CHAPTER 1

Introduction

In manufacturing industries Quality of products are the main challenging tasks for manufacturer. In these industries machining processes suffers various problems regarding optimum value of machining parameters for better surface finish and material removal rate. The work material selected for present study is EN-24 tool steel used in High strength machine parts, collets, spindles, studs, bolts, crank shafts, arbors etc[1].

Machining operations are used to produce a desired product by removing excess material from a blank in the form of chips and the surface generated through a process of plastic deformation. The work-piece at the time of running machining process is subjected to various mechanical forces and localized heating by tools cutting edges. Surface roughness indicates the state of a machined surface of work-piece. Surface roughness is quantified when surface level reaches to shininess or asperity clearly which define the character of a surface. The surface irregularities of a component may be created by machining, but they can also be created wide range of factors such as mechanical vibration of machine and tool rubbing etc, during machining. So process optimization is the discipline of adjusting a process so as to optimize some specified set of parameters without violating some constraints. When optimizing a process, the goal is to maximize one or more of the process specifications, while keeping all others within their constraints [3].

1.1 Turning process

Turning is a very important machining process in which a single point cutting tool is used to remove unwanted material from the surface of a rotating cylindrical work piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. Turning is carried out on lathe that provides the power to turn the work-piece at a given rotational speed and feed to the cutting tool at specified rate and depth of cut. Therefore, three cutting parameters namely cutting speed, feed and depth of cut need to be optimized in a turning operation.

Turning is carried out on a lathe machine that provides the power to turn the work-piece at a given rotational speed and feed is given to the cutting tool at specified rate and depth of cut. Therefore, three cutting parameters namely cutting speed, feed and depth of cut need to be determined in the turning operation. The purpose of turning operation is to remove unwanted material from the work-piece surface and produces better quality of surface finish of the parts. Surface roughness is another important factor to evaluate performance. Proper selection of cutting parameters can produce precise and lower surface roughness. So it is needed to optimize the process parameters such as cutting speed, feed and depth of cut to improve the response like material removal rate and surface roughness in a turning operation.

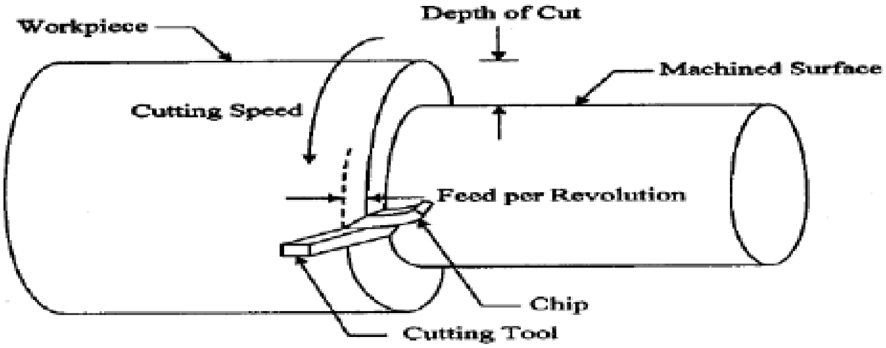

Figure 1.1 Parameters in turning operation [9]

1.2 Turning Parameters

The turning parameters such as cutting speed, feed and depth of cut play an important role in the production of quality product. Whenever two machined surfaces come in contact with each other, the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work-piece depend upon number of factors which are given below.

1.21 Cutting speed

The speed of the work piece surface relative to the edge of cutting tool during cut. Measured in (mm/min).The rotational speed of the spindle and the work-piece in revolution per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the work-piece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant then the cutting speed will vary.

$$V = \pi DN / 1000 \text{ (m/min)}$$

Here, “V” is the cutting speed in turning operation, “D” is the initial diameter of the work-piece in mm, and “N” is the spindle speed in rpm. It is found that an increase of cutting speed generally improves the surface quality of the product.

1.22 Feed

Feed is always given to the cutting tool in the turning operation, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$F_m = f\,N \text{ (mm/min)}$$

Here, F_m is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM. Experiments show that as the feed rate increases, the surface roughness also increases due to the increase in cutting force and vibration.

1.23 Depth of cut

It is the thickness of the layer to be removed (in a single pass) from the work-piece or the distance from the uncut surface of the work-piece to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work-piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work-piece

$$d_{cut} = D-d / 2 \text{ (mm)}$$

Here, D and d represent initial and final diameter (in mm) of the job respectively.

On the increase of depth of cut, increases the cutting resistance and the amplitude of vibrations as well as increases the temperature at the tool work-piece interface. Therefore, the surface quality of the work-piece deteriorated.

1.3 Material

An alloy steels defined as a steels alloyed with variety of elements in total amount ranging from 1% to 50% by weight to improve their mechanical properties. These are classified as low alloy and high alloy steels. The steels with alloy contains lower than 4-5% are considered as low alloy steels while those higher than 8% alloying elements are called high alloy steels. The common elements employed in these steels include Mn, Ni, Cr, Mo,V, Si and Boron are most commonly while Al, Co, Cu, Ce, Nb, Ti, W, Sn and Zr are less commonly used. These steels find wide range of applications such as turbine blades in jet engines, space craft and component for nuclear reactor, electrical motors and transformers etc. Some commonly used alloy steels and their grades are given in table1.1.

Table 1.1: Alloy designation of some engineering materials

Equivalent grade					
Internat. standard	BS	DIN	IS	EN	AISI/SAE
EN18	530A40	37Cr4	40Cr1	EN18	5140
EN19	709M4	42Cr4Mo2	40Cr4Mo2	EN19	4140
EN24	817M40	34CrNiMo6	40NiCr4Mo3	EN24	4340

Details of chemical composition and mechanical properties of EN-24 used for experimental work have been discussed in chapter experimental work.

1.4 Surface Roughness

The surface roughness may be defined as coarse, rough, medium and fine surface. There are many mathematical ways to find out surface roughness depending on its applications like Ra, Rt, Rq, R_k, but roughness average Ra is widely used in industry for the mechanical components for indication of surface roughness, also known as arithmetic aver-age (AA) or centre line average (CLA).

1.41 Roughness Average (Ra)

Roughness average Ra is the arithmetic average of the absolute values of roughness profile ordinates i.e. mathematical calculation can be done as below

$$R_a = \frac{1}{l}\int_0^l |Z(x)|\ dx$$

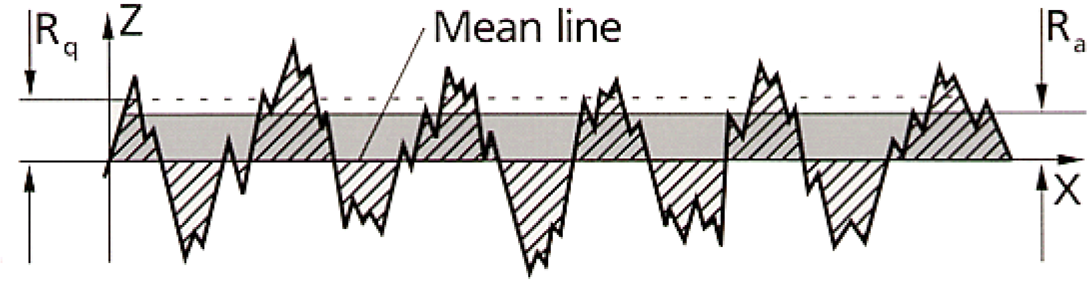

Figure 1.2: Roughness profile

1.42 Root Mean Square Roughness (Rq)

Square roughness Rq is the root mean square average of the roughness profile ordinates as shown in fig.1.2 is

$$R_q = \sqrt{\frac{1}{l}\int_0^l Z^2(x)\ dx}$$

Where l is sampling length

1.5 Material Removal Rate

Material removal rate is used to evaluate a machining performance. Material removal rate is expressed as the amount of material removed under a period of machining time and is calculated using the equation given below [6]

MRR= (Wi─Wf) / tm (gm/sec)

Where:

Wi = initial weight of work-piece before machining (gm)

Wf=final weight of work-piece after machining (gm)
tm =machining times(sec)

1.6 Cutting Temperature of tool work-piece interface

The tool work-piece interface getting heat during machining and temperature increases which is commonly know as cutting temperature or tool work-piece interface temperature. Maximum heat is generated on the tool-chip interface during machining. The heat generated on the cutting tool is important for the performance of the tool and quality of the work-piece. Cutting temperature is an important factor in the machining operations as it strongly influences the cutting forces, tool life and the work-piece surface integrity. Higher cutting temperatures decrease the yield strength of the work-piece material, making it more ductile. This results a decrease in cutting forces and hence improve the machinability of the material. However increased work-piece surface temperature. So temperature measurement is a major focus of machining research.[22] There are several techniques to measure the cutting temperature as following:

(i) Thermal paints technique; (ii) Thermocouple techniques -Tool-work thermocouple technique, Transverse thermocouple technique, and Embedded thermocouple technique; (iii) Infrared radiation pyrometer technique; (iv) Optical infrared radiation pyrometer technique; (v) Infra-red photography; (vi) Fine powder techniques; and (vii) Metallographic methods [23]

CHAPTER 2

Literature Review

Turning is the one of basic process of machining of material through which excess or undesired materials of cylindrical parts are removed. In manufacturing industries, surface finish of a product is very crucial in determining the quality Due to the increasing demand of higher precision components for its functional aspect, surface roughness of a machined part plays an important role in the modern manufacturing process. Turning is a machining operation, which is carried out on lathe. The quality of the surface plays a very important role in the performance of turning as a good quality turned surface significantly improves fatigue strength, corrosion resistance, or creep life. Surface roughness also affects several functional attributes of parts, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, load bearing capacity, coating or resisting fatigue. Therefore, the desired surface finish is usually specified and the appropriate processes are selected to reach the required quality.

Mahendra Korat et al. [2012] were conducted the experimental analysis to optimize the effect of cutting parameters on surface roughness and MRR of EN-24 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and ANOVA were employed to study the performance characteristics in turning operation. The experimental investigation showed the effect of cutting speed, feed, and depth of cut, nose radius and cutting environment on MRR and surface roughness in CNC turning of EN-24. ANOVA suggested that nose radius is most significant factor and cutting environment is most insignificant factor for both surface roughness and MRR. The ANOVA analysis of the experiment showed the result that the nose radius, depth of cut, feed; cutting speed and coolant condition affect the material removal rate by 40.68%, 20.96%, 20.55%, 14.88% and .023% respectively. The nose radius, depth of cut, feed; cutting speed and coolant condition affect the surface roughness by 65.38%, 25.15%, 3.06%, 1.41% and.09% respectively.

C.R.Barik et al. [2012] Investigated the experimental study of roughness characteristics of surface roughness generated in CNC turning of EN-31 alloy steel and optimization of machining parameters based on Genetic Algorithm. The three level central composite designs is employed for developing mathematical model for predicting surface roughness parameters. Response Surface Methodology is applied successfully in analyzing the effect of process parameters on surface roughness parameters. The second order mathematical model in terms of machining parameters is developed based on experimental results. The experiment was conducted considering three machining parameters, viz., spindle speed, feed and depth of cut as independent variables and the surface roughness as response variable. The model of surface roughness with ANOVA was employed. And for optimizing the cutting parameters, Genetic Algorithm process was implied to achieve minimum surface roughness.

Puneet Saini et al. [2014] the surface roughness and MRR in the surface finishing process of EN-24 were modeled and analyzed through RSM. Spindle speed, feed and depth of cut have been employed to carry the experimental study. Analyzed with ANOVA for Ra the experimental result showed that the feed is the most significant factor contributed 56.80%, where doc and spindle speed have 23.22% and 4% respectively. ANOVA Analysis for MRR showed that Depth of cut, feed and spindle speed contributed 56%, 23.43% and 6.33% respectively. Through multi response optimization the optimum value of the surface roughness comes out to be 1.46389 µm for MRR is 403.458 mm3/sec. It is also found that the feed & depth of cut are the major significant factor affecting surface roughness & MRR.

S. S. Acharya et al [2014] suggested the design of experiment and optimization of surface roughness, MRR, machining time was carried out by using Response Surface Methodology. Central composite design method was used for the total experimental design works its analysis and also for optimization of turning process parameters by which wastage of the machining time, power can be avoided. In this experimental work an investigation of turning process parameters on EN-34, for optimization of surface roughness, MRR and machining time in wet and minimum quantity lubrication system employed. The experiment was carried out by considering four controllable input variables namely cutting speed. feed, depth of cut and insert nose radius in the presence of wet system

Jakhale Prashant P et al[2013] developed an experimental work and investigated the effect of cutting parameters such as cutting speed, feed, depth of cut and tool insert geometry on surface roughness in high turning of alloy steel. The experiment was conducted using L9 orthogonal array in a TACCHI lathe CNC turning machine. The Taguchi experimental design was used to obtain optimum cutting condition and result were analyzed using ANOVA.

Krishankant et al. [2012**]** suggested an optimization of turning process by the effect of machining parameters applying Taguchi methods to improve the quality of machined product and engineering development of design for studying variation. EN-24 was used as the work-piece for carrying out the experimentation to optimize the MRR. The bar used, was 44mm diameter and 60mm length. The machining parameters i.e. spindle speed, feed, and depth of cut were optimized by Taguchi orthogonal array design with three level of turning parameters with the help of software Minitab15

N. Satheesh Kumar [2012] investigated, the effect of process parameters namely spindle speed and feed in turning of carbon alloy Steels in a CNC lathe were varied on surface roughness. The experiment was conducted using one factor at a time approach. The experiments were conducted on five different carbon alloy steels i.e. SAE8620, EN8, EN19, EN24 and EN47. The study revealed that the surface roughness was directly influenced by the spindle speed and feed.

Piyush Pal.et al [2015] focused and investigated to the process parameters on Machin ability performance characteristic of turning of Titanium based on Taguchi method. The L9 orthogonal array based on design of experiments was used to conduct the experiments on the cutting speed, feed and depth of cut were used as the process parameters where as the cutting force and temperature were selected as performance characteristic . The cutting speed was identified as the most influential process parameter on temperature. The cutting force and temperature were reduced significantly for turning operation by conducting experiments at the optimal parameter combination

L.B. Abhang et al [2010] studied, the methods of temperature measurement during machining were reviewed and a temperature measurement set-up based on tool work thermocouple method is prepared. During metal cutting, the heat generated is significant enough to cause local ductility of the work-piece material as well as of the cutting edge. Although softening and local ductility are required for machining hard materials, the heat generated has a negative influence on the tool life and performance. Therefore, the control of cutting temperature is required to achieve the desired tool performance

N. Satheesh Kumar et al [2012] conducted experimental analysis using ANOVA and a first-order and second-order mathematical model for chip-tool interface temperature have been developed by RSM coupled with factorial design. The tool-chip interface temperature is measured experimentally during turning of EN-31 steel alloy with tungsten carbide inserts using a tool-work thermocouple technique. The results are analyzed statistically and graphically. It was seen that from order model the cutting speed, feed and depth of cut were the most significantly influencing parameters for the chip-tool interface temperature followed by tool nose radius. And the second order effect of cutting speed appears to be highly significant. The developed empirical relation agrees well in velocity with the Shaw’s non-dimensional models. The first-order and second-order mathematical models are found to be adequately representing the cutting temperature. The equation clearly revealed that the cutting speed is main influencing factor on chip-tool interface temperature as compared to others. The increasing cutting speed, feed and depth of cut lead to an increase in cutting temperature. However, increasing the nose radius decreases the cutting temperature.

Measure the tool temperature at the tool chip interface many experimental methods have been developed over the past century. Since at the interface there is a moving contact between the tool and chip, experimental techniques such as standard pre-calibrated thermocouples can not be used to measure the interface temperature.

Piyush Pal et al [2015] done an experimental investigation was, of cutting forces and temperature during the orthogonal cutting of AISI 1045 steel using a tungsten carbide tool. Experiments conducted involve, measurement of cutting forces and the temperature using a dynamometer and an infrared camera to monitor the tool-work interface temperature. The experimental result was analyzed by design of experiment (DOE) methods, namely ANOVA, Regression analysis and RSM. It suggested that feed has greater influence compared to cutting speed on cutting forces and temperature. The prediction model obtained by RSM is better than that obtained by regression analysis.

M.Thiyagu et al **[2014]** observed experimental analysis using L9 orthogonal array under dry condition turning on EN-24 with coated carbide insert on CNC machine with applying Taguchi techniques. The orthogonal array, signal to noise ratio are employed to study the performance characteristics in turning operation. The feed was the most influential factor for quality of surface roughness in hard turning.

Shunmugesh.K et al **[2014]** used of Response Surface Methodology to find out optimal machining parameter. Machining parameters such as cutting speed, feed, and depth of cut were optimized. This experimental study shows the machining process in turning of 11sMn30 using carbide tip insert under dry condition. 11sMn30 is an alloy of magnesium and zinc which is mainly used the free cutting tool for bulk operation for joining elements in mechanical engineering and automotive components. By employing ANOVA the optimized values for surface roughness Ra were obtained and found out that the effect of depth of cut is the most significant factor on the surface roughness of the work-piece. From RSM analysis it was found the optimal control factors for minimizing the Ra were, cutting speed is 225 m/min, feed is .1 mm/rev and doc is 1.5 mm.

2.2 Research Gap

As thoroughly study of many research papers and journal summarized in literature review, I found that the research is continuously on progress in the field of optimization of turning process parameters on EN-24. There are significant influence of turning parameters, namely cutting speed, feed and depth of cut on Surface roughness, Material removal rate on EN-24.

The optimization of the turning parameters are required to get the optimal value of turning parameters. Various methods and Technique are being used to analyze the experimental work on EN-24 and investigated the optimum value of turning parameters to get better surface roughness and metal removal rate except work-piece tool interface temperature. The research papers have their own experimental set up and procedure to conduct the experimental, analysis and optimize the turning parameters. There is much difference in Conventional turning machine and CNC turning to control turning parameters. The data is more accurate in CNC mahine as compared to conventional machine. I found one major missing factor that is temperature measurement of work-piece surface in the research field on EN-24. The normally temperature measuring devices, like Thermocouple were used by conventional method. While today's advance Infrared Cameras are available and with the help software the temperature of any point on the work-piece can be measured.

We know that temperature has a significant influence on mechanical properties of material i.e. ductility, brittleness, toughness, hardness etc. Hence experimental study and statistical analysis of temperature is more important in turning process.

2.3 Research Objective

The aim of this research is the analytical and statistical analysis of experimental data of turning parameters of EN-24 by using Response Surface Methodology and to get the optimum value and their influences on Surface roughness, Material removal rate and Maximum temperature of work-piece tool interface surface.

- Preparation of Samples of EN-24 for experimental work.
- Conduct of experiment on CNC lathe machine.
- Statistical analysis of turning parameters using RSM and ANOVA.

CHAPTER 3

EXPERIMENTAL WORK

3.1 Work Material

In this experimental work, EN-24 tool steel which is a medium carbon steel (Bars having diameter 20 mm and length 100 mm) is used as work-piece for turning operation. It is used in High strength machine parts, collets, spindles, studs, bolts, crank shafts, arbors etc

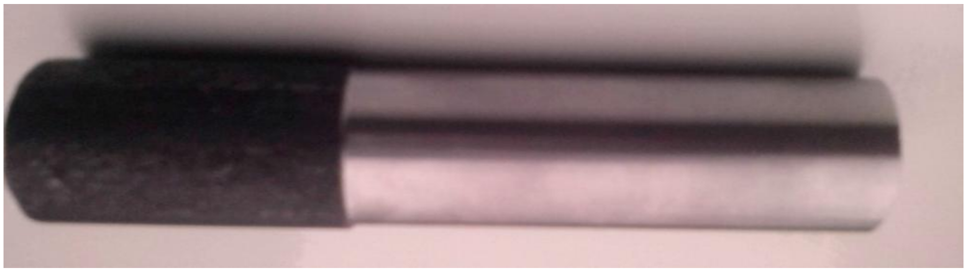

Figure 3.1 Turned work-piece of EN-24

Table 3.1 Chemical Composition of EN-24

Constituent	% composition
C	0.35-0.45
Si	0.1-0.30
Mn	0.5-0.7
Ni	1.3-1.8
Cr	0.9-1.4
Mo	0.2-0.35

Table 3.2 Mechanical Properties of EN-24[9]

S No	Mechanical Property	Range
1	Tensile stress	850-1000 N/mm²
2	Yield stress	680 N/mm²
3	Elongation	13%
4	Density	7.85 gm/cc
5	Hardness	248-302 BHN

3.2 Cutting Tool

The Coated Tungsten Carbide Turning insert used is CNMG120408

Tool material- Tungsten Carbide

Tool Coating material- Tin Coating

Tool Maker- WIDIA

C-Shape 80˚ diamond

N-clearance angle

M- Tolerance

G-insert type

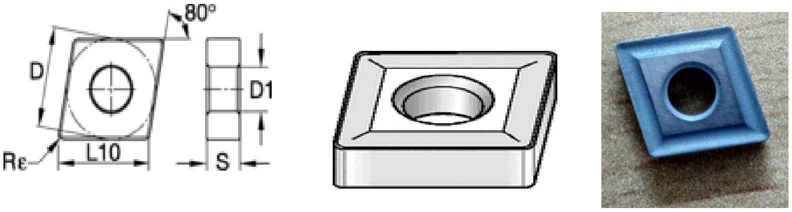

Figure 3.21 Tool Bit for turning

3.3 CNC Machine

The experiments were carried out on a CNC turning (LL20TL3) of Lakshmi Machine Works Limited, in Metal Cutting Laboratory, Mechanical Engineering Department, Delhi Technological University, New Delhi. EN-24 tool steel bars having diameter 20 mm and length 100mm is used as work material for turning process in dry condition.

CNC machine is used in the manufacturing sector that involves the use of computers to control machine tools. Tools that can be controlled in this manner include lathes, mills, routers and grinders. The CNC in CNC Machining stands for Computer Numerical Control. Under CNC Machining, machine tools function through numerical control. A computer program is customized for an object and the machines are programmed with CNC machining language (called G-code, M-codes) that essentially controls all features like feed rate, coordination, location and speeds. With CNC machining, the computer can control exact positioning and velocity. CNC machining is used in manufacturing both metal and plastic parts. There are many advantages to using CNC Machining. The process is more precise than manual machining, and can be repeated in exactly the same manner over and over again. Because of the precision possible with CNC Machining, this process can produce complex shapes that would be almost impossible to achieve with manual machining. CNC Machining is used in the production of many complex three-dimensional shapes. It is because of these qualities that CNC Machining is used in jobs that need a high level of precision or very repetitive tasks.

Figure 3.31: Pictorial View of CNC Turning Machine

Figure 3.32 Experimentation View

The CNC machine comprises of the computer in which the program is fed for cutting of the metal of the job as per the requirements. Motion is controlled along multiple axes, normally at least two (X and Y), and a tool spindle that moves in the Z (depth). The position of the tool is driven by motors through a series of step down gears in order to provide highly accurate movements, or in modern designs, direct-drive stepper motor or servo motors. Open loop control works as long as the forces are kept small enough and speeds are not too great. On commercial metalworking machines, closed loop controls are standard and required in order to provide the accuracy, speed, and repeatability demanded. All the cutting processes that are to be carried out and all the final dimensions are fed into the computer via the program. The computer thus knows what exactly is to be done and carries out all the cutting processes. CNC machine works like the Robot, which has to be fed with the program and it follows all your instructions.

3.32 G and M code Used in Part Programming

(i) G-codes:

G00 - Rapid Positioning	G61 - Exact Stop Check Mode

G01 - Linear Interpolation

G02 - Circular Interpolation CW

G03 - Circular Interpolation CCW

G04 – Dwell

G07 – Feed rate Sine Curve Control

G10 - Data Setting

G11 - Data Setting Cancel

G17 - XY Plane Selection

G18 - XZ Plane Selection

G19 - YZ Plane Selection

G20 - Input in Inches

G21 - Input in Metric

G27 - Reference Point Return Check

G62 – Automatic Corner Override

G63 – Tapping Mode

G64 - Cutting Mode

G65 - User Simple Macro Call

G66 - User Modal Macro Call

G67 - User Modal Macro Call Cancel

G70 – Finishing Cycle

G71 – Turning Cycle

G72 - Facing Cycle

G73 - Pattern Repeating Cycle

G74 – Drilling Cycle

G28 – Automatic Zero Return

G29 - Return from Zero Position

(ii) M-codes

M00 – Program Stop

M01 – Optional Program Stop

M02 – Program End

M03 - Spindle Clockwise

M04 - Spindle Counter Clockwise

M05 - Spindle Stop

M07 - Coolant 1 On

M08 - Coolant 2 On

M09 - Coolant Off

M30 - End Program, Return to Start

M98 - Call Subprogram

M99 - Cancel Subprogram

3.33 Programming of Turning Operation for CNC Machine

Progamme No. 0001

```
N010 G28 U0.0;
N020 G28 W0.0;
N030 T0707;
N040 G97 S2100 M03;
N050 G00 X50.0 Z50.0;
N060 G00 X20.0 Z10.0;
N070 G01 Z5.0 F0.15;
N080 G01 X19.0;
N090 G01 Z-70.0;
N100 G01 X40.0;
N110 G00 G28 U0.0;
N120 G28 W0.0;
N130 M30
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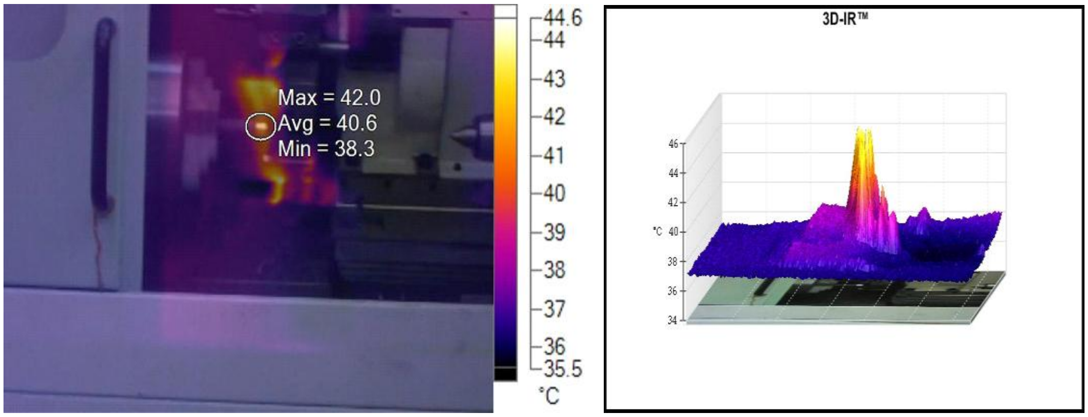
3.4 Infrared Camera

The Temperature of the work-piece at the time of machining was measured with infrared camera. Fluke model Ti400 Infrared camera was used to measure the Temperature of work-piece surface at the moment of turning process of EN-24.

Figure 3.41 Pictorial View of Infrared camera

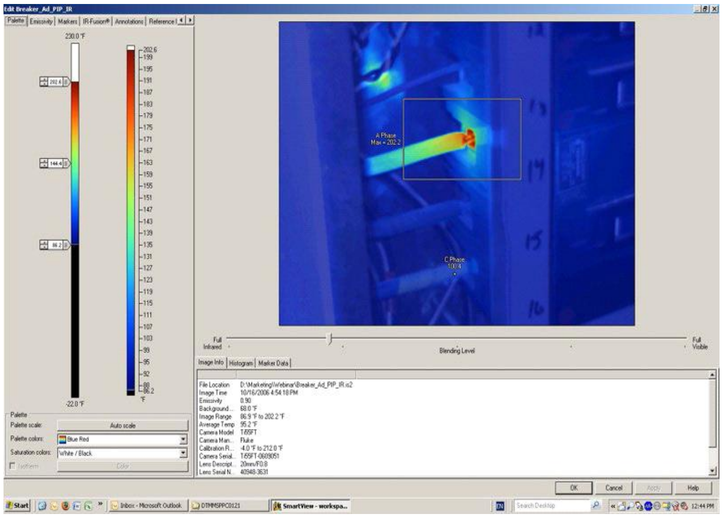
3.41 Feature and Function

A high performance, 320 x 240 infrared camera. Perfect for maintenance professionals due to its high-end features including wireless & Laser Sharp auto focus. Get an in-focus image like never before with the touch of a button. Laser Sharp Auto Focus, exclusive to Fluke, uses a built-in laser distance meter that calculates and displays the distance to your designated target with pinpoint accuracy. Other auto focus systems may focus on the surrounding landscape or closer targets and compromise an in-focus and your ability to get accurate temperature measurements. On target and in-focus. Every single Time. Ensure that the system is within calibration by viewing a black body reference or conducting a simple “tear duct check.”. Take time to look at the finding from several different angles and collect any other data that might be useful for your analysis, including additional visual images of the component. At that point, if it is appropriate, the correct emissivity and reflected temperature correction (RTC) can be used. Additional analysis is often easier to do back in the office at the computer. The software that comes with the Fluke thermal imaging camera supports simple but useful comparisons of asset condition over time. An alarm temperature can be loaded onto an image before it is uploaded into the camera. During the current inspection, both that alarm setting and the previous image can be used to determine the extent of any changes that might have occurred. The new thermal image and data document the new condition. This can all be included in a report generated back in the office. Matching thermal and visual images is very useful, and a second thermal image, either a comparison over time or a follow-up image, can also be included. Analysis of data over the long term is very important so plan on accumulating it in forms that facilitate this process The benefit is two-fold. First, you will see trends that may not be obvious in a day-to-day analysis.



(a) (b)

Figure 3.42 Experimental view of temp. Measurement (a) &3D graph (b) analysis.



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Emissivity 0.90
Background... 68.0 °F
Image Range 86.9 °F to 202.2 °F
Average Temp 95.2 °F
Camera Model Ti55FT
Camera Man... Fluke
Calibration R... -4.0 °F to 212.0 °F
Camera Serial... Ti55FT-0609051
Lens Descript... 20mm/F0.8
Lens Serial N... 40948-3631

Figure 3.43 Fluke infrared camera software

3.5 Surface Roughness Tester

Form Talysurf Intra surface roughness Tester made by Taylor Hobson was used to measure the surface roughness Value (Ra)

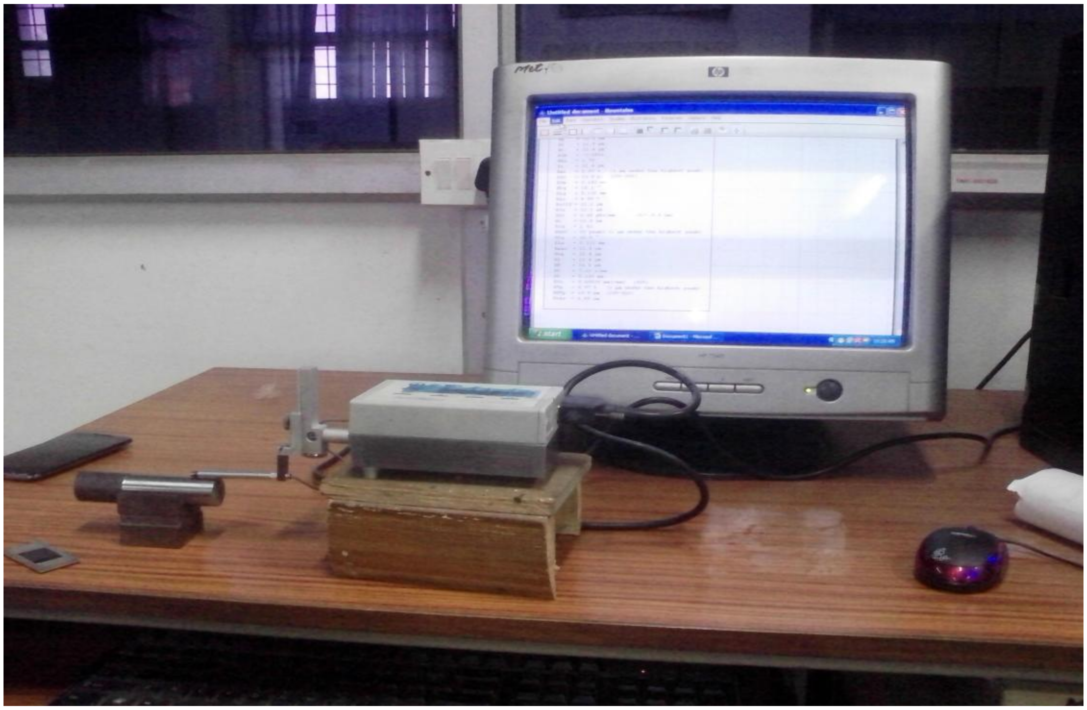
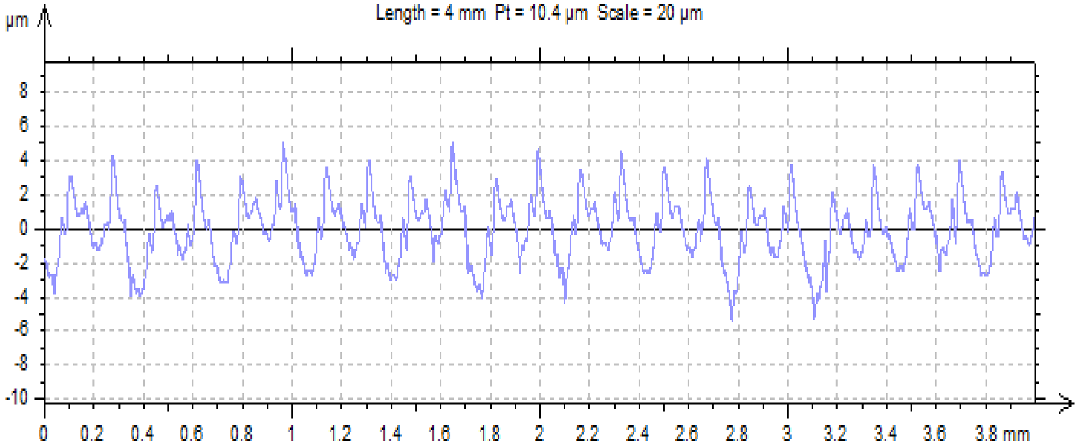
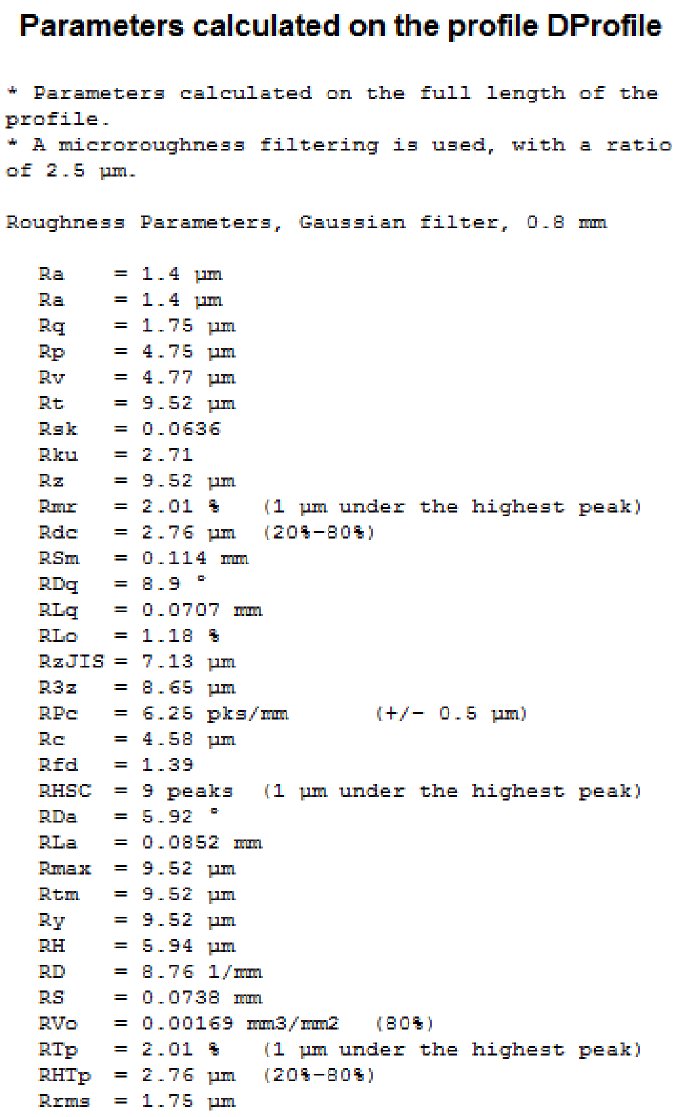


Figure3.51 Pictorial View of Measuring Surface Roughness





Parameters calculated on the profile DProfile

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* Parameters calculated on the full length of the
profile.
* A microroughness filtering is used, with a ratio
of 2.5 µm.

Roughness Parameters, Gaussian filter, 0.8 mm

   Ra    = 1.4 µm
   Ra    = 1.4 µm
   Rq    = 1.75 µm
   Rp    = 4.75 µm
   Rv    = 4.77 µm
   Rt    = 9.52 µm
   Rsk   = 0.0636
   Rku   = 2.71
   Rz    = 9.52 µm
   Rmr   = 2.01 %   (1 µm under the highest peak)
   Rdc   = 2.76 µm  (20%-80%)
   RSm   = 0.114 mm
   RDq   = 8.9 °
   RLq   = 0.0707 mm
   RLo   = 1.18 %
   RzJIS = 7.13 µm
   R3z   = 8.65 µm
   RPc   = 6.25 pks/mm       (+/- 0.5 µm)
   Rc    = 4.58 µm
   Rfd   = 1.39
   RHSC  = 9 peaks  (1 µm under the highest peak)
   RDa   = 5.92 °
   RLa   = 0.0852 mm
   Rmax  = 9.52 µm
   Rtm   = 9.52 µm
   Ry    = 9.52 µm
   RH    = 5.94 µm
   RD    = 8.76 1/mm
   RS    = 0.0738 mm
   RVo   = 0.00169 mm3/mm2   (80%)
   RTp   = 2.01 %   (1 µm under the highest peak)
   RHTp  = 2.76 µm  (20%-80%)
   Rrms  = 1.75 µm
```

Figure 3.5.2 View of surface roughness graph and its measured value

Feature and Function

Simple roughness parameters like Ra can be checked, if you need advanced analysis, higher levels of accuracy or greater flexibility, Form Talysurf Intra is the perfect choice. It combines industry leading specifications with simplicity of operation for unbeatable practicality and value**.**

i) 1mm vertical range16 nm resolution Delivers form (contour) as well as surface finishes measurement capability for precision metal forming and other applications

ii) In the shop floor application the horizontal traverse move to 50 mm. The unit combines both accuracy and portability.

iii) In form and contour case, the skidles waviness measurement 0.40 µm / 50 mm straightness error the high accuracy traverse, even on large components.

iv**)** The features of measured more effectively than ever before and 0 .05µm horizontal data spacing Small components. Reduced run-up and run-down length further improve usability.

v**)** Manual column, for large or tall components the available manual column provides a stable, dedicated work station for improved throughput

CHAPTER 4

STATISTICAL ANALYSIS

There are various methods and techniques are available for analysis of experimental data of different machining parameters and getting the optimum values. In general Taguchi, RSM and GA techniques are applied for developing mathematical model and ANOVA is used for statistical analysis.

4.1 Response Surface Methodology

The RSM is practical, economical and relatively easy for use and it was used by lot of researchers for modeling, analysis and optimization of machining processes. RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a dependent variable y called response is influenced by several independent variables x1, x2, …xk called factors and the objective is to optimize the response [10]. If all of these variables are assumed to be measurable, can be expressed as

$$y= f (x1; x2; \ldots\ldots\ldots\ldots xk)$$

the response surface optimizing the response variable y, it is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. The response or the dependent variable is assumed to be a random variable.

The efficiency of the response surface analysis is significantly influenced by selecting the proper choice of experimental designs. Two types of RSM are available for experimentation and they are Central Composite Design (CCD) and Box- Behnken Design (BBD) . CCD can be used when a comparatively accurate prediction of all response variable averages related to quantities measured during experimentation. Box-Behnken Design is normally used when performing non-sequential experiments. That is, performing the experiment only once. Both of these methodologies can be used to develop second-order quadratic relationship between the experimental factors and the responses. These designs allow efficient estimation of the first and second –order coefficients. Box-Behnken design involves fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken Design do not have axial points, thus we can be sure that all design points fall within the safe operating zone.

In RSM analysis, the approximation of y was proposed using the fitted second-order polynomial regression model which is called the quadratic model.

4.2 Design of Experiments

The first step in model generation using RSM is the design of experiments.[10] Experimental design is a statistical technique that enables an investigator to conduct realistic experiments, analyze data efficiently, and draw meaningful conclusions from the analysis. The aim of scientific research is usually to show the statistical significance of an effect that a particular factor (input parameter) exerts on the dependent variable (output/response) of interest. Specifically, the goal of DOE is to identify the optimum settings for the different factors that affect the production process. The primary reason for using statistically designed experiments is to obtain maximum information from minimum amount of resources being employed. An experiment or run may be defined as a test in which purposeful changes are made to the input variables of a process so that the possible reasons for the changes in the output/response could be identified. The experimental strategy frequently practiced by the industries is one factor at-a time approach in which the experiments are carried out by varying one input factor and keeping the other input factors constant. This approach fails to analyze the combined effect, when all the input factors vary together which simultaneously govern the experimental response. A well designed experiment is important because the results and conclusions that can be drawn from the experimental response depend to a large extent on the manner in which data were collected.

4.3 Analysis of Variance (ANOVA)

ANOVA is a statistical decision making tool, used to analyze the experimental data, for detecting any differences in the response means of the factors being tested. ANOVA is also needed for estimating the error variance for the factor effects and variance of the prediction error. In general, the purpose of analysis of variance is to determine the relative magnitude of the effect of each factor and to identify the factors significantly affecting the response under consideration (objective function).

4.4 Case study (1) for surface roughness (Ra)

Design of Experiment

The experimental data were used to develop the quadratic response surface model for surface roughness using Design Expert Version 8. Experiments were conducted on three turning process parameters namely speed, feed and depth of cut and five levels have been selected of these turning parameters for design of experiment as shown in table 4.1. Using Design Expert Version 8 software, I have developed table 4.2 of total 20 Run for experiments which were performed on CNC machine.

Table 4.1: Process variables with boundation

Independent Variables	**Level**				
	-1.68	**-1**	**0**	**+1**	**+1.68**
Speed(rpm)	1500	1800	2100	2400	2700
Feed(mm/rev)	0.05	0.10	0.15	0.20	0.25
Depth of Cut(mm)	0.50	0.75	1.00	1.25	1.50

Table 4.2: Design of experiment matrix for Surface Roughness (Response value Ra)

Sl. No.	**Std. Order**	**Run Order**	**Coded value**			**Actual value**			**Ra (μm)**
			A: speed (rpm)	**B: Feed (mm/rev)**	**C: DOC (mm)**	**A: speed (rpm)**	**B: Feed (mm/rev)**	**C: DOC (mm)**	
1	20	1	0	0	0	2100	0.15	1.00	1.34
2	13	2	0	0	-1.68	2100	0.15	0.50	1.18
3	7	3	-1	1	1	1800	0.20	1.25	2.00
4	2	4	1	-1	-1	2400	0.10	0.75	0.90
5	6	5	1	-1	1	2400	0.10	1.25	0.83
6	16	6	0	0	0	2100	0.15	1.00	1.35
7	9	7	-1.68	0	0	1500	0.15	1.00	1.45
8	17	8	0	0	0	2100	0.15	1.00	1.40

9	4	9	1	1	-1	2400	0.20	0.75	1.24
10	18	10	0	0	0	2100	0.15	1.00	1.39
11	10	11	1.68	0	0	2700	0.15	1.00	0.80
12	14	12	0	0	1.68	2100	0.15	1.50	1.70
13	3	13	-1	1	-1	1800	0.20	0.75	1.47
14	1	14	-1	-1	-1	1800	0.10	0.75	1.05
15	8	15	1	1	1	2400	0.20	1.25	1.25
16	19	16	0	0	0	2100	0.15	1.00	1.31
17	5	17	-1	-1	1	1800	0.10	1.25	1.30
18	12	18	0	1.68	0	2100	0.25	1.00	1.53
19	11	19	0	-1.68	0	2100	0.05	1.00	0.72
20	15	20	0	0	0	2100	0.15	1.00	1.33

Table 4.3: Design summary

Sl. No.	**Factor**	**Name**	**Units**	**Type**	**Subtype**	**Min**	**Max**	**-1 actual**	**+1 actual**	**Mean**	**Std. Dev.**
1	A	Speed	Rpm	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83
2	B	Feed	Mm/ rev	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83
3	C	DOC	Mm	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83

Response range is from 0.72 to 2.0, ratio of max to min 2.7778 and Std.dev.is 0.309262

Analysis & Discussion.

(i) From Table 4.8 the model F-Value 69.50 implies that, the model is significant. There is only 0.01% chance that a “Model F-Value” this large could occur due to noise.

(ii) The Value of “Prob>F” less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, A^2, B^2 and C^2 are significant model terms. Values greater than 0.1000 indicate, the model terms are not significant.

(iii) From Table 4.8 the “Lack of Fit F-Value” of 3.66 implies, there is a 9.03% chance that a “Lack of Fit F-Value” this large could occur due to noise. Lack of Fit is bad- we want the model fit.

(iv) The determination co-efficient “R-Squared” is a measure of the degree of fit. When “R-Squared” approaches unity, the better-the-response model fits the actual data. From Table4.4 “The Predicted R-Squared” of 0.8970 is in reasonable agreement with the “Adjusted R-Squared of 0.9701.

(v) “Adequate Precision” measures the Signal to Noise ratio. A ratio greater than 4 is desirable. From table 4.4 the ratios of 32.909 indicate an adequate signal. This model can be used to navigate the design space.

(vi) Normal Probability plot of the Studentized residuals to check fir Normality of residuals. In Fig4.5 (a) the normal probability plots of the residuals for surface roughness follows a straight line implying that the errors (residuals) were normally independently distributed.

(vii) Studentized residuals v/s Predicted value to check the constant error. If all is o.k. then go on model graph. Fig.4.5 (b) depict the plot of actual response value to the predicted for surface roughness. . All points fall evenly on both sides of the 45° line

Table 4.4: Summary of Quadratic

Sl. No.	**Source**	**Sequential p-value**	**Lack of fit p-value**	**Adjusted R-Squared**	**Predicted R-Squared**	**Adequate Precision**	**Adeq. Precision**
1	Linear	< 0.0001	0.0013	0.7842	0.6820		
2	2F1	0.1059	0.0022	0.8134	0.7575		
3	**Quadratic**	**<0.0001**	**0.0909**	**0.9701**	**0.8970**	**32.909**	**32.909**
4	Cubic	0.1102	0.1583	0.9834			

Table 4.5: Sequential Model Sum of Square (Type-1)

Sl. No.	**Source**	**Sum Of Squares**	**df**	**Mean Square**	**F Value**	**p-value prov>F**	**Remarks**
1	Mean Vs Total	32.61	1	32.61			
2	Linear Vs Mean	1.49	3	0.50	24.02	< 0.0001	
3	2F1 Vs Linear	0.12	3	0.040	2.49	0.1059	
4	**Quadratic Vs 2FI**	**0.18**	**3**	**0.060**	**21.10**	**< 0.0001**	**Suggested**
5	Cubic Vs Quad	0.019	4	4.773E-003	3.01	0.1102	Aliased
6	Residual	9.5E-003	6	1.58E-003			
7	Total	34.43	20	1.72			

Table 4.6 : Lack of Fit Test

Sl. No.	Source	Sum Of Squares	Df	Mean Square	F Value	p-value prob>F	Remarks
1	Linear	0.32	11	0.029	24.02	0.0013	
2	2F1	0.20	8	0.025	20.73	0.0020	
3	**Quadratic**	**0.022**	**5**	**4.492E-003**	**3.66**	**0.0903**	**Suggested**
4	Cubic	3.37E-003	1	3.370E-003	2.75	0.1583	Aliased
5	Pure Error	6.133E-003	5	1.22E-003	2.75		

Table 4.7: Model Summary Statistics

Sl. No.	Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	Remarks
1	Linear	0.14	0.8183	0.7842	0.8970	0.58	
2	2F1	0.13	0.8847	0.8314	0.7575	0.44	
3	**Quadratic**	**0.053**	**0.9843**	**0.9701**	**0.8970**	**0.19**	**Suggested**
4	Cubic	0.040	0.9948	0.9834	0.5864	0.75	Aliased

Table 4.8: Analysis of Variance (ANOVA) for Response Surface Quadratic Model

Sl. No.	Source	Sum of Squares	df	Mean Square	F Value	p-value prob>F	Remarks
1	Model	1.79	9	0.20	69.50	< 0.0001	Significant
2	A-Speed	0.53	1	0.53	185.74	< 0.0001	Significant
3	B-Feed	0.77	1	.77	269.20	< 0.0001	Significant
4	C-DOC	0.19	1	0.19	65.11	< 0.0001	Significant
5	AB	0.016	1	0.016	5.67	0.0386	Significant
6	AC	0.088	1	0.088	30.85	0.0002	Significant
7	BC	0.016	1	0.016	5.67	0.0386	Significant
8	A^2	0.079	1	0.079	27.51	0.0004	Significant
9	B^2	0.079	1	0.079	27.51	0.0004	Significant
10	C^2	0.020	1	0.020	7.09	0.0238	Significant
11	Residual	0.029	10	2.86E-003			
12	**Lack of Fit**	**0.022**	**5**	**4.49E-003**	**3.66**	**0.0903**	**Not significant**
13	Pure Error	6.133E-003	5	1.22E-003			
14	Cor Total	1.82	19				

Final Equation in terms of coded factors:

$$Ra = +1.35 - 0.20 *A + 0.24 *B + 0.12 *C -0.045 *A *B -0.10 *A *C + 0.045 *B *C - 0.074 *A^2 -0.074 *B^2 + 0.037 *C^2$$

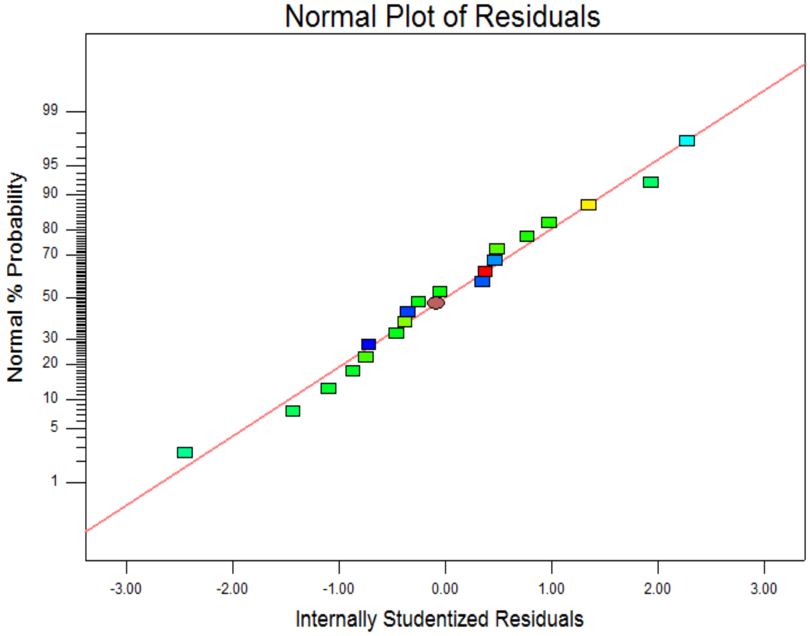

Figure: 4.1(a) Normal probability plot of Residuals for Surface roughness

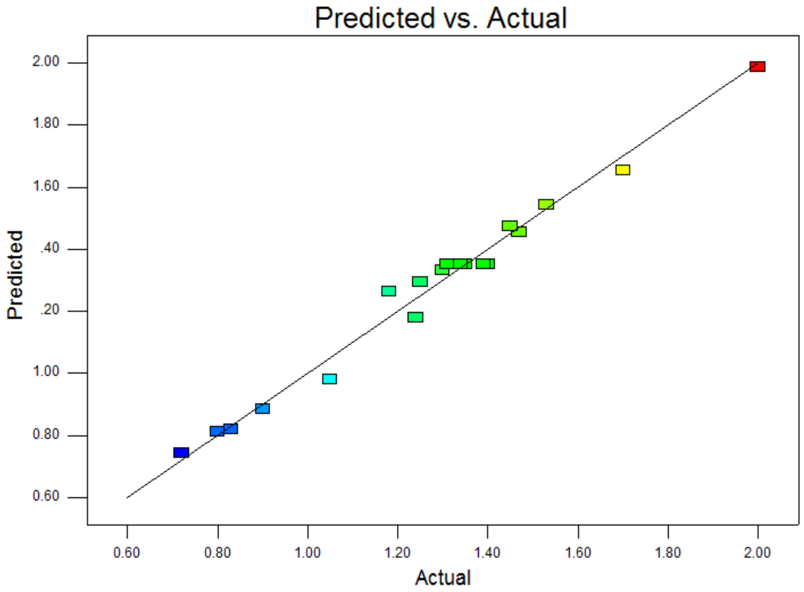

Figure4.1 (b) Actual Vs Predicted value of Surface roughness

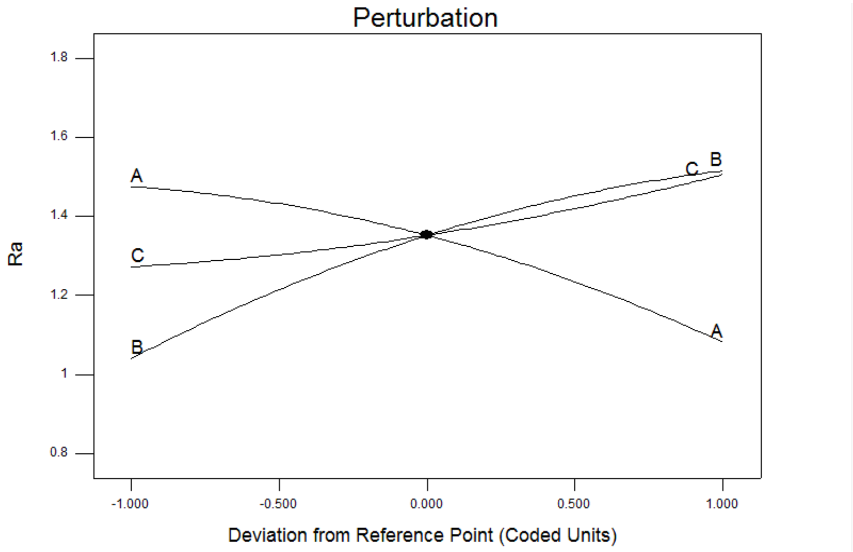

Figure 4.2- Perturbation graph for Ra

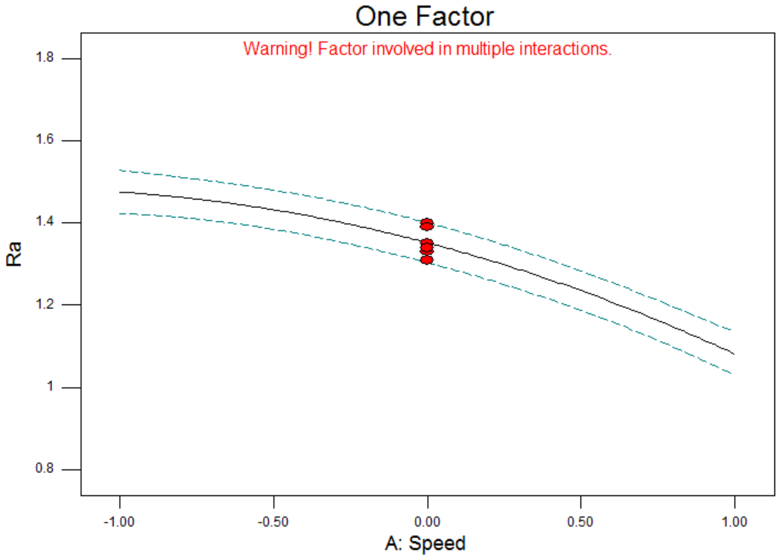

Figure4.3 (a): One factor interaction plot between speed and Ra

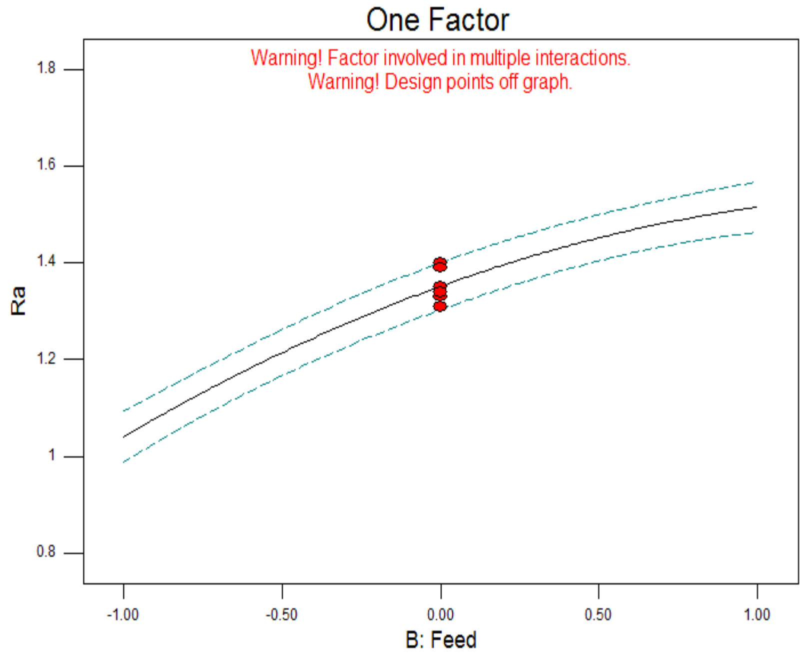

Figure4.3 (b): One factor interaction plot between Feed and Ra

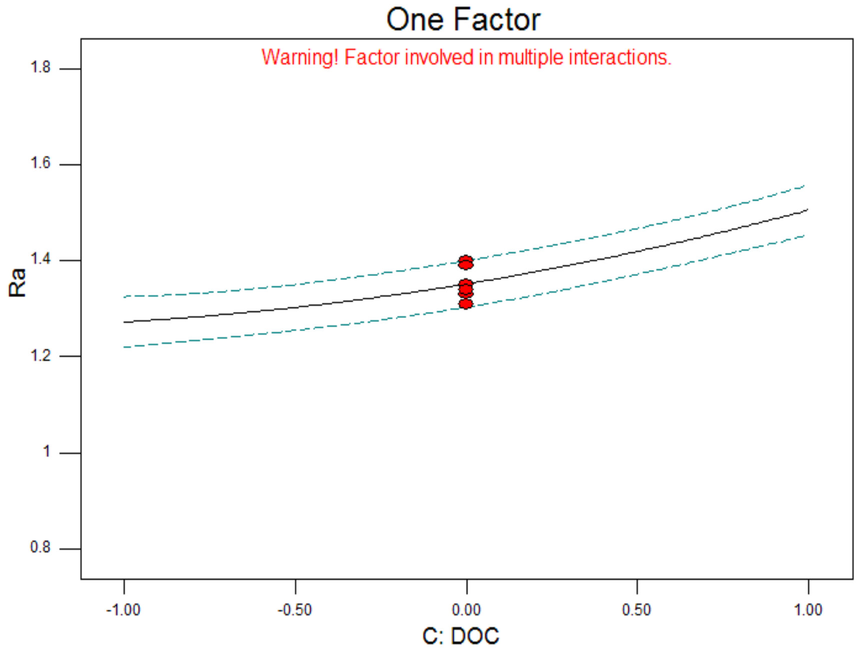

Figure4. 3(c) one factor interaction plot between Doc and Ra

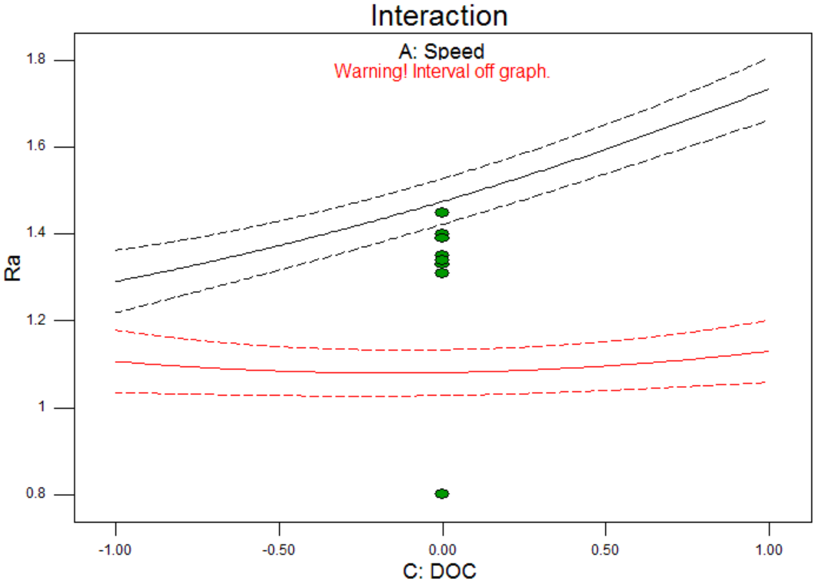

Figure4.4 (a) Plot of two factor interaction A and C for Ra

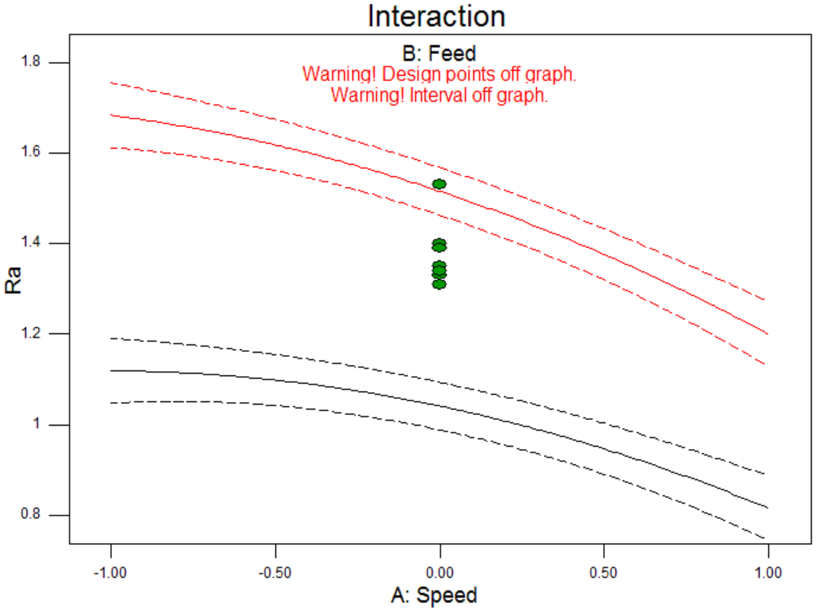

Figure4.4 (b) Plot of two factor interaction A and B for Ra

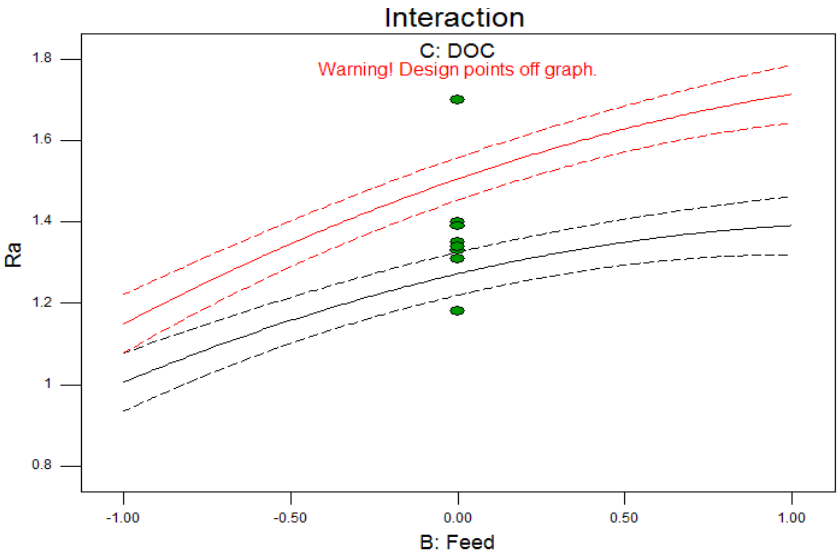

Figure4.4(c) Plot of two factor interaction B and C for Ra

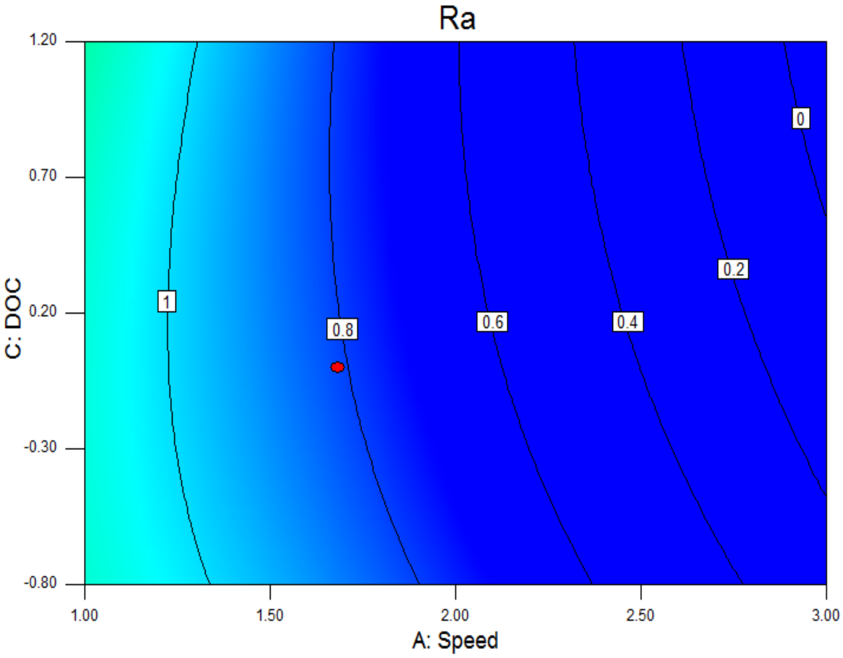

Figure4.5 (a) Contour plot of two factor interaction A and C for Surface roughness

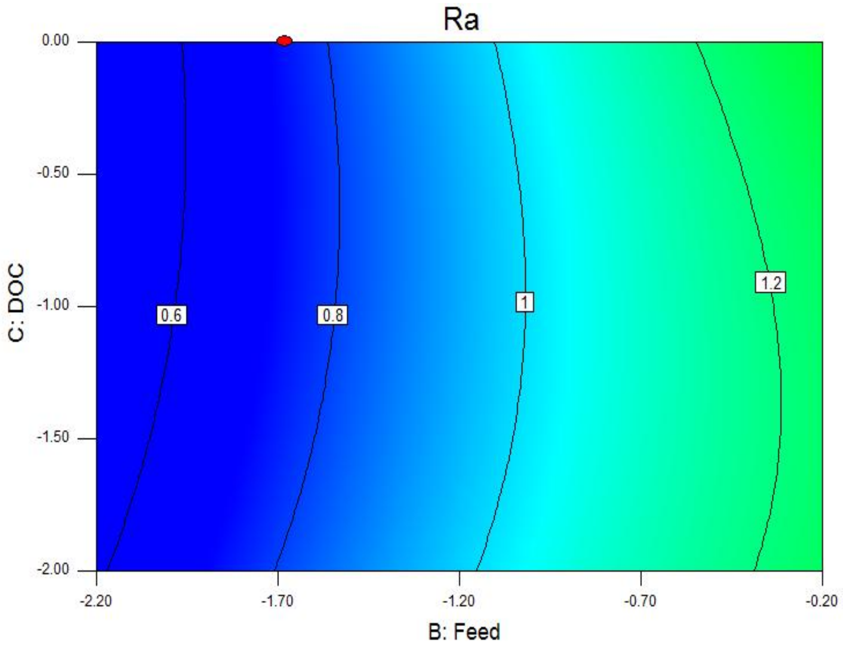

Figure4.5 (b): Contour plot of two factor interaction B and C for Surface roughness

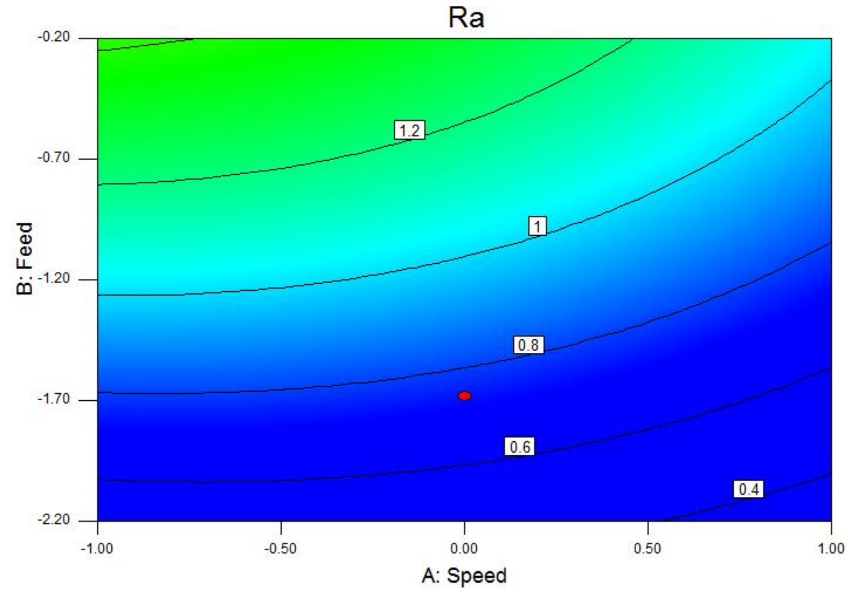

Figure4.5 (c): Contour plot of two factor interaction B and A for Surface roughness

.

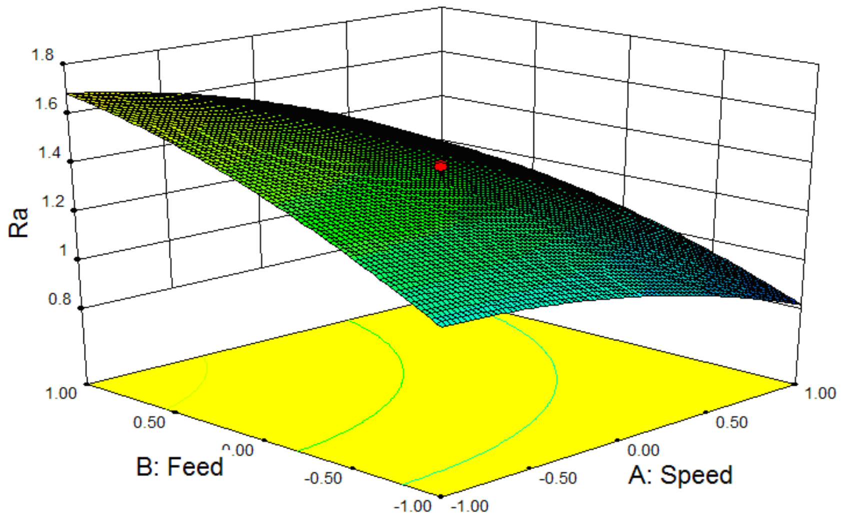

Figure4.6 (a) 3-D plot Interaction of A and B for Surface roughness

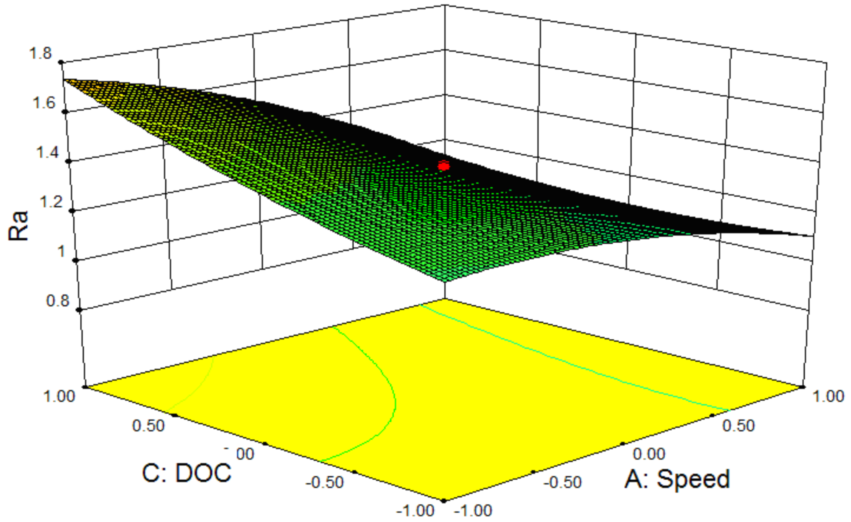

Figure: 4.6(b) 3-D plot Interaction of A and C for Surface roughness

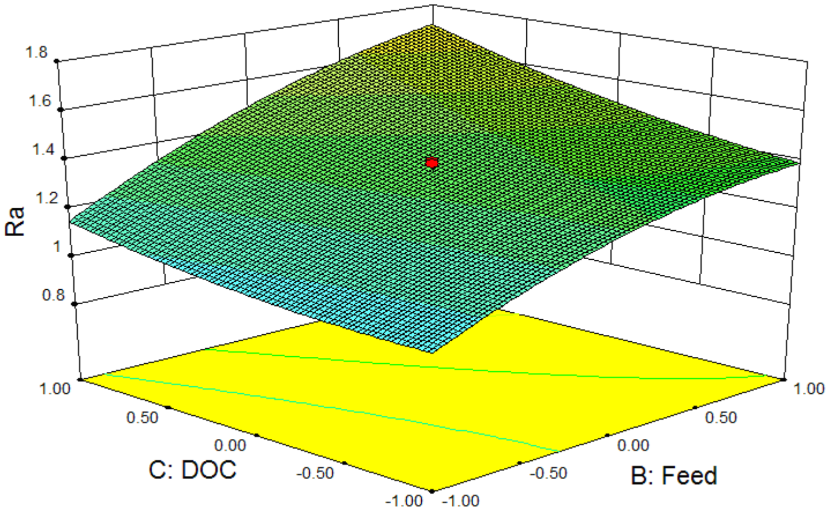

Figure4.6(c) 3-D plot Interaction of B and C for Surface roughness

(viii) From analysis of contour plots 4.4(a) 4.4(b), 4.4(c) and 3D plots4.5(a), 4.5(b), 4.5(c) for surface roughness the least value of surface roughness 0.72 µm was evident at cutting speed 2700 rpm, feed 0.05mm/rev and depth of cut 0.50mm.

From the above analysis it was investigated that the feed is the significant contributor to the better surface finish followed by the spindle speed and depth of cut

4.5 Case study (2) for Material Removal Rate

The experimental data were used to develop the quadratic response surface model for Material Removal Rate using Design Expert Version 8. Experiments were conducted on three turning process parameters namely speed, feed and depth of cut and five levels have been selected of these turning parameters for design of experiment as shown in table 4.9. Using Design Expert Version 8 software, I have developed table 4.10 of total 20 Run for experiments which were performed on CNC machine

Table 4.9: Process variables with boundation

Independent Variables	**Level**				
	-1.68	**-1**	**0**	**+1**	**+1.68**
Speed(rpm)	1500	1800	2100	2400	2700

Feed(mm/rev)	0.05	0.10	0.15	0.20	0.25
Depth of Cut(mm)	0.50	0.75	1.00	1.25	1.50

Table 4.10: Design of experiment matrix for Material removal rate (Response value MRR)

Sl. No.	**Std. Order**	**Run Order**	**Coded value**			**Actual value**			**MRR (µm)**
			A: Speed (rpm)	**B: Feed (mm/rev)**	**C: DOC (mm)**	**A: Speed (rpm)**	**B: Feed (mm/rev)**	**C: DOC (mm)**	
1	20	1	0	0	0	2100	0.15	1.00	1.409
2	13	2	0	0	-1.68	2100	0.15	0.50	1
3	7	3	-1	1	1	1800	0.20	1.25	2.8
S4	2	4	1	-1	-1	2400	0.10	0.75	1.3
5	6	5	1	-1	1	2400	0.10	1.25	1.93
6	16	6	0	0	0	2100	0.15	1.00	1.49
7	9	7	-1.68	0	0	1500	0.15	1.00	1.4
8	17	8	0	0	0	2100	0.15	1.00	1.46
9	4	9	1	1	-1	2400	0.20	0.75	1.52
10	18	10	0	0	0	2100	0.15	1.00	1.45
11	10	11	1.68	0	0	2700	0.15	1.00	2.5
12	14	12	0	0	1.68	2100	0.15	1.50	2.98
13	3	13	-1	1	-1	1800	0.20	0.75	1.21
14	1	14	-1	-1	-1	1800	0.10	0.75	0.7
15	8	15	1	1	1	2400	0.20	1.25	3.42
16	19	16	0	0	0	2100	0.15	1.00	1.433
17	5	17	-1	-1	1	1800	0.10	1.25	1.2
18	12	18	0	1.68	0	2100	0.25	1.00	2
19	11	19	0	-1.68	0	2100	0.05	1.00	0.32
20	15	20	0	0	0	2100	0.15	1.00	1.416

Table 4.11 : Design summary

Sl. No.	**Factor**	**Name**	**Units**	**Type**	**Subtype**	**Min**	**Max**	**-1 actual**	**+1 actual**	**Mean**	**Std. Dev.**
1	A	Speed	Rpm	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83
2	B	Feed	Mm/rev	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83

3	C	DOC	Mm	numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83

Response range is from 0.32 to 3.42, ratio of max to min 10.67875 and Std.dev.is 0.764372

Analysis and discussion.

(i) From Table 4.16 the model F-Value 524.57 implies that, the model is significant. There is only 0.01% chance that a “Model F-Value” this large could occur due to noise.

(ii) The Value of “Prob>F” less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC, A^2, B^2 and C^2 are significant model terms. Values greater than 0.1000 indicate, the model terms are not significant.

(iii) From Table 4.16 the “Lack of Fit F-Value” of 4.18 implies, there is a7.13% chance that a “Lack of Fit F-Value” this large could occur due to noise. Lack of Fit is bad-we want the model fit.

(iv) The determination co-efficient “R-Squared” is a measure of the degree of fit. When “R-Squared” approaches unity, the better-the-response model fits the actual data. From Table4.12 “The Predicted R-Squared” of 0.9859 is in reasonable agreement with the “Adjusted R-Squared of 0.9960.

(v) “Adequate Precision” measures the Signal to Noise ratio. A ratio greater than 4 is desirable. From table 4.12 the ratios of 88.907 indicate an adequate signal. This model can be used to navigate the design space.

(vi) Normal Probability plot of the Studentized residuals to check for Normality of residuals. In Fig4.16 (a) the normal probability plots of the residuals for surface roughness follows a straight line implying that the errors (residuals) were normally independently distributed.

(vii) Studentized residuals v/s Predicted value to check the constant error. If all is o.k. then go on model graph. Fig.4.16 (b) depict the plot of actual response value to the predicted for surface roughness. . All points fall evenly on both sides of the 45° line

Table 4.12 : Summary of Quadratic

Sl. No.	Source	Sequential p-value	Lack of fit p-Value	Adjusted R-Squared	Predicted R-Squared	Adeq. Precision	Remarks
1	Linear	< 0.0001	<0.0001	0.7854	0.6844		
2	2F1	0.1016	<0.0001	0.8338	0.7496		

3	**Quadratic**	**<0.0001**	**0.0713**	**0.9969**	**0.9859**	**88.907**	**Suggested**
S4	Cubic	0.2572	0.0462	0.9969	0.8743		Aliased

Table 4.13 : Sequential Model Sum of Square (Type-1)

Sl. No.	Source	Sum Of Squares	df	Mean Square	F Value	p-value prov>F	Remarks
1	Mean Vs Total	54.25	1	54.25			
2	Linear Vs Mean	9.10	3	3.03	24.23	<0.0001	
3	2F1 Vs Linear	0.74	3	0.25	2.54	0.1016	
4	**Quadratic Vs 2FI**	**1.24**	**3**	**o.41**	**175.99**	<0.0001	**Suggested**
5	Cubic Vs Quad	0.013	4	3.158E-003	1.75	0.2572	Aliased
6	Residual	0.011	6	1.805E-003			
7	Total	65.35	20	3.27			

Table 4.14: Lack of Fit Test

Sl. No.	Source	Sum Of Squares	Df	Mean Square	F Value	p-value prob>F	Remarks
1	Linear	2.00	11	0.16	200.41	0.0001	
2	2F1	1.26	8	0.16	173.45	0.0001	
3	**Quadratic**	**0.019**	**5**	**3.786E-003**	**4.10**	**0.0713**	**Suggested**
4	Cubic	6.299E-003	1	6.299E-003	6.95	0.0462	Aliased
5	Pure Error	4.532E-003	5	9.064E-003	2.75		

Table 4.15: Model Summary Statistics

Sl. No.	Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	Remarks
1	Linear	0.35	0.8196	0.7858	0.6844	3.54	
2	2F1	0.31	0.8863	0.8338	0.7436	2.78	
3	**Quadratic**	**0.048**	**0.9979**	**0.9960**	**0.9859**	**0.16**	**Suggested**
4	Cubic	0.042	0.9990	0.9969	0.8743	1.40	Aliased

Table 4.16: Analysis of Variance (ANOVA) for Response Surface Quadratic Model

Sl. No.	Source	Sum of Squares	Df	Mean Square	F Value	p-value prob>F	Remarks
1	Model	11.08	9	1.23	524.57	< 0.0001	Significant
2	A-Speed	1.24	1	1.24	527.44	< 0.0001	Significant
3	B-Feed	3.23	1	3.23	1378.1	< 0.0001	Significant
4	C-DOC	4.63	1	4.63	1972.3	< 0.0001	Significant
5	AB	0.020	1	0.020	8.52	0.0153	Significant
6	AC	0.024	1	0.024	10.31	0.0093	Significant
7	BC	0.70	1	0.70	296.71	0.0001	Significant

8	A^2	0.51	1	0.51	218.52	0.0001	Significant
9	B^2	0.12	1	0.12	50.31	0.0001	Significant
10	C^2	0.59	1	0.59	252.52	0.0001	Significant
11	Residual	0.023	10	2.346E-003			
12	Lack of Fit	0.019	5	2.786E-003	4.18	0.0713	Not significant
13	Pure Error	4.532E-003	5	9.604E-003			
14	Cor Total	11.10	19				

Final Equation in terms of coded factors:

$MRR = +1.44+0.30*A+0.49*B+0.58*C-0.050*A*B+0.055*A*C+0.30*B*C+0.19*A^2-0.091*B^2+0.20*C^2$

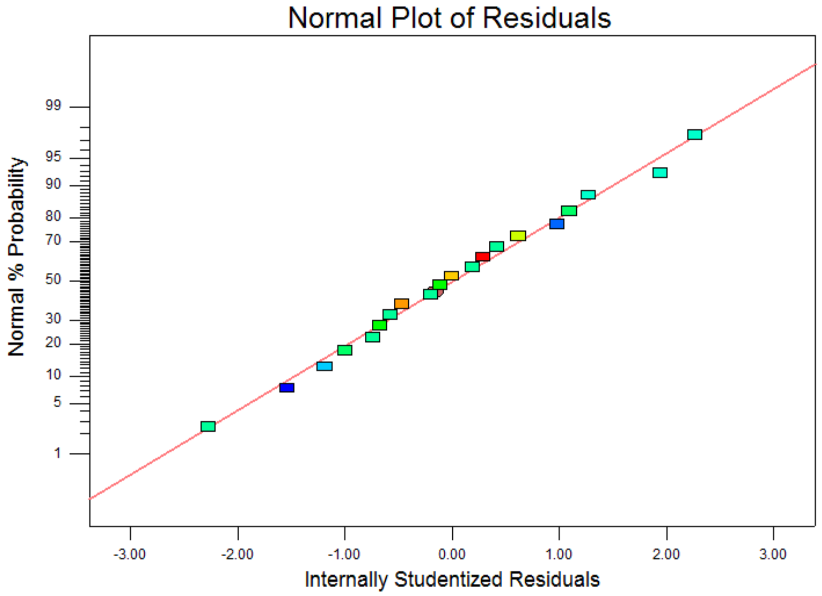

Figure: 4.16(a) Normal probability plot of Residuals for MRR

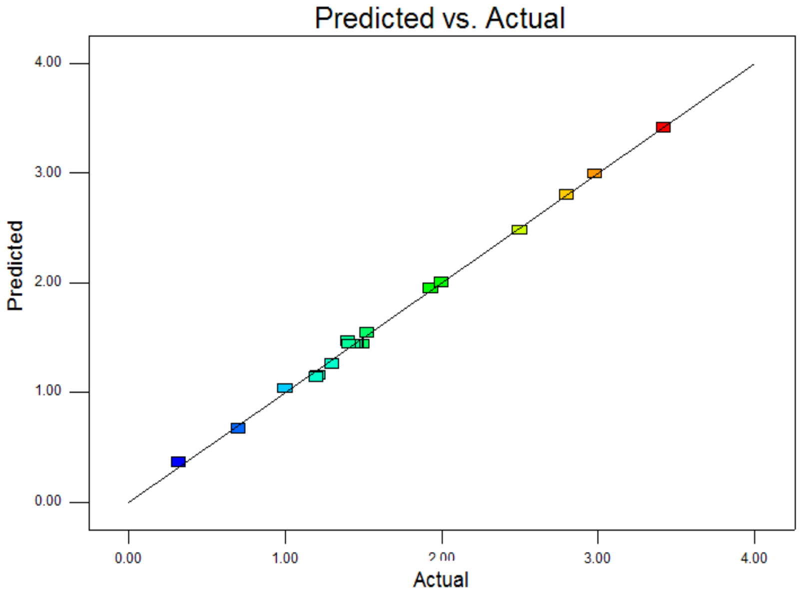

Figure: 4.16(b) Actual Vs Predicted value of MRR

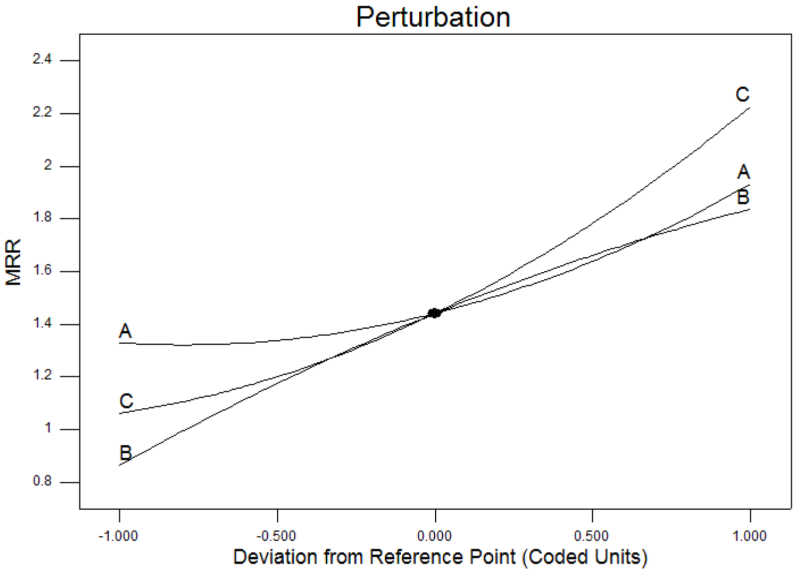

Figure4.17 Perturbation graph for MRR

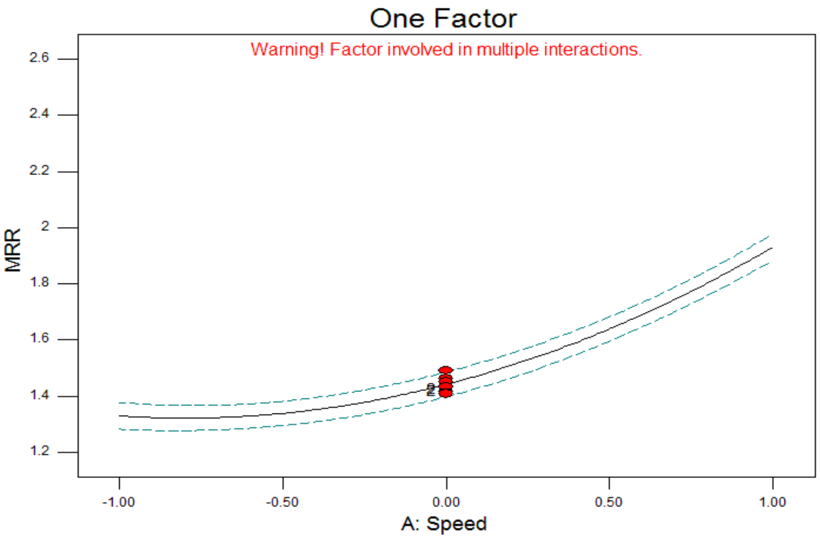

Figure: 4.18(a) one factor interaction plot between speed and MRR

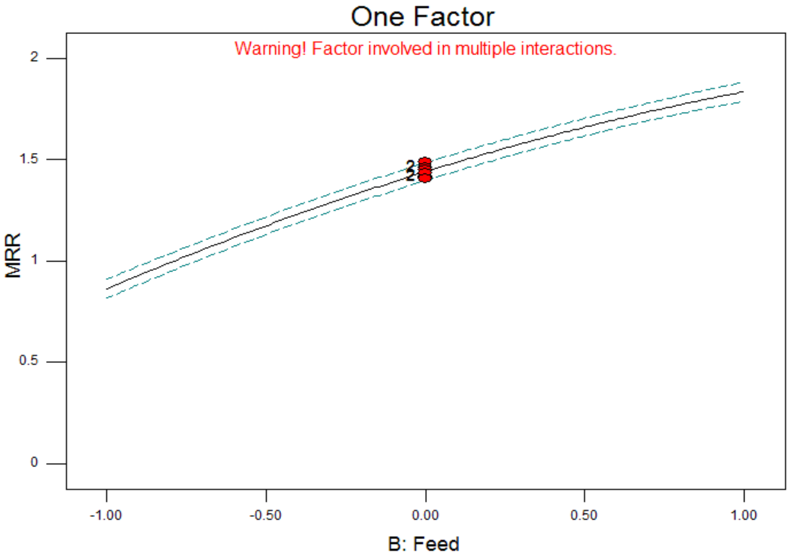

Figure: 4.18(b) One factor interaction plot between feed and MRR

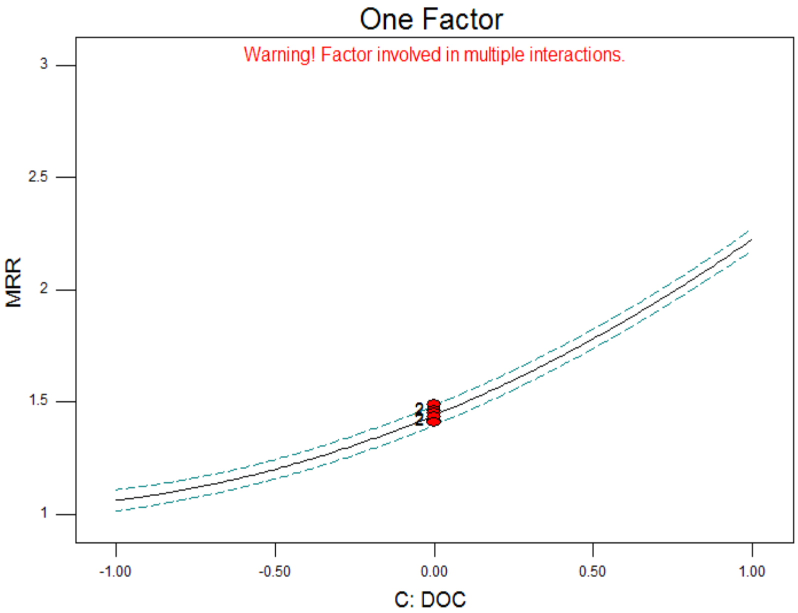

Figure: 4.18(c) **One factor interaction plot between DOC and MRR**

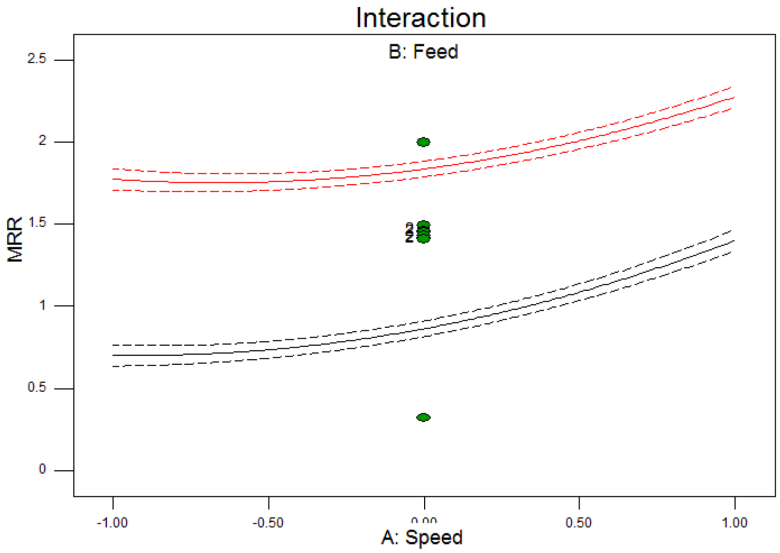

Figure: 4.19(a) **Plot of two factor interaction A and B for MRR**

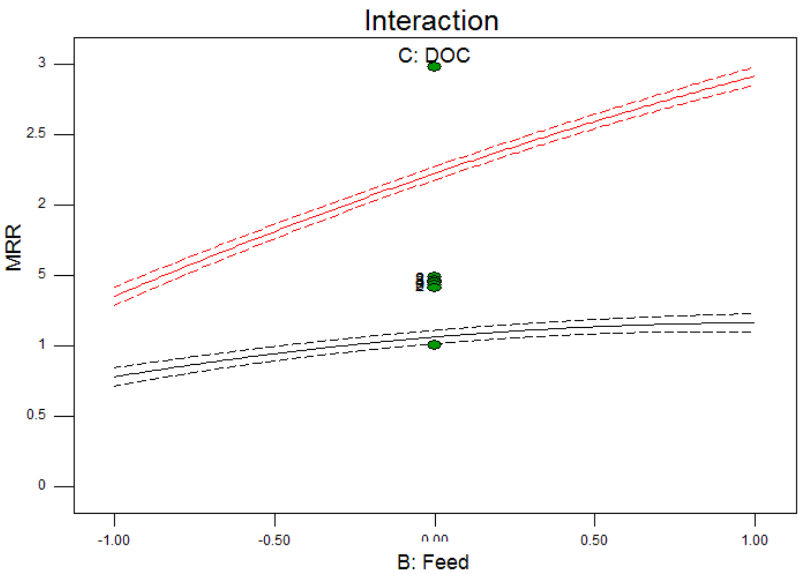

Figure: 4.19(b) Plot of two factor interaction B and C for MRR

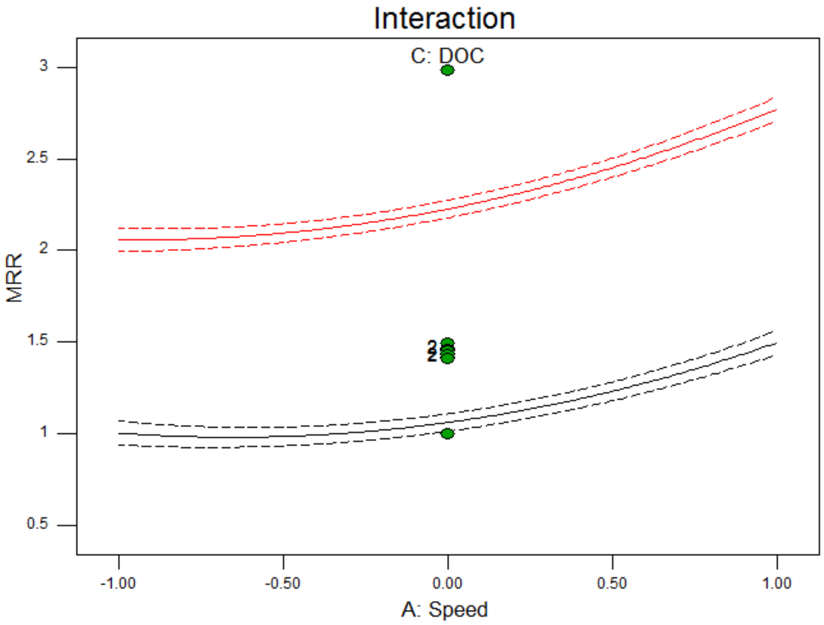

Figure: 4.19 (c) Plot of two factor interaction A and C for MRR

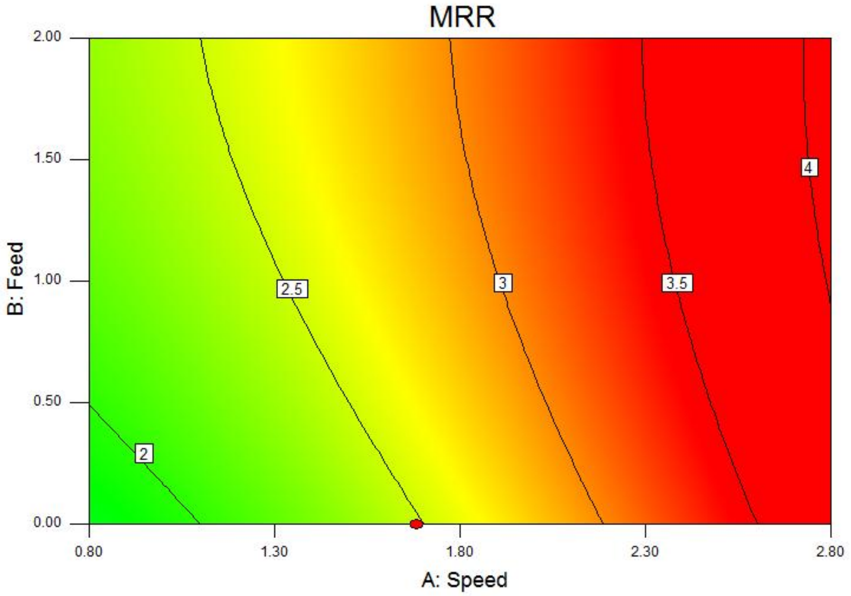

Figure4.20 (a) Contour plot of two factor interaction A and C for MRR

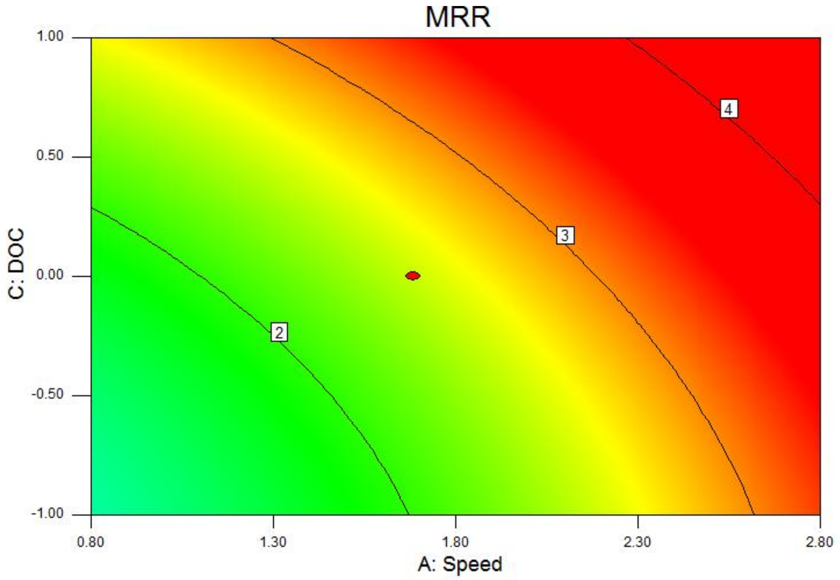

Figure:4.20(b) Contour plot of two factor interaction A and C for MRR

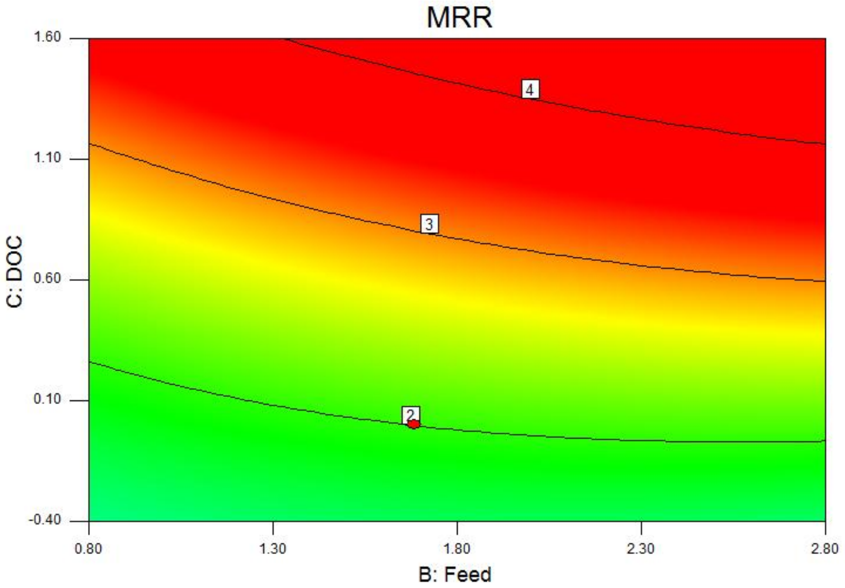

Figure4.20(c) Contour plot of two factor interaction B and C for MRR

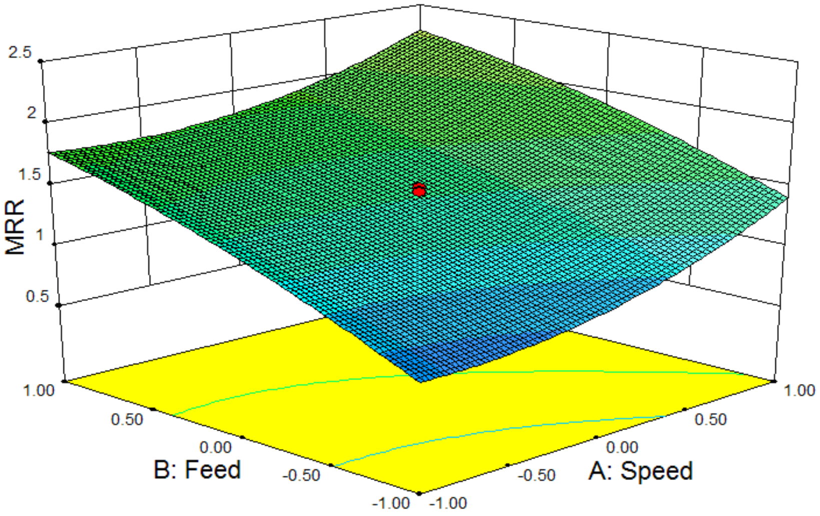

Figure: 4.21(a) 3D plot Interaction of A and C for MRR

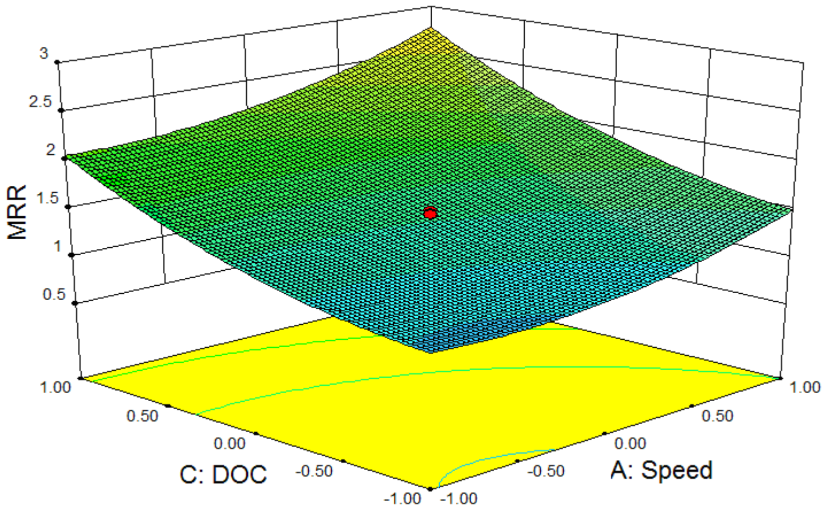

Figure: 4.21(b) 3D plot Interaction of A and C for MRR

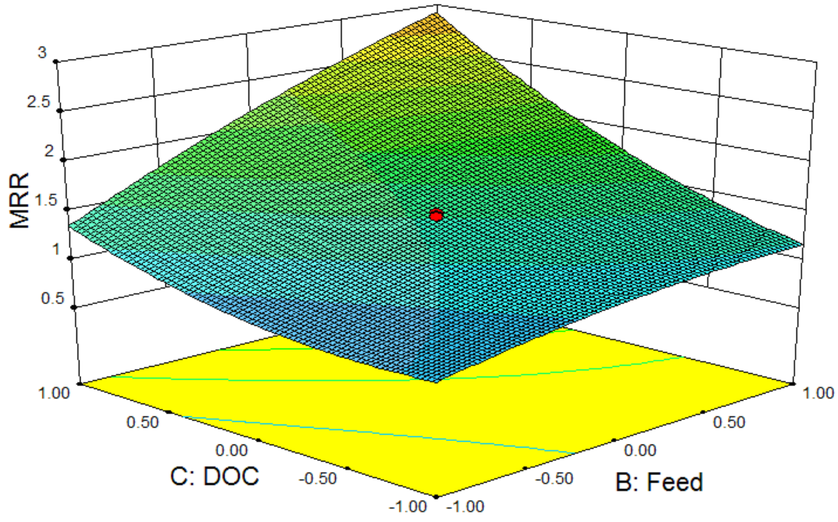

Figure4.21(c) 3D plot Interaction of B and C for MRR

(viii) From analysis of contour plots 4.4(a) 4.4(b), 4.4(c) and 3D plots 4.5(a), 4.5(b), 4.5(c) for Material Removal Rate the Maximum value of MRR 3.42 gm/sec was evident at cutting speed 2700 rpm, feed 0.25mm/rev and depth of cut 1.50mm.

From the above analysis it was investigated that the depth of cut is the significant contributor to the maximum material removal rate followed by the feed and spindle speed.

4.6 Case Study (3) for Cutting Temperature of Work-piece Tool interface

The experimental data were used to develop the quadratic response surface model for Cutting Temperature of work-piece tool interface using Design Expert Version 8. Experiments were conducted on three turning process parameters namely speed, feed and depth of cut and five levels have been selected of these turning parameters for design of experiment as shown in table 4.17. Using Design Expert Version 8 software, I have developed table 4.18 of total 20 Run for experiments which were performed on CNC machine

Table 4.17: Process variables with boundation

Independent Variables	**Level**				
	-1.68	**-1**	**0**	**+1**	**+1.68**
Speed(rpm)	1500	1800	2100	2400	2700
Feed(mm/rev)	0.05	0.10	0.15	0.20	0.25
Depth of Cut(mm)	0.50	0.75	1.00	1.25	1.50

Table 4.18: Design of experiment matrix for Maximum machining Temperature (Response value Tmax)

Sl. No.	**Std. Order**	**Run Order**	**Coded value**			**Actual value**			**Tmax (^{o}C)**
			A: Speed (rpm)	**B: Feed (mm/rev)**	**C: DOC (mm)**	**A: Speed (rpm)**	**B: Feed (mm/rev)**	**C: DOC (mm)**	
1	20	1	0	0	0	2100	0.15	1.00	40
2	13	2	0	0	-1.68	2100	0.15	0.50	39
3	7	3	-1	1	1	1800	0.20	1.25	68
S4	2	4	1	-1	-1	2400	0.10	0.75	38.8
5	6	5	1	-1	1	2400	0.10	1.25	42
6	16	6	0	0	0	2100	0.15	1.00	38.8
7	9	7	-1.68	0	0	1500	0.15	1.00	35
8	17	8	0	0	0	2100	0.15	1.00	42
9	4	9	1	1	-1	2400	0.20	0.75	44
10	18	10	0	0	0	2100	0.15	1.00	40.6

11	10	11	1.68	0	0	2700	0.15	1.00	42
12	14	12	0	0	1.68	2100	0.15	1.50	68
13	3	13	-1	1	-1	1800	0.20	0.75	40.9
14	1	14	-1	-1	-1	1800	0.10	0.75	37.8
15	8	15	1	1	1	2400	0.20	1.25	75
16	19	16	0	0	0	2100	0.15	1.00	41
17	5	17	-1	-1	1	1800	0.10	1.25	42.6
18	12	18	0	1.68	0	2100	0.25	1.00	69
19	11	19	0	-1.68	0	2100	0.05	1.00	39.3
20	15	20	0	0	0	2100	0.15	1.00	43

Table 4.19: Design summary

Sl. No.	Factor	Name	Units	Type	Subtype	Min	Max	-1 actual	+1 actual	Mean	Std. Dev.
1	A	Speed	Rpm	Numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83
2	B	Feed	Mm/rev	Numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83
3	C	DOC	Mm	Numeric	Continuous	-1.68	1.68	-1.00	1.00	0.00	0.83

Response range is from 35 to 75, ratio of max to min 2.14286 and Std.dev.is 12.3762

Analysis and Discussion

(i) From Table 4.24 the model F-Value 170.09 implies that, the model is significant. There is only 0.01% chance that a “Model F-Value” this large could occur due to noise.

(ii) The Value of “Prob>F” less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC, A^2, B^2 and C^2 are significant model terms. Values greater than 0.1000 indicate, the model terms are not significant. In this case AC is in – significant factor. Backward Elimination method can be used for insignificant term.

(iii) From Table 4.24 the “Lack of Fit F-Value” of 0.73 not significant relative to pure error. there is a 63.28% chance that a “Lack of Fit F-Value” this large could occur due to noise. Lack of Fit is bad- we want the model fit.

(iv) The determination co-efficient “R-Squared” is a measure of the degree of fit. When “R-Squared” approaches unity, the better-the-response model fits the actual data. From Table4.20 “The Predicted R-Squared” of 0.9718 is in reasonable agreement with the “Adjusted R-Squared of 0.9877.

(v) “Adequate Precision” measures the Signal to Noise ratio. A ratio greater than 4 is desirable. From table 4.20 the ratios of 40.914 indicate an adequate signal. This model can be used to navigate the design space.

(vi) Normal Probability plot of the Studentized residuals to check for Normality of residuals. In Fig4.22 (a) the normal probability plots of the residuals for surface roughness follows a straight line implying that the errors (residuals) were normally independently distributed.

(vii) Studentized residuals v/s Predicted value to check the constant error. If all is o.k. then go on model graph. Fig.4.22 (b) depict the plot of actual response value to the predicted for surface roughness. . All points fall evenly on both sides of the 45^{o} line

Table 4.20 : Summary of Quadratic

Sl. No.	**Source**	**Sequential p-value**	**Lack of fit p-value**	**Adjusted R-Squared**	**Predicted R-Squared**	**Adeq. Precision**	**Remarks**
1	Linear	0.0003	0.0004	0.6281	0.4701		
2	2F1	0.1133	<0.0007	0.7061	0.5819		
3	**Quadratic**	**<0.0001**	**0.6328**	**0.9877**	**0.9718**	**40.941**	**Suggested**
S4	Cubic	0.5293	0.5334	0.9870	0.9205		Aliased

Table 4.21 : Sequential Model Sum of Square (Type-1)

Sl. No.	**Source**	**Sum Of Squares**	**df**	**Mean Square**	**F Value**	**p-value prov>F**	**Remarks**
1	Mean Vs Total	42947.91	1	42947.91			
2	Linear Vs Mean	1998.90	3	606.38	11.70	0.0003	
3	2F1 Vs Linear	326.17	3	106.72	2.42	0.1133	
4	**Quadratic Vs 2FI**	**566.27**	**3**	**188.76**	**99.94**	<0.0001	**Suggested**
5	Cubic Vs Quad	6.97	4	1.74	0.88	0.5293	Aliased
6	Residual	11.92	6	1.99			
7	Total	45858.14	20	2292.91			

Table 4.22 : Lack of Fit Test

Sl. No.	**Source**	**Sum Of Squares**	**Df**	**Mean Square**	**F Value**	**p-value prob>F**	**Remarks**
1	Linear	900.39	11	81.85	37.41	0.0004	
2	2F1	574.21	8	71.70	32.00	0.0007	
3	**Quadratic**	**1.25**	**5**	**1.50**	**0.73**	**0.6328**	**Suggested**

4	Cubic	0.98	1	0.98	0.45	0.5334	Aliased
5	Pure Error	10.94	5	2.19			

Table 4.23 : Model Summary Statistics

Sl. No.	Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	Remarks
1	Linear	7.55	0.6869	0.6281	0.4701	1542.08	
2	2F1	6.71	0.7989	0.7061	0.5819	1216.69	
3	**Quadratic**	**1.37**	**0.9935**	**0.9877**	**0.9718**	**82.02**	**Suggested**
4	Cubic	1.41	0.9959	0.9870	0.9275	231.19	Aliased

Table 4.24: Analysis of Variance (ANOVA) for Maximum Machining Temperature Quadratic Model

Sl. No.	Source	Sum of Squares	df	Mean Square	F Value	p-value prob>F	Remarks
1	Model	2891	9	231.16	170.09	< 0.0001	Significant
2	A-Speed	36.32	1	36.32	19.23	< 0.0014	Significant
3	B-Feed	996.35	1	996.35	527.51	< 0.0001	Significant
4	C-DOC	966.22	1	966.22	511.56	< 0.0001	Significant
5	AB	11.76	1	11.76	6.23	0.0317	Significant
6	AC	0.66	1	0.66	0.35	0.5672	
7	BC	313.75	1	313.75	166.11	0.0001	Significant
8	A^2	13.43	1	13.43	7.11	0.0236	Significant
9	B^2	300.69	1	33.69	159.20	0.0001	Significant
10	C^2	271.20	1	271.20	143.58	0.0001	Significant
11	Residual	18.89	10	1.89			
12	Lack of Fit	7.95	5	1.59	0.73	0.6326	Not significant
13	Pure Error	10.94	5	2.19			
14	Cor Total	2910.23	19				

Final Equation in terms of coded factors

$Tmax = +40.92+1.63*A+8.54*B+8.41*C+1.21*A*B+0.29*A*C+6.29*B*C-0.97*A^2+4.57*B^2+4.34*C^2$

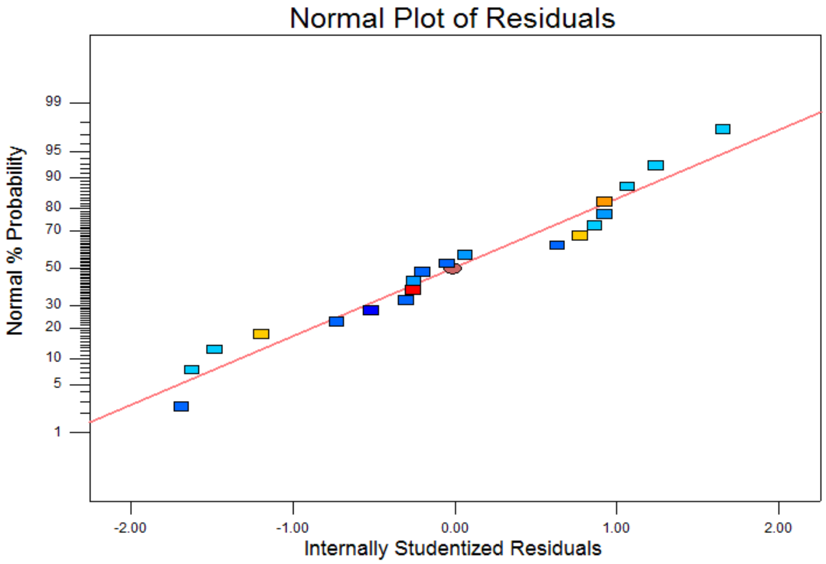

Figure4.22 (a) Normal probability plot of Residuals for Tmax

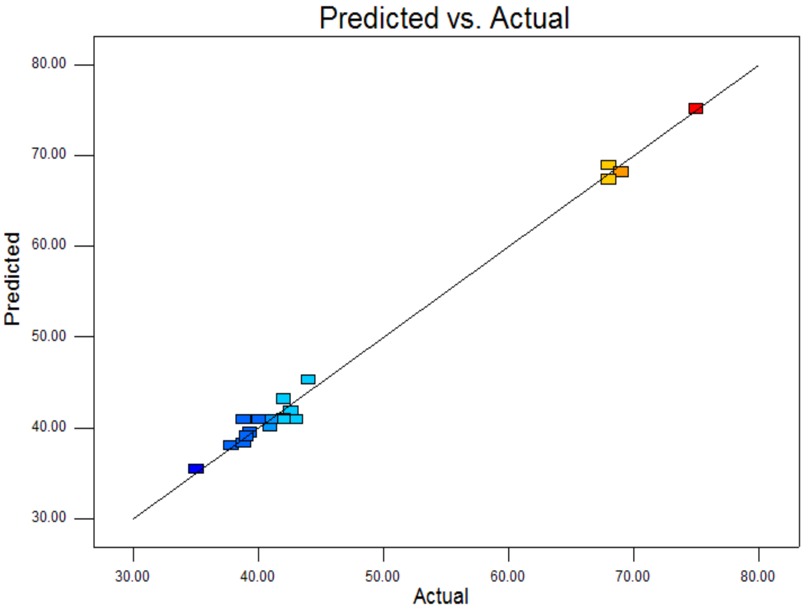

Figure4.22(b) Actual Vs Predicted value of Tmax

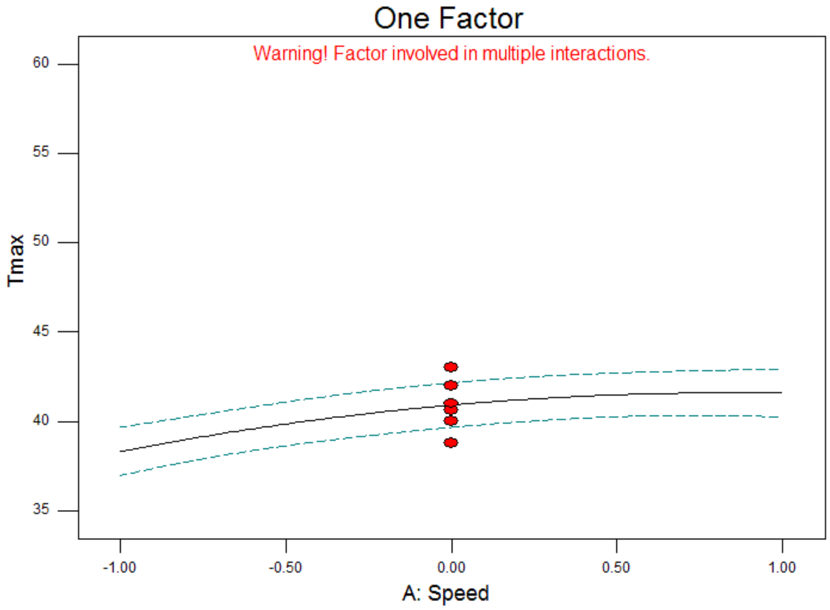

Figure4.23 (a): one factor interaction plot between speed and Tmax

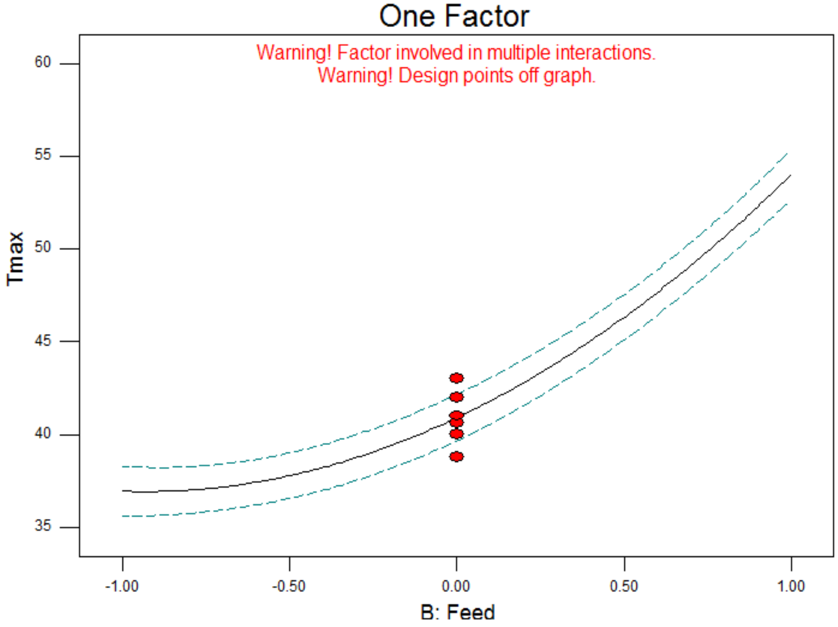

Figure4.23 (b) :one factor interaction plot between feed and Tmax

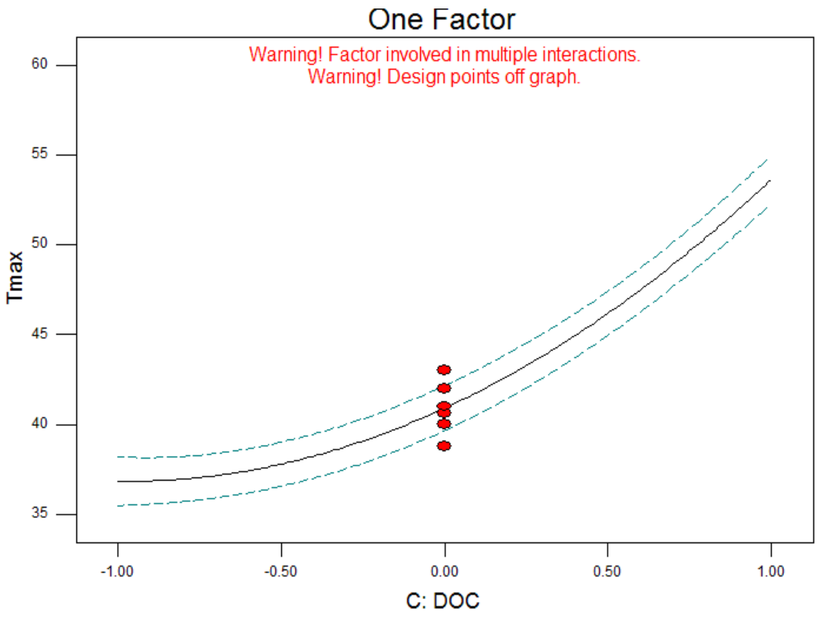

Figure4.23(c) one factor interaction plot between DOC Tmax

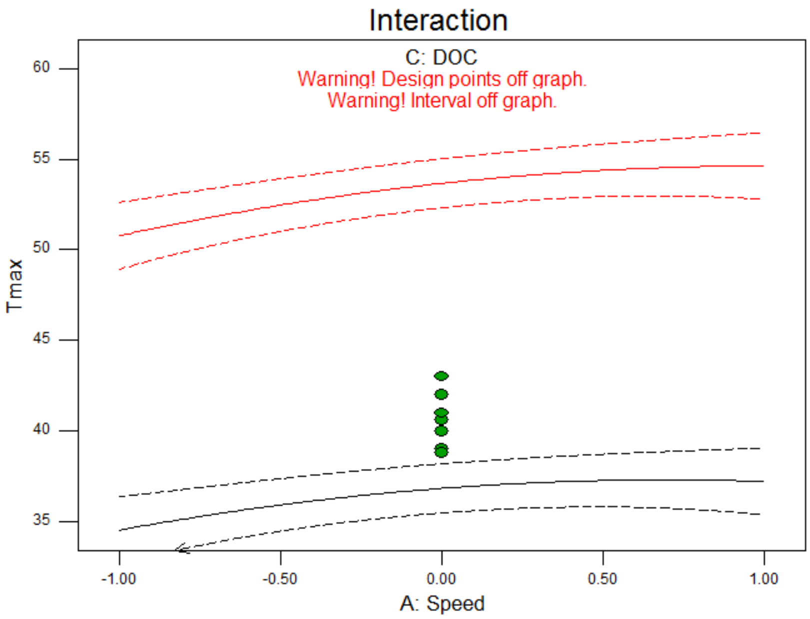

Figure4.24(a): Plot of two factor interaction A and C for Tmax

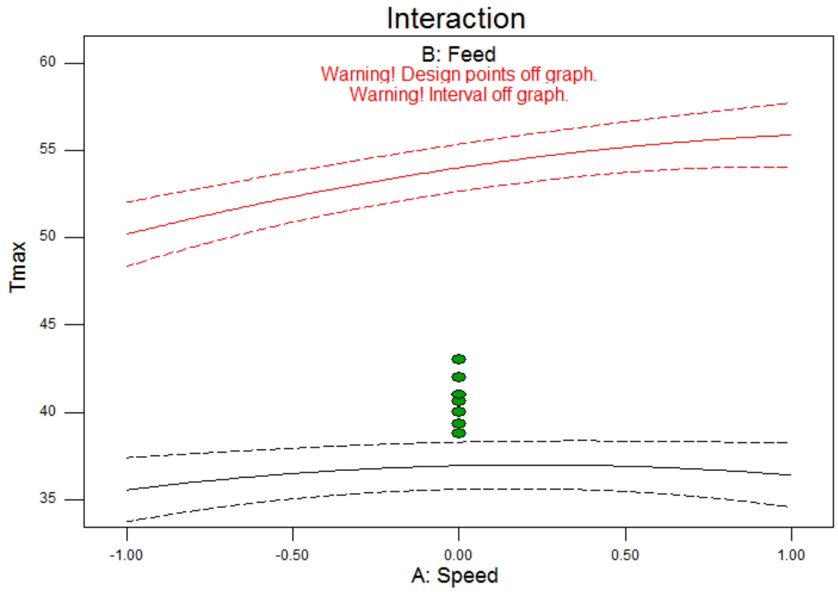

Figure4.24(b): Plot of two factor interaction A and B for Tmax

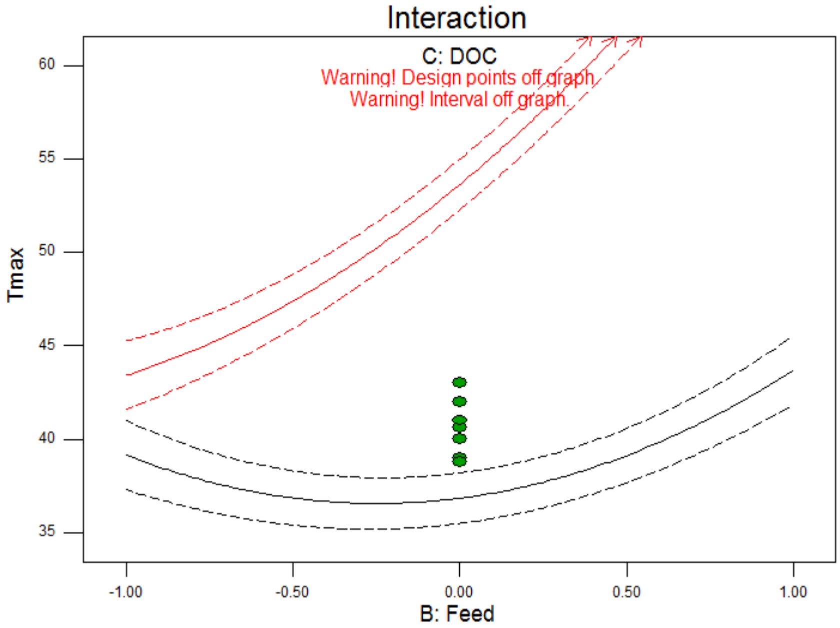

Figure4.24(c): Plot of two factor interaction B and C for Tmax

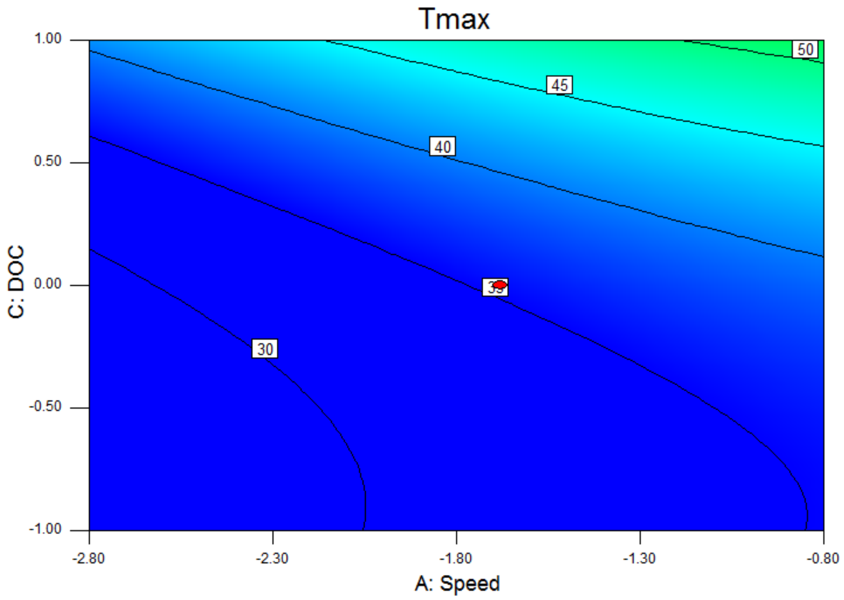

Figure4.25 (a): **Contour plot of two factor interaction A and C for Tmax**

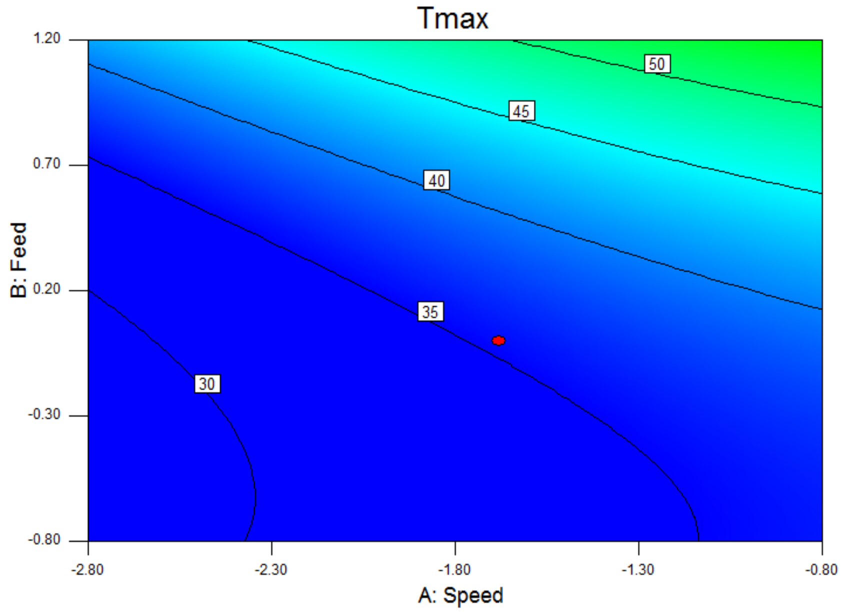

Figure4.25 (b) Contour plot of two factor interaction A and B for Tmax

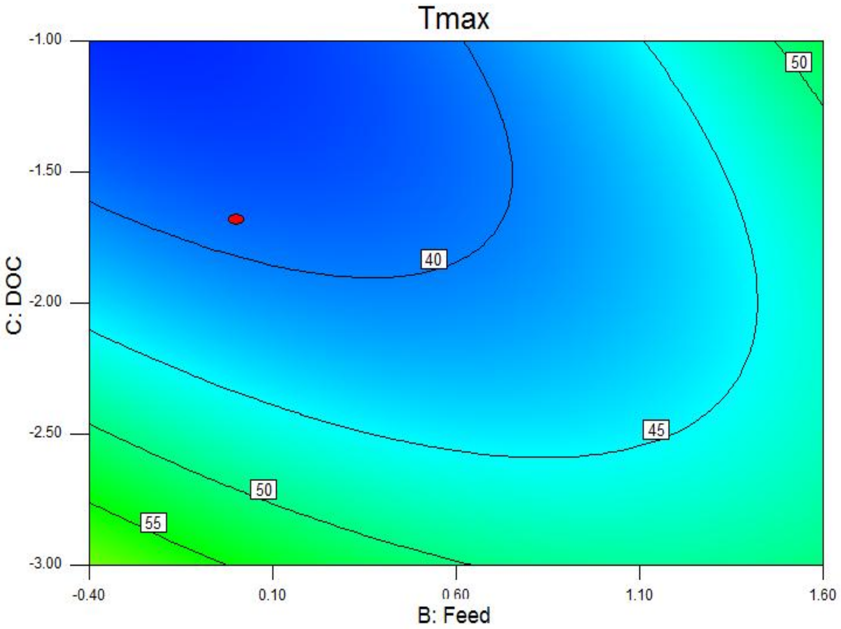

Figure4.25(c) Contour plot of two factor interaction B and C for Tmax

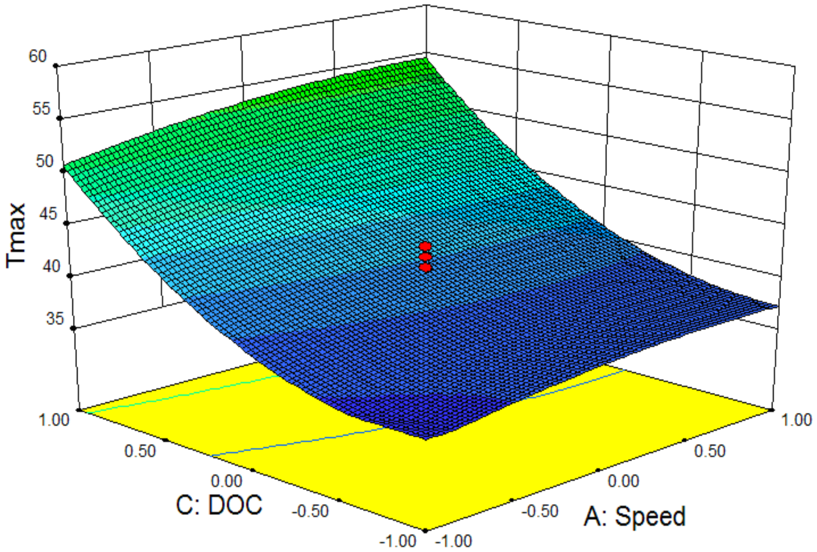

Figure4.26 (a): plot Interaction of A and C for Tmax

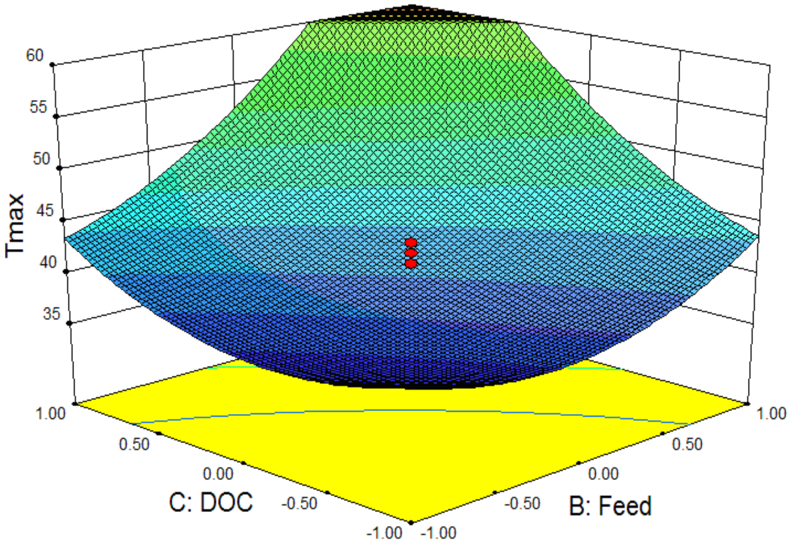

Figure4.26 (b): plot Interaction of B and C for Tmax

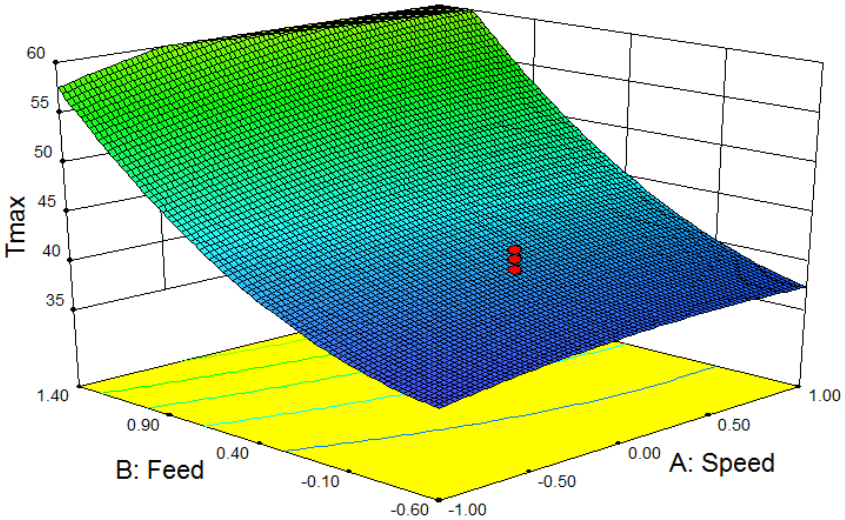

Figure4.26 (c): plot Interaction of B and A for Tmax

(viii) From analysis of contour plots 4.25(a) 4.25(b), 4.25(c) and 3D plots4.26(a), 4.26(b), 4.26(c) for Tmax the least value of Tmax 35 °C was evident at cutting speed 1500 rpm, feed 0.05mm/rev and depth of cut 0.50mm.

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CHAPTER 5

Result & Conclusion

In this study, the surface roughness, MRR and maximum Cutting temperature of work-piece tool interface in the turning process of EN-24 tool steel were modeled and analyzed using RSM and Analysis of Variance. Spindle speed, feed and depth of cut have been employed to carry out the experiment study. The result and conclusion have been summarized as follows.

1. Analyzed the case study (1) for surface roughness with ANOVA the experimental results showed that feed is the most significant factor (42.30 %) followed by spindle speed (29.12 %) and depth of cut (10.43 5) for Ra value. The least Ra value 0.72µm was at cutting speed 2700 rpm, feed 0.05 mm/rev and depth of cut 0.50mm. The feed and depth of cut have directly proportional influence on Ra, while spindle speed has inverse effect.
2 The experimental results analysis with ANOVA of case study(2) for MRR showed that the Depth of cut is the most significant factor contributed 41.71% followed by feed and spindle speed 29.71 % and 11.17 % respectively. The maximum MRR value 3.42 gm/sec was seen at spindle speed 2700 rpm, feed 0.25mm/rev and depth of cut 1.50mm. These parameters are directly influencing the MRR value.
3 The results of analysis of case study (3) for cutting temperature of work-piece tool interface with analysis of variance showed that feed was the most significant influencing factor (34.24 %) followed by depth of cut (34.23 %) and spindle speed (1.24 %) for Tmax. The minimum value of maximum work -piece tool interface temperature 35 °C was found at cutting speed 1500 rpm, feed 0.05mm/rev and depth of cut 0.50mm.

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