	0.51	0.513
14	0.68	0.64	0.65	0.657
15	0.61	0.60	0.56	0.59

Table 3.1.4.2 Average Surface roughness obtained on non-hardened specimens of EN-36

Work piece	Trail 1 (µm)	Trail 2 (µm)	Trail 3 (µm)	Average (µm)
1	0.55	0.66	0.56	0.59
2	0.38	0.34	0.27	0.33
3	0.50	0.54	0.64	0.56
4	0.42	0.59	0.35	0.453
5	0.52	0.46	0.36	0.446
6	0.37	0.30	0.38	0.35
7	0.48	0.53	0.39	0.466
8	0.39	0.50	0.44	0.433
9	0.37	0.39	0.38	0.38
10	0.59	0.65	0.53	0.59
11	0.45	0.56	0.66	0.566
12	0.50	0.54	0.49	0.51
13	0.53	0.55	0.48	0.52
14	0.66	0.64	0.61	0.633
15	0.53	0.56	0.62	0.57

In order to employ regression analysis and analysis of variance, the data is tabulated as shown in table 3.1.4.1 and 3.1.4.2.

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Table 3.1.4.3 Surface Roughness of EN-36 (Hardness 30 HRC)

Std Order	Run Order	Pt Type	Blocks	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Surface Roughness (µm)
3	1	2	1	180	0.20	0.7	0.63
9	2	2	1	200	0.10	0.5	0.476
13	3	0	1	200	0.15	0.7	0.56
10	4	2	1	200	0.20	0.5	0.45
1	5	2	1	180	0.10	0.7	0.477
11	6	2	1	200	0.10	0.9	0.45
6	7	2	1	220	0.15	0.5	0.543
8	8	2	1	220	0.15	0.9	0.537
2	9	2	1	220	0.10	0.7	0.48
4	10	2	1	220	0.20	0.7	0.466
15	11	0	1	200	0.15	0.7	0.577
5	12	2	1	180	0.15	0.5	0.587
12	13	2	1	200	0.20	0.9	0.513
7	14	2	1	180	0.15	0.9	0.657
14	15	0	1	200	0.15	0.7	0.59

Table 3.1.4.4 Surface Roughness of EN-36 (without hardening)

Std Order	Run Order	Pt Type	Blocks	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness (µm)
3	1	2	1	180	0.20	0.7	0.59
9	2	2	1	200	0.10	0.5	0.33
13	3	0	1	200	0.15	0.7	0.56
10	4	2	1	200	0.20	0.5	0.453
1	5	2	1	180	0.10	0.7	0.446
11	6	2	1	200	0.10	0.9	0.35
6	7	2	1	220	0.15	0.5	0.466
8	8	2	1	220	0.15	0.9	0.433
2	9	2	1	220	0.10	0.7	0.38
4	10	2	1	220	0.20	0.7	0.59
15	11	0	1	200	0.15	0.7	0.566
5	12	2	1	180	0.15	0.5	0.51
12	13	2	1	200	0.20	0.9	0.52
7	14	2	1	180	0.15	0.9	0.633
14	15	0	1	200	0.15	0.7	0.57

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IV. RESULT AND CONCLUSION

This chapter mainly emphasis on the results obtained from the experimental exploration and inspection with respect to the material removal rate and surface roughness in turning operation. The results are analyzed which factors among speed, feed and depth of cut are more significant applying Box Behnkan design of experiments under Response Surface Methodology.

In this proposed work, Minitab version-16 software is used to draw the graphs and plots for both surface roughness and material removal rate. As the process parameters change from one level to another, its main effects and interactions on Material Removal Rate (MRR) and Surface Roughness (SR) are calculated and plotted. In order to check the sufficiency of the second order model, analysis of variance (ANOVA) has been employed.

A. Regression Analysis for Surface Roughness

Regression is employed to investigate and find out the interrelation ship between the response variable and the unknown variables. In order to find out the regression analysis and ANOVA analysis we have to follow the following steps:

1) Step-1: Prepare the input matrices use spread sheet of Microsoft Excel

Here we import the values for the response variable as per the design matrix obtained in Minitab V-16 software from excel sheet. The values are imported as per it has been obtained during experiment.

	A	B	C	D	E	F	G	H
1					WITH HARDNESS			
2	StdOrder	RunOrder	PtType	Blocks	Speed	Feed	Depth of Cut	SR
3	3	1	2	1	180	0.2	0.7	0.63
4	9	2	2	1	200	0.1	0.5	0.467
5	13	3	0	1	200	0.15	0.7	0.56
6	10	4	2	1	200	0.2	0.5	0.45
7	1	5	2	1	180	0.1	0.7	0.477
8	11	6	2	1	200	0.1	0.9	0.45
9	6	7	2	1	220	0.15	0.5	0.543
10	8	8	2	1	220	0.15	0.9	0.537
11	2	9	2	1	220	0.1	0.7	0.48
12	4	10	2	1	220	0.2	0.7	0.466
13	15	11	0	1	200	0.15	0.7	0.577
14	5	12	2	1	180	0.15	0.5	0.587
15	12	13	2	1	200	0.2	0.9	0.42
16	7	14	2	1	180	0.15	0.9	0.657
17	14	15	0	1	200	0.15	0.7	0.59
18								

Fig 4.1.1: Importing values for surface roughness from excel sheet

2) Step-2: Analyzing the response surface design

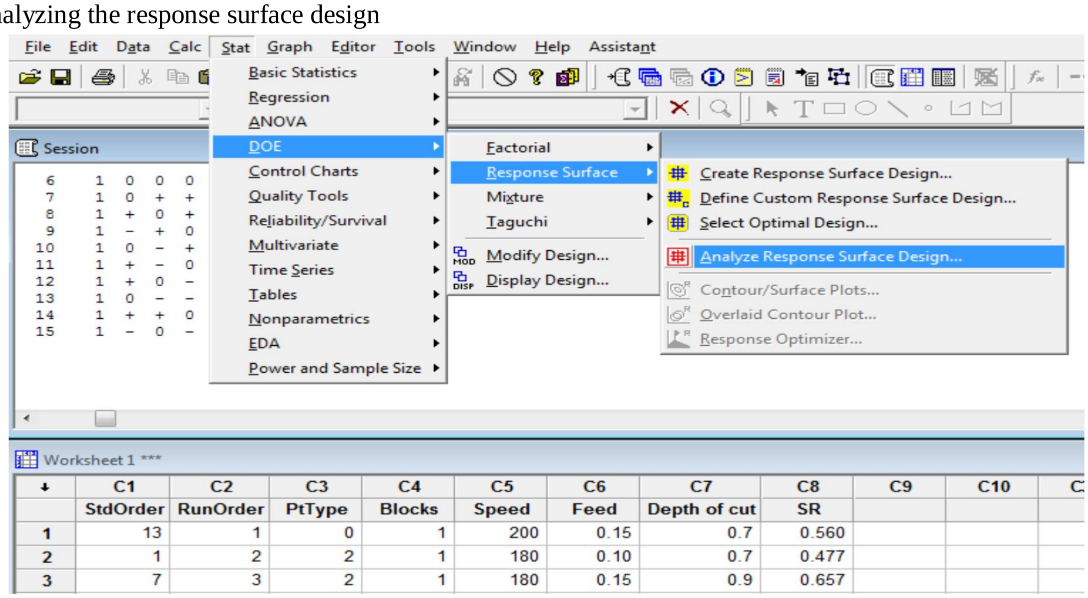

Fig 4.1.2: Analyzing response surface design

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3) *Step-3 and Step-4:* Selecting the response surface and Inserting the confidence interval for the Response Surface Design Prediction

Here in this step responses are selected and the data is analyzed using uncoded units.

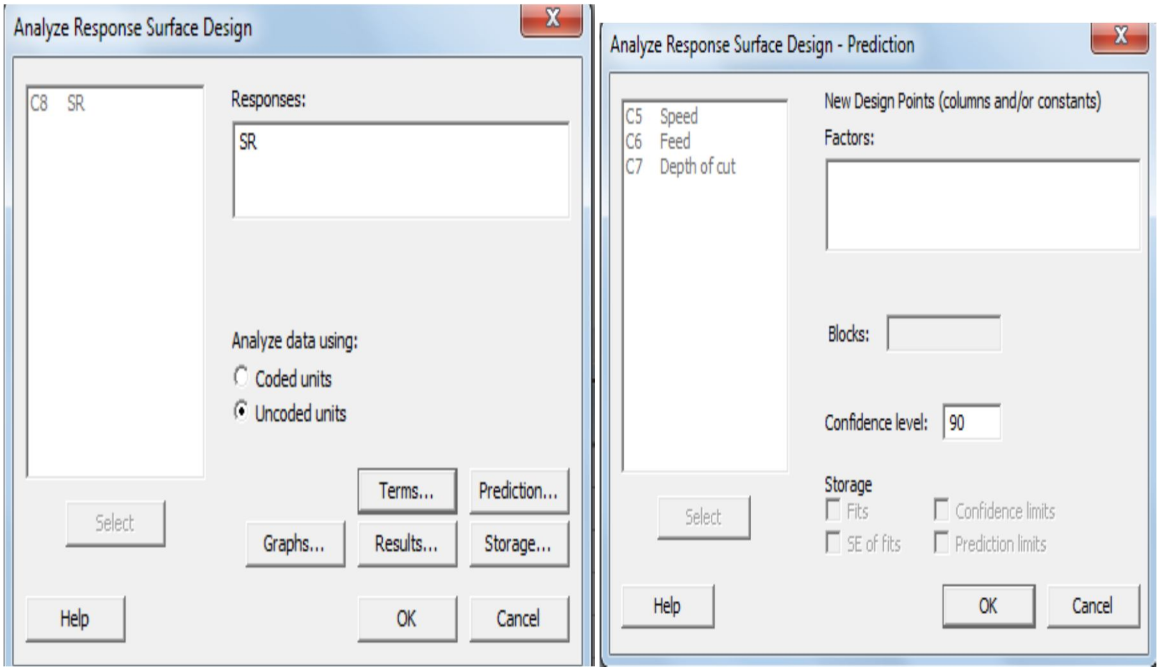

Fig 4.1.3: Selecting the response to analyze Response Surface Design and Analyze Response Surface Design prediction

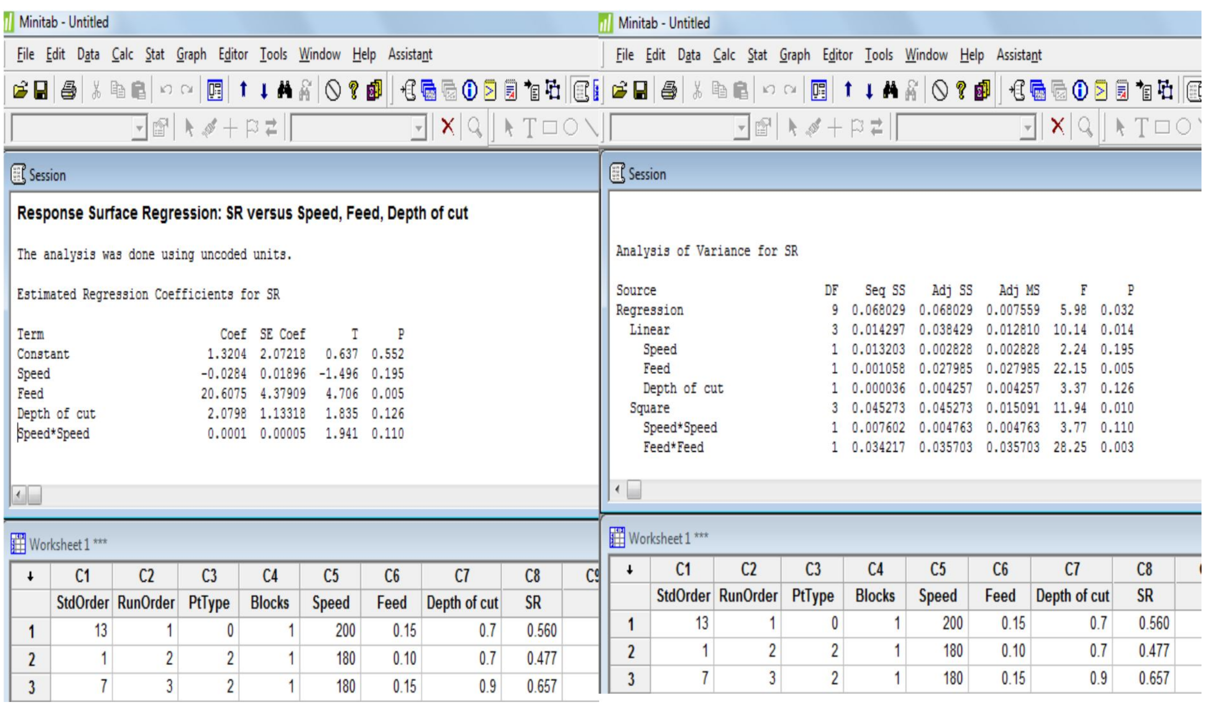

Fig 4.1.4: Estimated Regression Coefficient obtained for the response variable and Analysis of Variance obtained for the response variable

Following regression estimate table and the table for analysis of variance (ANOVA) were obtained from Minitab V-16 software for SR without material hardening and with hardening to (30HRC).

Table 4.1.1: Estimated Regression Coefficients for Surface Roughness on the specimens without hardening

Terms	Coeff.	SE Coeff.	T test	P value
Constant	1.1197	1.69312	0.661	0.538
Cutting speed	-0.0236	0.01549	-1.699	0.150
Feed	7.0200	3.57804	1.962	0.017*
Depth of cut	4.5900	0.92589	4.957	0.004*
Cutting speed* Cutting speed	0.0001	0.00004	1.828	0.127
Feed*Feed	-33.2500	6.04633	-5.499	0.003*
Depth of cut*Depth of cut	-1.8906	0.37790	-5.003	0.004*
Cutting speed *Feed	0.0215	0.01452	1.480	0.199
Cutting speed *Depth of cut	-0.0094	0.00363	-2.582	0.049*
Feed*Depth of cut	0.1750	1.45228	0.120	0.909
S = 0.0290457	**R-Square = 96.48%**		**R-Square (adjusted) = 90.14%**	

Table 4.1.2: Analysis of Variance for SR on the specimens without hardening

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.115513	0.115513	0.012835	15.21	0.004
Linear	3	0.059043	0.029446	0.009815	11.63	0.011
Cutting speed	1	0.013122	0.002434	0.002434	2.89	0.150
Feed	1	0.043071	0.003247	0.003247	3.85	0.107
Depth of Cut	1	0.002850	0.020733	0.020733	24.58	0.004
Square	3	0.048983	0.048983	0.016328	19.35	0.004
Cutting speed * Cutting Speed	1	0.005668	0.002818	0.002818	3.34	0.127
Feed*Feed	1	0.022198	0.025513	0.025513	30.24	0.003
Depth of Cut*Depth of Cut	1	0.021117	0.021117	0.021117	25.03	0.004
Interaction	3	0.007486	0.007486	0.002495	2.96	0.137
Cutting speed *Feed	1	0.001849	0.001849	0.001849	2.19	0.199
Cutting speed *Depth of Cut	1	0.005625	0.005625	0.005625	6.67	0.049
Feed*Depth of Cut	1	0.000012	0.000012	0.000012	0.01	0.909
Residual Error	5	0.004218	0.004218	0.000844		
Lack-of-Fit	3	0.004114	0.004114	0.001371	26.37	0.037
Pure Error	2	0.000104	0.000104	0.000052		
Total	14	0.119731				

Here DOF denotes degree of freedom; it is an amount of information provided by your data so as to calculate the unknown variables. Here Seq SS denotes sequential sum of square and Adj SS denotes adjusted sum of square and Adj MS denotes adjusted mean square. F denotes f value, which is the ratio of mean square. P denotes p value, which is used to show weather the results so obtained are significant or not.

Table 4.1.3: Estimated Regression Coefficients for SR on the specimens with hardening

Terms	Coeff.	SE Coeff.	T test	P value
Constant	1.3204	2.07218	0.637	0.552
Cutting speed	-0.0284	0.01896	-1.496	0.195
Feed	20.6075	4.37909	4.706	0.005*
Depth of cut	2.0798	1.13318	1.835	0.126
Cutting speed * Cutting speed	0.0001	0.00005	1.941	0.110
Feed*Feed	-39.3333	7.39997	-5.315	0.003*
Depth of cut*Depth of cut	-0.7646	0.46250	-1.653	0.159
Cutting speed*Feed	-0.0417	0.01777	-2.349	0.066*
Cutting speed*Depth of cut	-0.0047	0.00444	-1.069	0.334
Feed*Depth of cut	-0.3250	1.77742	-0.183	0.862
S = 0.0355483	**R-Square =91.50%**		**R-Square (adjusted) =86.20%**	

Table 4.1.4: Analysis of Variance for Surface Roughness on the specimens with hardening

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.068029	0.068029	0.007559	5.98	0.032
Linear	3	0.014297	0.038429	0.012810	10.14	0.014
Cutting speed	1	0.013203	0.002828	0.002828	2.24	0.195
Feed	1	0.001058	0.027985	0.027985	22.15	0.005
Depth of Cut	1	0.000036	0.004257	0.004257	3.37	0.126
Square	3	0.045273	0.045273	0.015091	11.94	0.010
Cutting speed * Cutting speed	1	0.007602	0.004763	0.004763	3.77	0.110
Feed*Feed	1	0.034217	0.035703	0.035703	28.25	0.003
Depth of Cut*Depth of Cut	1	0.003454	0.003454	0.003454	2.73	0.159
Interaction	3	0.008458	0.008458	0.002819	2.23	0.203
Cutting speed *Feed	1	0.006972	0.006972	0.006972	5.52	0.066
Cutting speed *Depth of Cut	1	0.001444	0.001444	0.001444	1.14	0.334
Feed*Depth of Cut	1	0.000042	0.000042	0.000042	0.03	0.862
Residual Error	5	0.006318	0.006318	0.001264		
Lack-of-Fit	3	0.005866	0.005866	0.001955	8.64	0.106
Pure Error	2	0.000453	0.000453	0.000226		
Total	14	0.074347				

B. Main effect Plot for Surface Roughness

The main effects plots are mainly employed to find out the optimal response by employing the optimal design conditions. After doing the ANOVA and regression analysis the main effect plot is obtained by following the steps:

1) *Step-1:* Go to start then ANOVA and select the Main effect plot

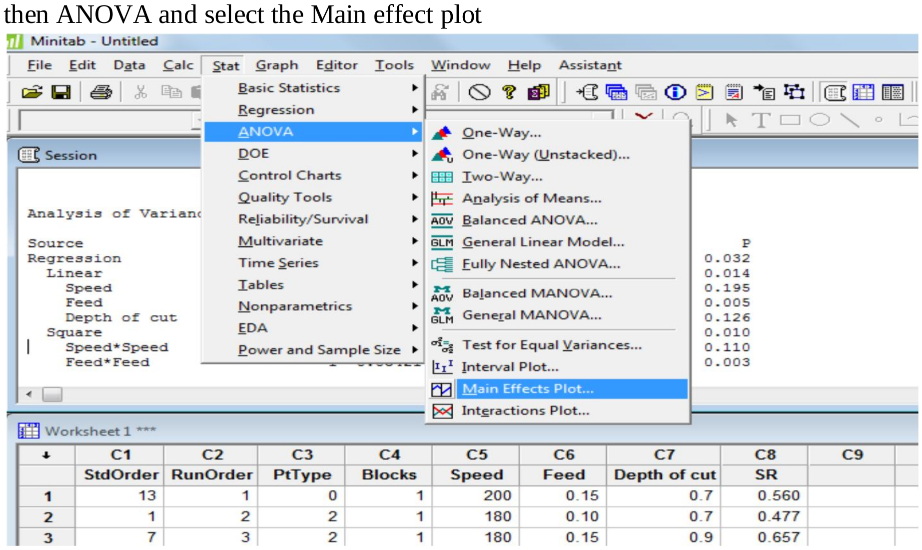

Fig 4.1.1.1: Minitab window for main effect plot

2) *Step-2:* Select the responses and factors for main effect plot

After clicking on main effect plot in step-1 a dialog box is appeared as in fig 4.8.Here in this step the different responses and factors are selected. After clicking ok in fig 4.8 a graph is obtained for main effect plot.

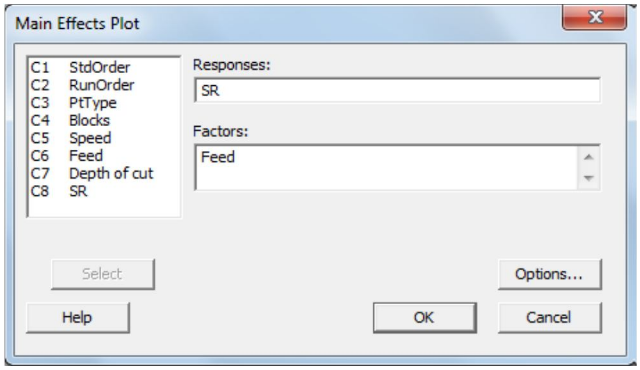

Fig 4.1.1.2: Select responses and factors for main effect plot

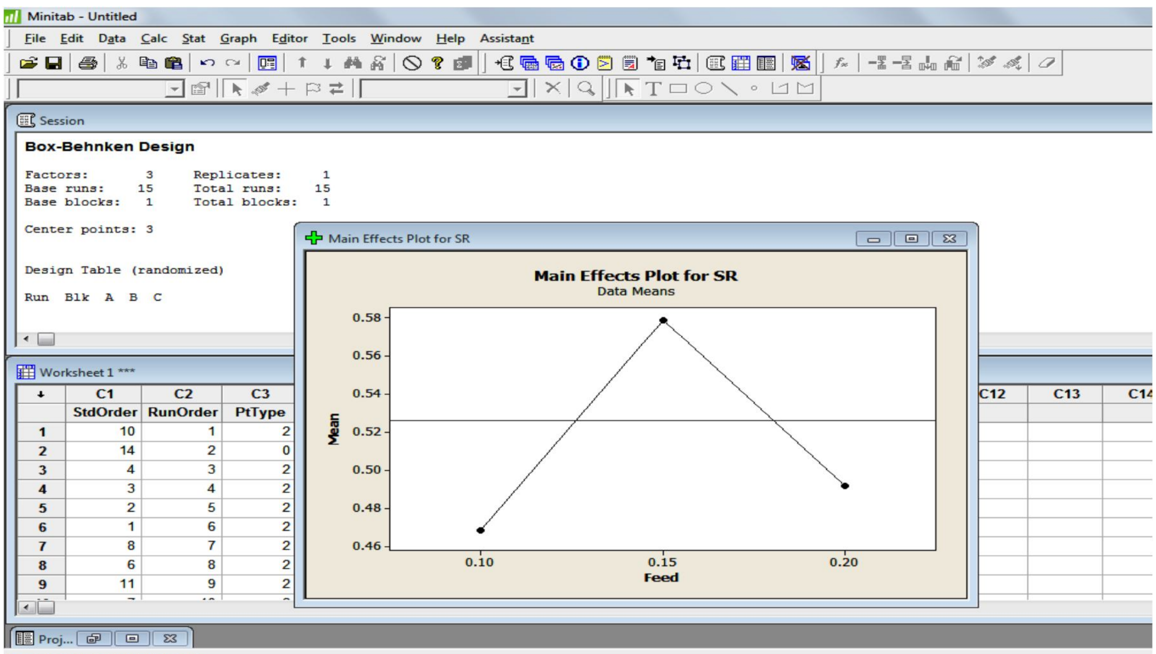

Fig 4.1.1.3: Main effect plot graph in Minitab window

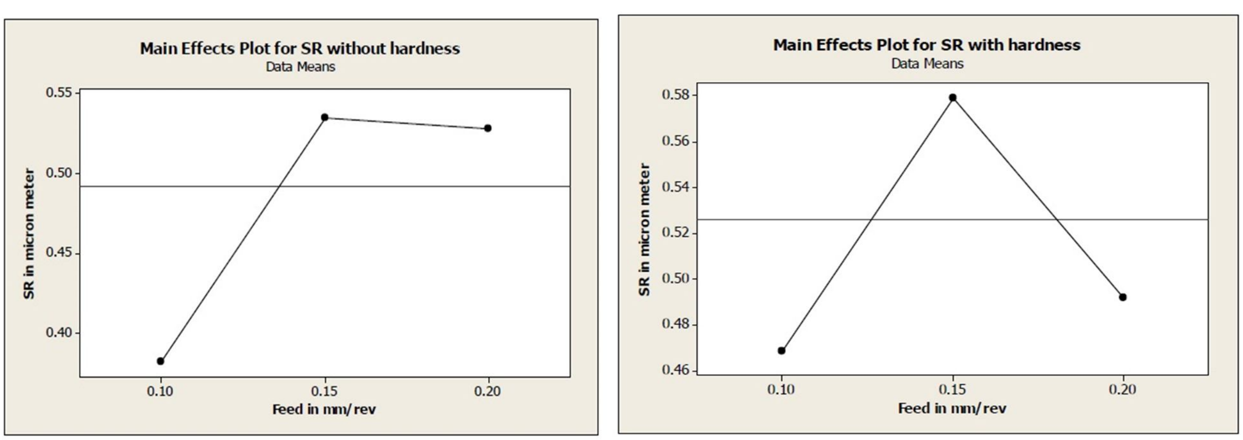

Fig 4.1.1.4: Main effect plot for SR v/s Feed on without and without hardened specimens

C. Interaction plot for Surface Roughness

Interaction plots are used to show the effect of two parameters on the response variable. After doing the ANOVA and regression analysis the interaction effect plot is obtained in Minitab by following the given steps:

1) *Step-1:* Click on start and then ANOVA and select the Interactions plot

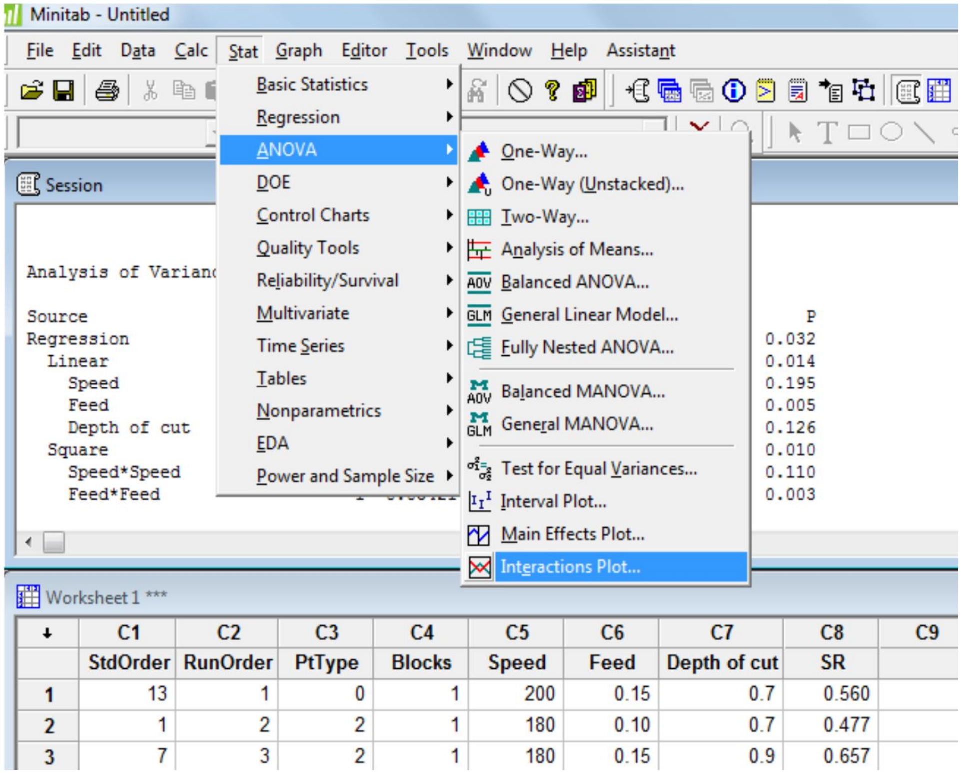

Fig 4.1.2.1: Minitab window for Interactions plot

2) Step-2: Select the responses and factors for Interactions effect Plot

After clicking on interactions plot in step-1 a dialog box is obtained. Here in this step the different responses and factors are selected. After clicking ok in fig 4.1.2.2 a graph is obtained for interactions plot

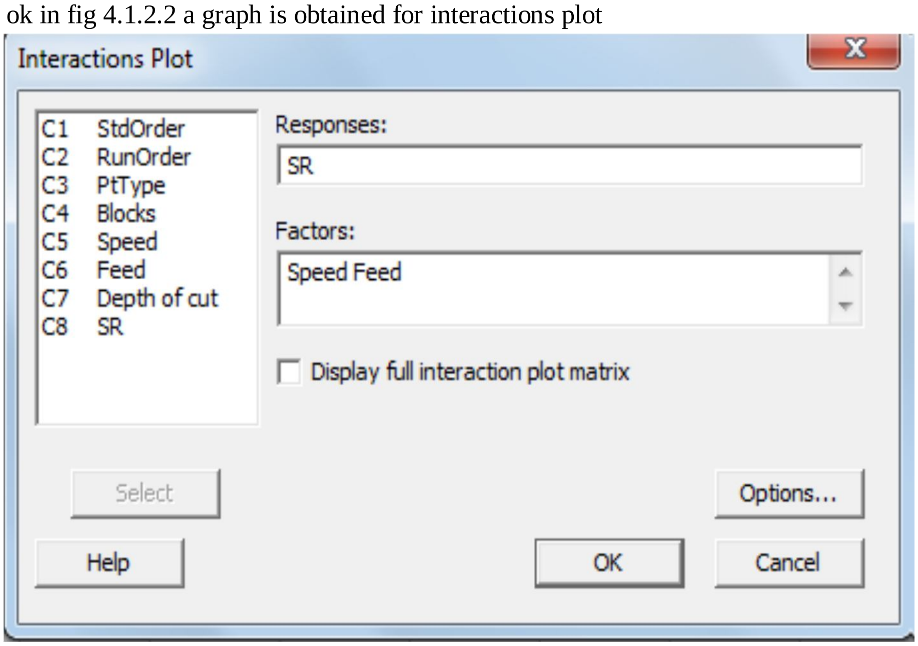

Fig 4.1.2.2: Select responses and factors for interactions plot

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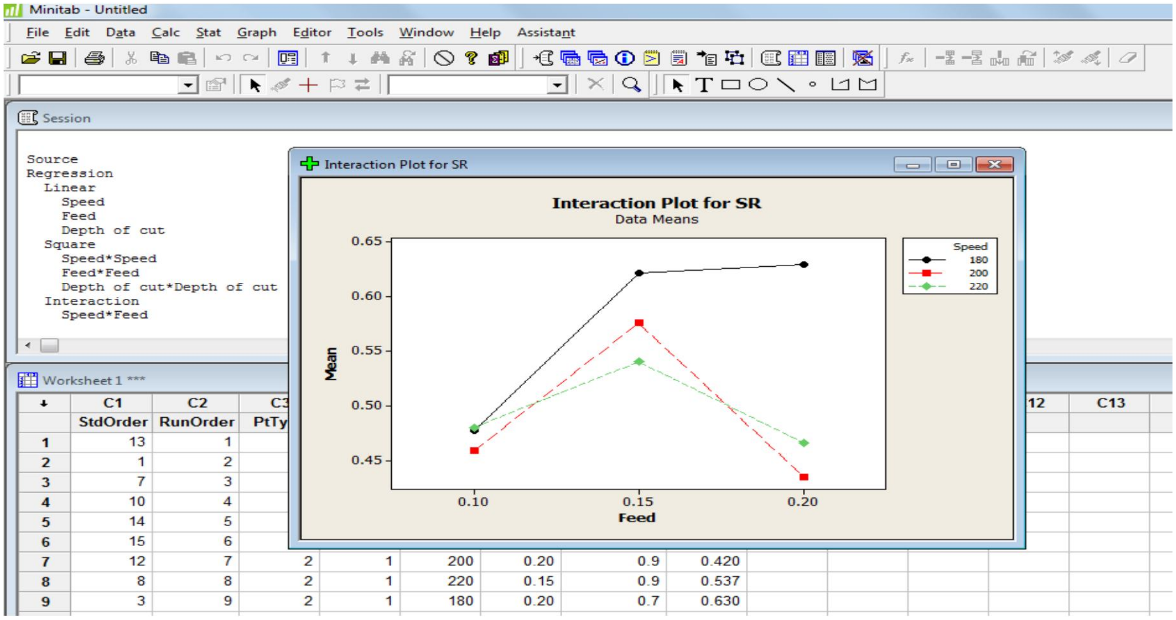

Fig 4.1.2.3: Interaction plot graph in Minitab window

Demonstrates interaction plot due to the impact of various different factors on surface roughness (Ra value).

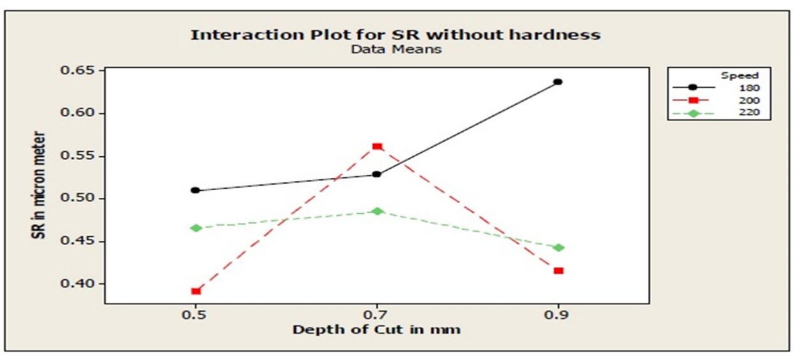

Fig 4.1.2.4: Interaction plot for surface roughness v/s DOC for the specimens without hardening

The interaction plot for SR for the specimens without hardening. In figure the speeds are shown in different color lines. Its surface roughness is plotted along y-axis and its respective depth of cut plotted along x-axis.

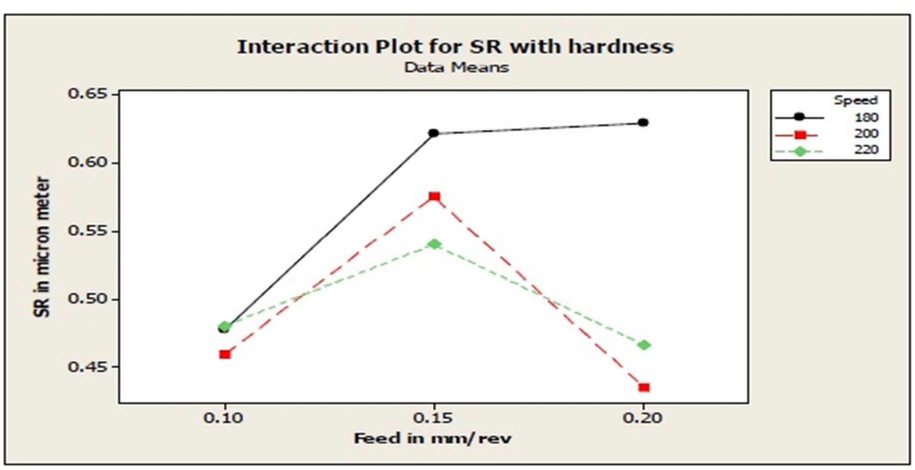

Fig 4.1.2.5: Interaction plot for SR v/s Feed for the specimens with hardening

Table 4.1.2.1 the machining parameters for Optimum Surface Roughness

Material condition	Feed (mm/rev)	Speed (rpm)	Depth of cut (mm)	SR(µm)
Without hardening	0.10	200	0.5	0.33
With hardening	0.20	200	0.9	0.425

V. CONCLUSION

This dissertation work is mainly focused on the optimization of Surface Roughness (SR). Suitable combination of different process parameters are done to produce low Surface Roughness possible. The experiment was planned as per Box Behnken design under Response Surface Methodology (RSM) in order to carry out the machinability study. Analysis of variance (ANOVA) is used to check adequacy of the proposed model. After the completion of the experiment and detailed analysis, following conclusions were drawn:

A. Optimum Surface Roughness (SR) of 0.33 is obtained for EN-36 material (without hardening) at a feed rate of 0.10 mm/rev, speed of 200 rpm and depth of cut of 0.5 mm. For EN-36 hardened to 30 HRC the surface roughness obtained is 0.425 at a feed rate of 0.20 mm/rev, speed of 200 rpm and depth of cut 0.9 mm.

B. The result of ANOVA for Surface Roughness shows that the feed and depth of cut are the more significant parameters for the material without hardening, where as the least significant parameter is speed. For the material hardened to 30 HRC feed is the more significant parameter where as the least significant parameter is speed followed by depth of cut.

C. The experiment model obtained helps the designer in selecting a best suitable combination of design parameters to get optimum Surface Roughness during the turning operation. This helps in reducing the machining time, cost and tool wear rate.

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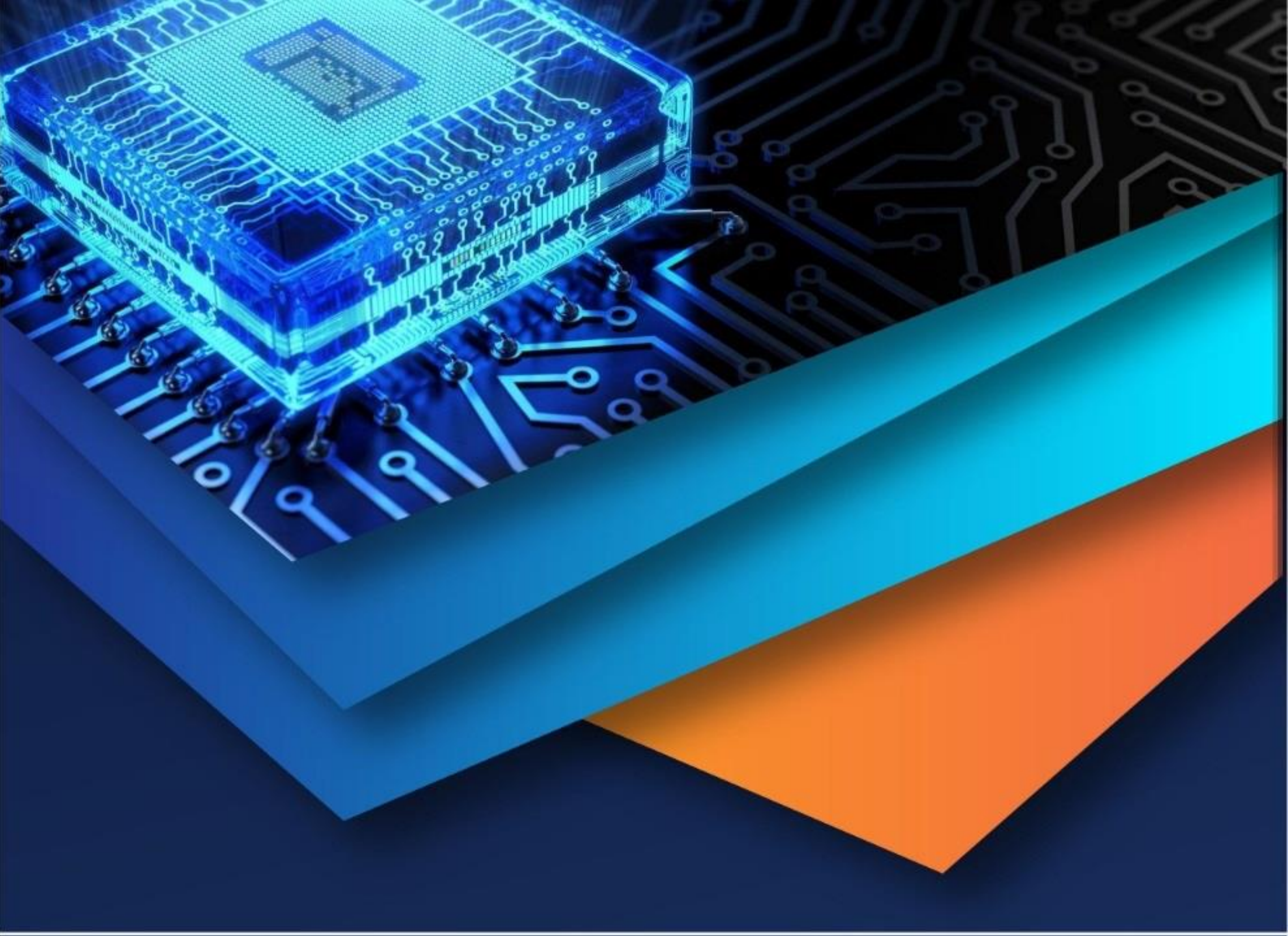

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