

**Comparison of effect of cutting parameters in turning of
EN8 material using HCS Single point cutting tool using
Response Surface Methodology in both wet & dry conditions**

*A project report submitted in partial fulfillment of the
requirements for the Award of the Degree of*

**BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING**

by

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(Approved by AICTE, Affiliated to Andhra University, Accredited by NBA, NAAC- 'A' grade approved)

SANGIVALASA, VISAKHAPATNAM (District) – 531 162

2021

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)


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CERTIFICATE

This is to certify that the Project Report entitled “**COMPARISON OF EFFECT OF CUTTING PARAMETERS IN TURNING OF EN8 MATERIAL USING HCS SINGLE POINT CUTTING TOOL USING RESPONSE SURFACE METHODOLOGY IN BOTH WET AND DRY CONDITIONS**” being submitted by **LOLADHATTU ABHISHEKTA VARMA** (317126520031), **BODDU PRATHYUSHA NAIDU** (317126520006), **DATLA MURALI MANOHAR VARMA** (317126520014), **SEERAPU PRASANNA KUMAR** (317126520048), in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**, ANITS. It is the work of bona-fide, carried out under the guidance and supervision of **DR.N.V.N.INDRA KIRAN**, Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ACKNOWLEDGEMENTS

We express immensely our deep sense of gratitude to Dr.N.V.N Indra Kiran, Professor, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, Sangivalasa, Bheemunipatnam Mandal, Visakhapatnam district for his valuable guidance and encouragement at every stage of the work made it a successful fulfillment.

We were very thankful to Prof. T.V.Hanumantha Rao, Principal, Prof.D.Prasada Rao, Dean and Dr.B.Naga Raju, Head of the Department, Mechanical Engineering Department, Anil Neerukonda Institute of Technology & Sciences for their valuable suggestions.

We wish to thank all the staff in department, non-teaching staff in the workshop for their kind cooperation and support given throughout of our project.

Last but not the least, we like to convey our thanks to all who have contributed either directly or indirectly for the completion of our work.

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ABSTRACT

The cutting tool plays a very important role in the machining process of a part in production. It not only performs the cutting action but helps in getting required surface finish and accuracy of the part. In order to perform these tasks the tool has to be strong enough to withstand wear resistance and serve for long period of time to produce more number of components with the same accuracy. Machining is important in metal manufacturing process to achieve near-net shape, good dimensional accuracy and for aesthetic requirements.

The experiment is to study, determine and compare the effects of various parameters such as tool temperature, cutting forces, surface roughness and cycle time in turning of EN-8 material with the help of High Carbon Steel multi-functional cutting tools. The above operation is carried out in wet condition using bharat petroleum cutting oil as a lubricant. The cutting operations were carried out on a conventional lathe machine thereby making turning operation at different spindle speed(N) of 500, 200 rpm. Also feed of 0.5 rev/min, 1 rev/min. Depth of cut 1mm, 1.5mm. Our project also deals with optimization of cutting parameters on EN-8 specimen in turning operation to obtain maximum MRR , minimum cutting forces and minimum work piece temperature using surface response analysis.

The adequacy of the developed model is checked using response surface method (R.S.M),By using the mathematical model the main and interaction effect of various process parameters on MRR, is studied. The developed model helps in selection of proper machining parameters for the specific material and also helps in achieving the desired material removal rate.

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ACCEPTANCE LETTER TO AUTHOR

Dear Author,

With reference to your paper submitted "Comparison of effect of cutting parameters in turning of EN-8 material using HCS Single point cutting tool using Response Surface Methodology in both wet & dry conditions " we are pleased to accept the same for publication in *IJMTE* Volume XI, Issue VI, JUNE 2021.

Manuscript ID: IJMTE/3746

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Best regards,
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CHAPTER 1

INTRODUCTION

1.1 TURNING OPERATION

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

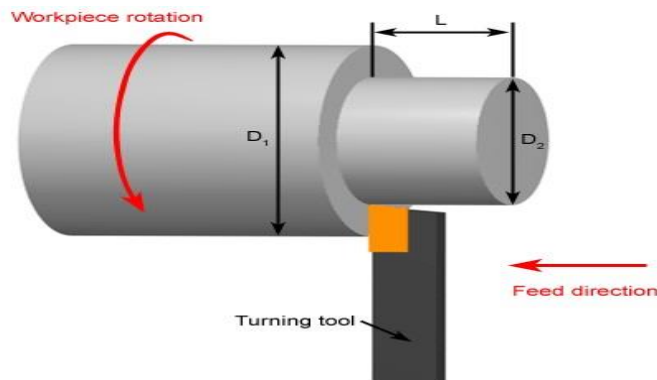


Figure 1.1: Adjustable parameters in turning operation

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setup as a single-point which is often employed in turning. In such setups, each tool will operate independently as a single cutting tool.

1.2 ADJUSTABLE CUTTING PARAMETERS IN TURNING

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right on the machine.

1.2.1 Speed:

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it defines the speed of rotation. But, the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply, the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same

$$v = \pi DN / 1000$$

Here, v is the cutting speed in turning in m/min,

D is the initial diameter of the work piece in mm,

N is the spindle speed in r.p.m.

1.2.2 Feed:

Feed always refers to the cutting tool, 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.

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

Here,

F_m is the feed in mm per minute,

f - Feed in mm/rev and

N - Spindle speed in r.p.m.

1.2.3 Depth of Cut:

Depth of cut is practically self explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work 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

$$D_{cut} = \frac{D - d}{2}$$

D_{cut} - Depth of cut in mm

D - Initial diameter of the work piece

d - Final diameter of the work piece

1.3 CUTTING TOOLS FOR LATHES

1.3.1 Tool Geometry

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. The standard terminology is shown in the following figure 1.2. For single point tools, the most important angles are the rake angles and the end and side relief angles

1.3.1(a) Flank

A flat surface of a single-point tool that is adjacent to the face of the tool. During turning, the side flank faces the direction that the tool is fed into the work piece, and the end flank passes over the newly machined surface.

1.3.1(b) Face

The flat surface of a single point tool through which, the work piece rotates during turning operation. On a typical turning setup, the face of the tool is positioned upwards.

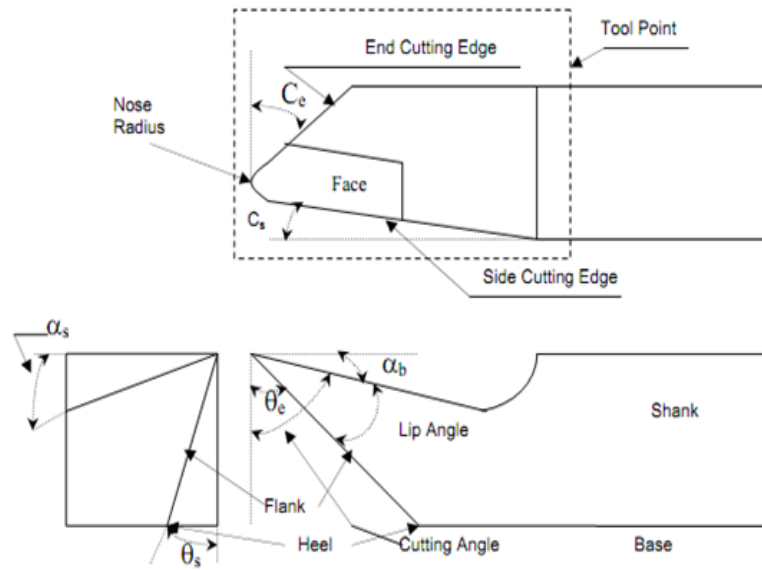


Fig 1.2: Geometry of tool

1.3.1(c) Back rake angle

If viewed from the side facing the end of the work piece, it is the angle formed by the face of the tool and a line parallel to the floor. A positive back rake angle tilts the tool face back, and a negative angle tilts it forward and up

1.3.1(d) Side rake angle

If viewed from behind the tool looking down the length of the tool holder, it is the angle formed by the face of the tool and the centre line of the work piece. A positive side rake angle tilts the tool face down toward the floor, and a negative angle tilts the face up and toward the work piece.

1.3.1(e) Side cutting edge angle

If viewed from above looking down on the cutting tool, it is the angle formed by the side flank of the tool and a line perpendicular to the work piece centreline. A positive side cutting edge angle moves the side flank into the cut, and a negative angle moves the side flank out of the cut.

1.3.1(f) End cutting edge angle

If viewed from above looking down on the cutting tool, it is the angle formed by the end flank of the tool and a line parallel to the work piece centreline. Increasing the end cutting

edge angle tilts the far end of the cutting edge away from the work piece.

1.3.1(g) Side relief angle

If viewed from behind the tool looking down the length of the tool holder, it is the angle formed by the side flank of the tool and a vertical line down to the floor. Increasing the side relief angle tilts the side flank away from the work piece.

1.3.1(h) End relief angle

If viewed from the side facing the end of the work piece, it is the angle formed by the end flank of the tool and a vertical line down to the floor. Increasing the end relief angle tilts the end flank away from the work piece.

1.3.1(i) Nose radius:

It is the rounded tip on the cutting edge of a single point tool. A zero degree nose radius creates a sharp point of the cutting tool.

1.3.1(j) Lead angle:

It is the common name for the side cutting edge angle. If a tool holder is built with dimensions that shift the angle of an insert, the lead angle takes this change into consideration. The back rake angle affects the ability of the tool to shear the work material and form the chip. It can be positive or negative. Positive rake angles reduce the cutting forces resulting in smaller deflections of the work piece, tool holder, and machine. If the back rake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide and diamond tools. The higher the hardness, the smaller will be the back rake angle. For high-speed steels, back rake angle is normally chosen in the positive range.

1.4 CUTTING TOOL MATERIALS

The classes of cutting tool materials currently in use for machining operation are high-speed tool steel, cobalt-base alloys, cemented carbides, ceramic, and polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. The Ideal cutting tool material should have all of the

following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant
- Chemically inert to the work material and cutting fluid

To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

Some common cutting tool materials are described below:

1.4.1 Carbon steels

Carbon steels have been used since the 1880s for cutting tools. However carbon steels start to soften at a temperature of about 180°C. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for Woodworking and they can be used in a router to machine aluminium sheet up to about 3mm thick.

1.4.2 High speed steels (HSS)

HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) was developed first and typically contains 12 - 18% tungsten, plus about 4% chromium and 1-5% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4-12% cobalt. It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which

had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades. These contain 5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and many grades contain 5 - 10% cobalt. HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10 - 60 m/min.



Fig 1.3: High speed steel(HSS) tool

1.4.3 Cast Cobalt alloys

Introduced in early 1900s these alloys have compositions of about 40 - 55% cobalt, 30% chromium and 10 - 20% tungsten and are not heat treatable. Maximum hardness values of 55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use.

1.4.4 Carbides

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometres) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a

significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has a higher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 when coated.

1.4.4 High Carbide Steels (HCS)

Generally, the high carbon steels contain from 0.60 to 1.00% C with manganese contents ranging from 0.30 to 0.90%. The pearlite has a very fine structure, which makes the steel very hard. Unfortunately this also makes the steel quite brittle and much less ductile than mild steel.



Fig 1.4: High Carbide Steel (HCS) Single Point Cutting Tool

Medium and high carbon steels are widely used in many common applications. Increasing carbon as the primary alloy for the higher strength and hardness of steels is usually the most economical approach to improved performance. However, some of the effects of elevated carbon levels include reduced weldability, ductility and impact toughness. When these reduced properties can be tolerated, the increased strength and hardness of the higher carbon materials can be used to a significant advantage. Common applications of higher carbon steels include forging grades, rail steels, spring steels (both flat rolled and round), pre-stressed concrete, wire rope, tire reinforcement, wear resistant steels (plates

and forgings), and high strength bar.

1.5 TURNING MACHINES

The turning machines are, of course, every kind of lathes. Lathes used in manufacturing can be classified as engine, turret, automatics, and numerical control etc. They are heavy duty machine tools and have power drive for all tool movements. They commonly range in size from 12 to 24 inches swing and from 24 to 48 inches centre distance, but swings up to 50 inches and centre distances up to 12 feet are not uncommon.

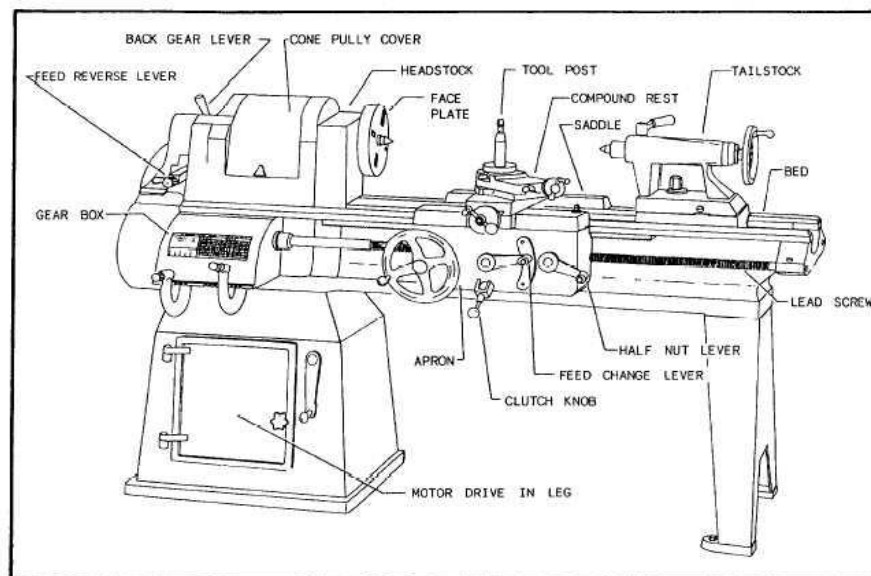


Fig 1.5: Engine lathe

1.5.1 Turret Lathes

In a turret lathe, a longitudinally feed able, hexagon turret replaces the tailstock. The turret, on which six tools can be mounted, can be rotated about a vertical axis to bring each tool into operating position, and the entire unit can be moved longitudinally, either manually or by power, to provide feed for the tools. When the turret assembly is backed away from the spindle by means of a capstan wheel; the turret indexes automatically at the end of its movement, thus, bring each of the six tools into operating position. The square turret on the cross slide can be rotated manually about a vertical axis to bring each of the four tools into operating position. On most machines, the turret can be moved transversely, either manually or by power, by means of the cross slide, and longitudinally through power or manual operation of the carriage. In most cases, a fixed tool holder also is added to the back end of the cross slide; this often carries a parting tool. Through these basic features of a turret lathe, a number of tools can be set on the machine and then

quickly be brought successively into working position so that a complete part can be machined without the necessity for further adjusting, changing tools, or making measurements.

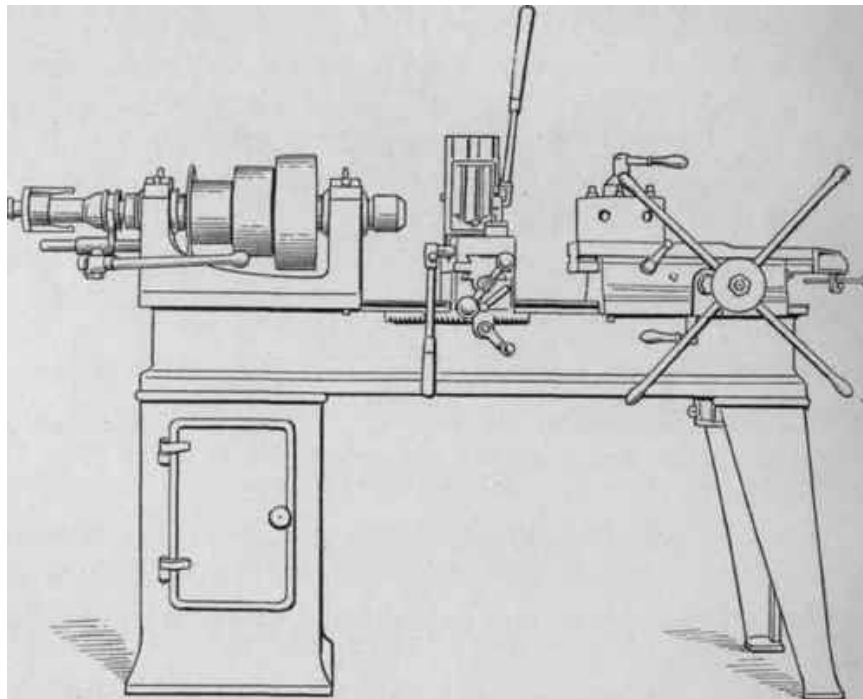


Figure1.6: Turret lathe

1.5.2 Single-Spindle Automatic Screw Machines

There are two common types of single-spindle screw machines, One, an American development and commonly called the turret type (Brown & Sharp), is shown in the following figure1.5. The other is of Swiss origin and is referred to as the Swiss type. The Brown & Sharp screw machine is essentially a small automatic turret lathe, designed for bar stock, with the main turret mounted on the cross slide. All motions of the turret, cross slide, spindle, chuck, and stock-feed mechanism are controlled by cams. The turret cam is essentially a program that defines the movement of the turret during a cycle. These machines usually are equipped with an automatic rod feeding magazine that feeds a new length of bar stock into the collect as soon as one rod is completely used

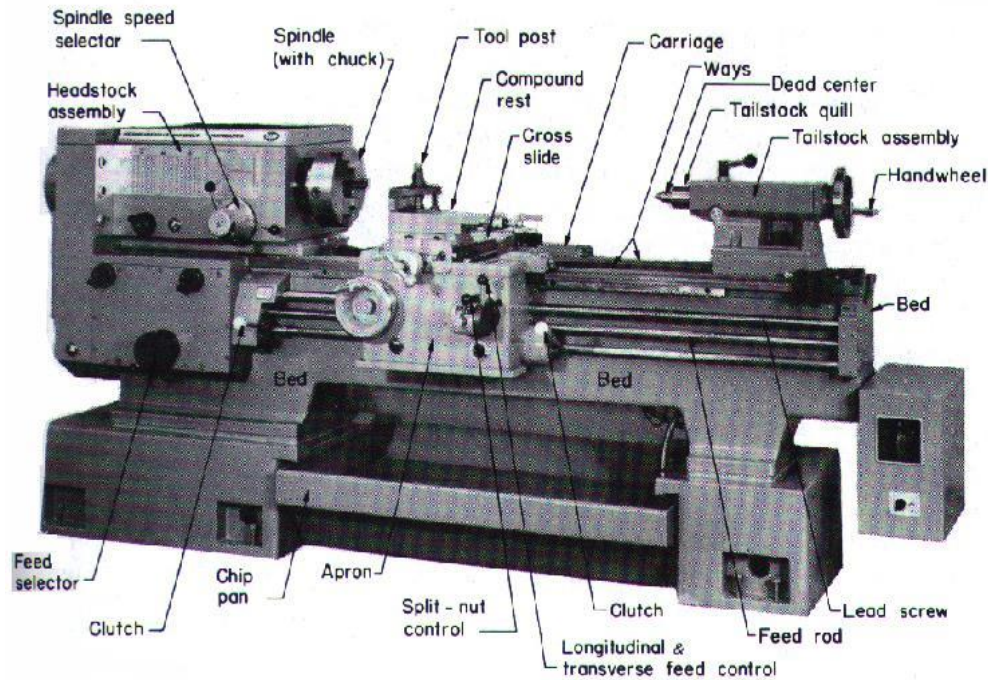


Fig 1.7: Single spindle automatic screw lathe

this speckle image can be related to the surface characteristics. The degree of correlation of two speckle patterns produced from the same surface by two different illumination beams can be used as a roughness parameter. Monochromatic plane wave with an angle of incidence with respect to the normal to the surface; multi-scattering and shadowing effects are neglected. The photo-sensor of a CCD camera placed in the focal plane of a Fourier lens is used for recording speckle patterns. Assuming Cartesian coordinates x, y, z , a rough surface can be represented by its ordinates $Z(x, y)$ with respect to an arbitrary datum plane having transverse coordinates (x, y, z) . Then the rms value of surface roughness can be defined and calculated roughness values.

a. Inductance method: An inductance pickup is used to measure the distance between the surface and the pickup. This measurement gives a parametric value that may be used to give a comparative roughness. However, this method is limited to measuring magnetic materials.

b. Ultrasound: A spherically focused ultrasonic sensor is positioned with a non normal incidence angle above the surface. The sensor sends out an ultrasonic pulse to the personal computer for analysis and calculation of roughness parameters.

1.6 Temperature Gun Measurement

Temperature guns have electronic sensors that enable them to collect the amount of heat energy coming from a given object whose temperature would otherwise be difficult to measure. These guns often use infrared beams and you only have to aim at the object whose temperature you are interested in measuring without having to touch it. The sensors have the capability to collect the accurate temperature provided the gadget is functional



Fig 1.8:Temperature gun

There are however some basics that you must know in order to use these temperature guns correctly.

First, the temperature gun uses beams to collect information on the heat energy that is coming from a given object. Thus, the gun does not state whether the heat is coming from the intended object or the surroundings. This means that in order to collect the right temperature measurement, you will have to ensure that you point the gun directly at the object whose temperature you intend to measure. You need to be as close as possible to avoid reading other heat waves that may interfere with your reading's accuracy. The gun will only read the heat energy on the area where it is pointing, and for accuracy, you must aim directly at the object whose temperature you intend to measure.

1.7 Turning dynamometer

A machine tool dynamometer is a multi-component dynamometer that is used to measure forces during the use of the machine tool. Empirical calculations of these forces can be cross-checked and verified experimentally using these machine tool dynamometers.



Fig 1.9: Turning Dynamometer

With advances in technology, machine-tool dynamometers are increasingly used for the accurate measurement of forces and for optimizing the machining process. These multi-component forces are measured as an individual component force in each co-ordinate, depending on the coordinate system used. The forces during machining are dependent on depth of cut, feed rate, cutting speed, tool material and geometry, material of the work piece and other factors such as use of lubrication/cooling during machining.

Turning dynamometers may be strain gauge or piezoelectric type and may be of one, two or three dimensions capable to monitor all of PX, PY and PZ. For ease of manufacture and low cost, strain gauge type turning dynamometers are widely used and preferably of 2 – D (dimension) for simpler construction, lower cost and ability to provide almost all the desired force values.

1.8 INTRODUCTION TO MINITAB

Minitab is a statistics package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMNITAB, a statistical analysis program by NIST. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania, with subsidiaries in Coventry, England(Minitab Ltd.), Paris, France (Minitab SARL) and Sydney, Australia (Minitab Pty.).

Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics-based process improvement methods. Minitab 16, the latest version of the software, is available in 7 languages: English, French, German, Japanese, Korean, Simplified Chinese, & Spanish.

Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab Inc. produces two other products that complement Minitab 16: Quality Trainer, an eLearning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 16 to simultaneously develop the user's statistical knowledge and ability to use the Minitab software and Quality Companion 3, an integrated tool for managing Six Sigma and Lean Manufacturing projects that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise you can print projects and its elements.

1.8.1 Minitab Project and Worksheets

Minitab has two main types of files, projects and worksheets. Worksheets are files that are made up of data; think of a spread sheet containing variables of data. Projects are made up of the commands, graphs and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise you can print projects and its elements.

The Menu bar: You can open menus and choose commands. Here you can find the built-in routines.

The Toolbar: Shortcuts to some Minitab commands.

1.8.2 Two windows in MINITAB

1.Session Window: The area that displays the statistical results of your data analysis and can also be used to enter commands.

2.Worksheet Window: A grid of rows and columns used to enter and manipulate the data. Note: This area looks like a spreadsheet but will not automatically update the columns when entries are changed.

Other windows include

- **Graph Window:** When you generate graphs, each graph is opened in its own window.
- **Report Window:** Version 13 has a report manager that helps you organize your results in a report.
- **Other Windows:** History and Project Manager are other windows. See Minitab help for more information on these if needed

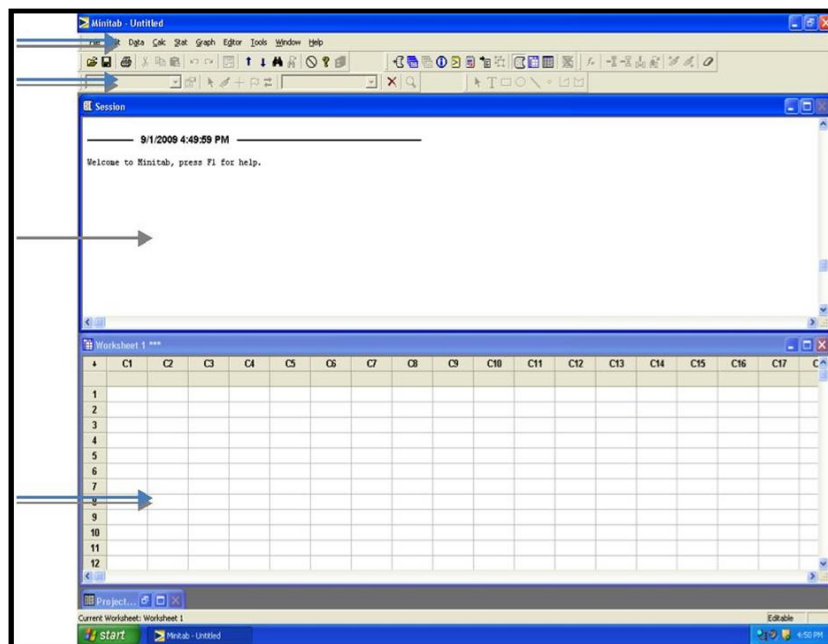


Fig 1.10: Environment in Minitab Software

CHAPTER 2

LITERATURE REVIEW

Ilhan Asilturk (2011): This paper focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness.

M.Suresh(2017): This paper demonstrates efficient turning of high performance EN series material can be achieved through proper selection of turning process parameters to minimise surface roughness and maximise the material removal rate. This present paper outlines an experimental study to optimise and study the effects of process parameters in CNC turning on surface roughness of EN19/AISI4140 (medium carbon steel) work material in dry environment conditions. The orthogonal array, signal to noise ratio and regression technique were employed to study the performance characteristics in CNC turning operation. Four machining parameters were chosen as process parameters. They are cutting speed, feed rate, tool nose radius and depth of cut. The experimentation plan was designed using Taguchi's L9 orthogonal array (OA) and Minitab-16 statistical software. Optimal values of process parameters for desired performance characteristics were obtained by Taguchi design of experiment. Moreover prediction models had been developed with the help of regression analysis to find the effect of cutting parameters.

N.Satheesh Kumar(2012): This paper investigates the effect of process parameters in turning of Carbon Alloy Steels in a CNC lathe. The parameters namely the spindle speed and feed rate are varied to study their effect on surface roughness. The experiments are conducted using one factor at a time approach. The five different carbon alloy steels used for turning are SAE8620, EN8, EN19, EN24 and EN47. The study reveals that the surface roughness is directly influenced by the spindle speed and feed rate. It is observed that the surface roughness increases with increased feed rate and is higher at lower speeds and vice versa for all feed rates.

T.Selvaraj(2017): The experimented to seek optimum machining parameters are determined in turning operation of EN25 steel with coated carbide tools using combined techniques for order preference by similarity to ideal solution (TOPSIS) are Hierarchy process (AHP) method

B.Singaravel etal(2017): The experimented analysis to estimate an optimum machining parameters using Taguchi based concept coupled with principal component analysis (PCA) on turning of EN25 steel with CVD& PVD coated carbide ntools. This study described the

minimization of surface roughness , cutting forces and maximization of material removal rate (MRR)and optimized by S/N ratio analysis of variance (ANOVA). finally implemented a result based on percentage of contribution of machining parameters on machining performance of EN25 steel

Vivek John(2013): EN19 is a high quality,high tensile alloy steel usually ready to machine, giving good ductility and shock resistance properties combined with resistance to wear .In Taguchi design of experiment method the parameters factors which can be controlled and noise factors which cannot which influence products quality are considered.

Mr. Amol N. Varade ,Mr. Kamlesh P. Kadia (2015): The main aim of this Project work is to study experimentally the influence of depth of cut, cutting speed, and feed rate on the tool tip temperature, Material Removal Rate, Surface Roughness during turning process. The experiments will be obtained by varying one parameter while, the remaining two parameter were kept constant. So the influence of tool tip on different machining parameters is done in this research work. To increase the tool life, Taguchi Optimization method is used to optimization of machining parameters. Through this study, not only the optimal cutting parameters for turning operations are obtained, but also the main cutting parameters that affect the cutting performance in turning operations will be evaluated. Experimental results will be provided to confirm the effectiveness of this approach. It will give the best result for turning operation of EN19 Material.

A.Kriyadeesh,P.Srinivasrao,C.Labeshkumar(2019): This paper deals with the experimental investigation and testing on a single point cutting tool with carbide inserts and high speed steel tool .It is to be proved that carbide inserts have better performance than HSS tools on machining operation. Components with higher surface quality, higher material removal rate in less time and lower tool wear is only possible by carbide insert tools. The tool material selected for this experiment are cemented & tungsten carbide inserts along with high speed steel tool on machining medium carbon steel EN19. The complete machining process is performed on cnc lathe machine Hence the intention of this project is to minimize the surface roughness, tool wear, machining time and increasing the material removal rate. Taguchi's L9 orthogonal array is favor for this investigation work.

Bhiksha Gugulothu, A. Raveendra, M.Uma mahesh (2017): Good surface quality and better material removal rate are desired for the proper functioning of the produced parts. It was seen that the desired surface roughness and material removal rate were not obtained consistently in turning of EN 8 steel applications (Camshaft). These higher values of surface roughness results in rework and increases cost hence the main objective is optimization of surface roughness and material removal rate a general optimization of surface roughness and material removal rate are deemed to be necessary for the most of manufacturing industry.In this study the effect of the machining parameters are investigated, also optimum process parameters are studied. An L9 orthogonal array (mixed level design), analysis of variance (ANOVA) and the signal to noise (S/N) ratio are used in this study.

CHAPTER 3

DESIGN OF EXPERIMENTS

3.1 Design of Experiments (DOE) Overview

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the effects that are important. If there is an interaction between two input variables

They should be included in design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable.

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

3.1.1 Planning

Careful planning help in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Here are some steps need to go through:

- **Define the problem.** Developing a good problem statement helps in studying the right variables.
- **Define the objective.** A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, define the goals of the experiment.
- **Develop an experimental plan that will provide meaningful information.** Review relevant background information, such as theoretical principles, and knowledge gained through observation or previous experimentation.

- **Make sure the process and measurement systems are in control.** Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system. Minitab provides numerous tools to evaluate process control and analyze your measurement system.

3.1.2 Screening

In many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality. This reduction allows focusing process improvement efforts on the really important variables. Screening suggests the “best” optimal settings for these factors.

The following methods are often used for screening:

- Two-level full and fractional factorial designs are used extensively in industry
- Plackett-Burman designs have low resolution, but they are useful in some screening experimentation and robustness testing.
- General full factorial designs (designs with more than two-levels) may also be useful for small screening experiments.

3.1.3 Optimization

After identifying the vital variables by screening, there is need to determine the "best" or optimal values for these experimental factors. Optimal factor values depend on the process objective.

The optimization methods available in Minitab include general full factorial designs (designs with more than two-levels), response surface designs, mixture designs, and Taguchi designs.

- Factorial Designs Overview describes methods for designing and analyzing general full factorial designs.
- Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.
- Mixture Designs Overview describes methods for designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of the components (factors), rather than their magnitude, are important.

- Response Optimization describes methods for optimizing multiple responses. Minitab provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.
- Taguchi Designs Overview describes methods for analyzing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-outer array designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4 Verification

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results.

3.2 Advantages & Disadvantages of DOE

DOE became a more widely used modelling technique superseding its predecessor one-factor-at- time (OFAT) technique. One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DOE shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses. DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE function in such manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs. Most usually, experiments will have error occurring. Some of them might be predictable while some errors are just out of control. DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behaviour. However, when it comes to nonlinear behaviour, DOE does not always give the best results.

3.3 STEPS INVOLVED IN TABULATION AND ANALYSIS Vol. 6 No. 32020www.iiardpub.or USING MINITAB STATISTICAL SOFTWARE:

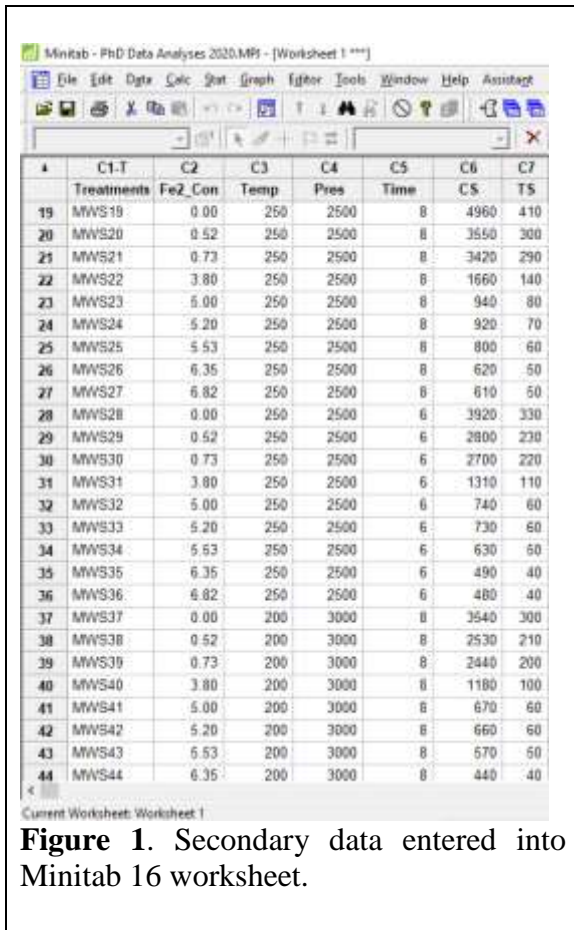


Figure 1. Secondary data entered into Minitab 16 worksheet.

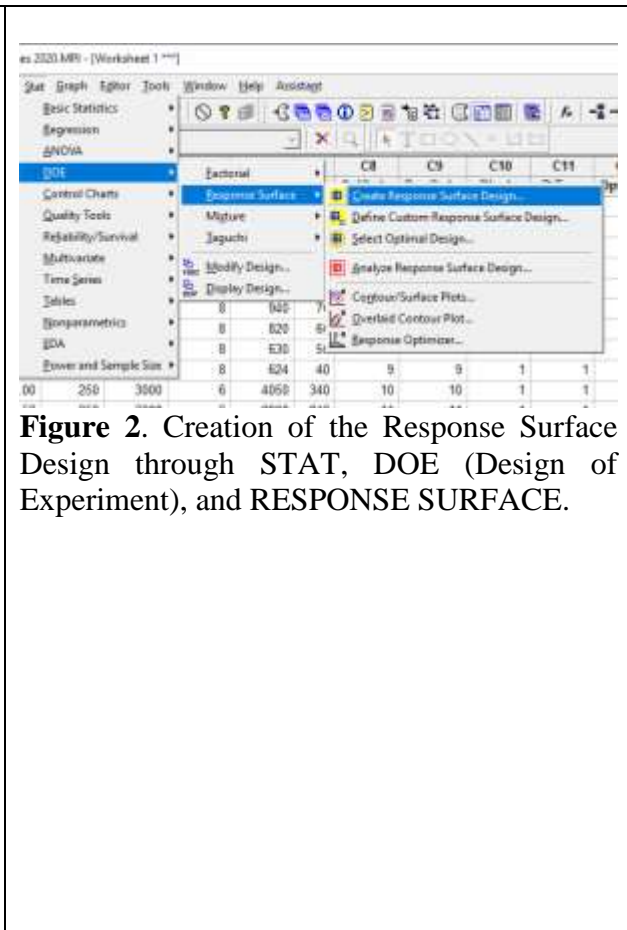


Figure 2. Creation of the Response Surface Design through STAT, DOE (Design of Experiment), and RESPONSE SURFACE.

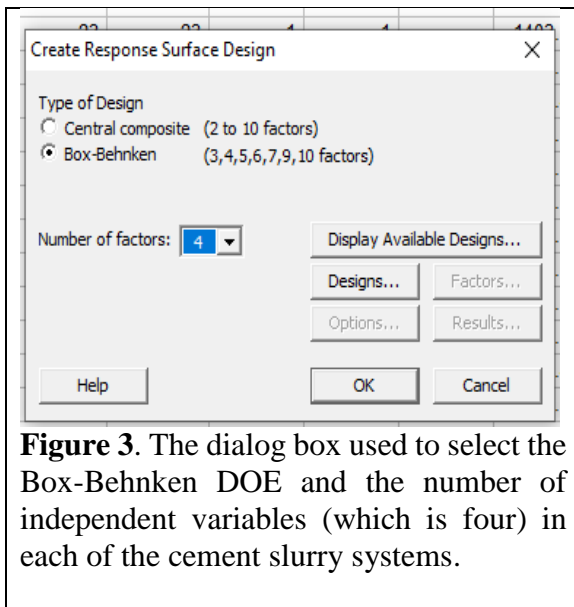


Figure 3. The dialog box used to select the Box-Behnken DOE and the number of independent variables (which is four) in each of the cement slurry systems.

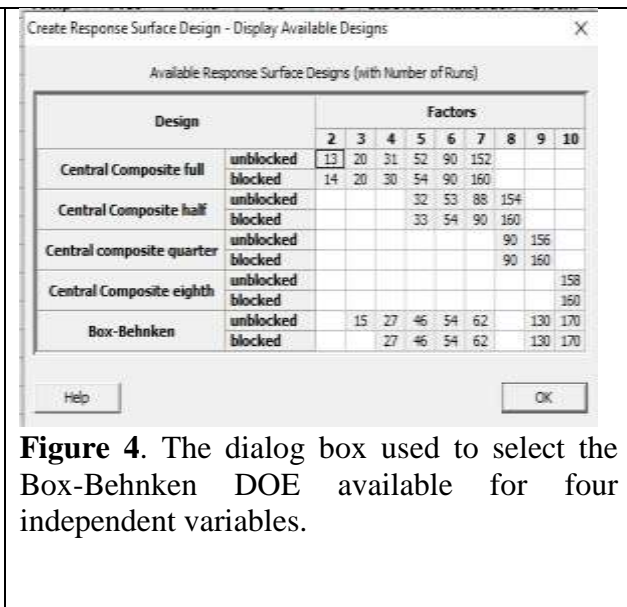


Figure 4. The dialog box used to select the Box-Behnken DOE available for four independent variables.

Fig 3.1

3.4 DEFINING CONTINUOUS AND RESPONSES CONSTRAINTS:



Figure 5. Definition of the Custom Response Surface Design through STAT, DOE and RESPONSE SURFACE, to select the available for four independent variables.

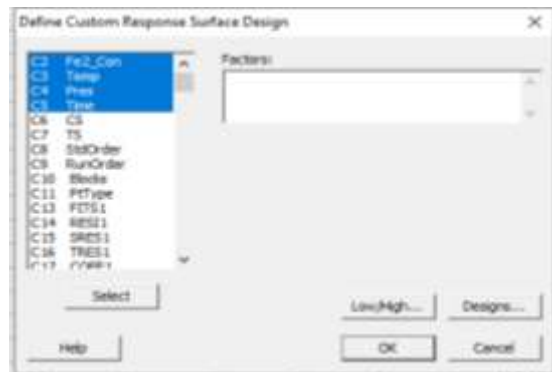


Figure 6. Selection of the four independent variables from the dialog box of Define Custom Response Surface Design.

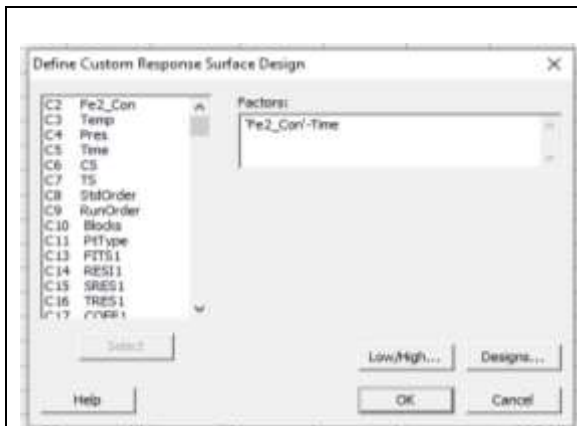


Figure 7. The four independent variables are have been selected from the dialog box of Define Custom Response Surface Design.

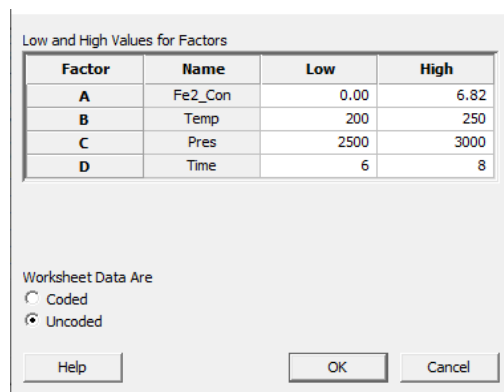


Figure 8. The range for the four independent variables were setup here, in the Low and High Value for Factor dialog box.

Fig 3.2

3.5 ALGORITHMIC CODED REPRESENTATION:

Table 1. Box-Behnken Design Randomised Design Output in RSM

Box-Behnken Design Randomised Design Output in RSM					
Factors:	4	Replicates:	1		
Base runs:	27	Total runs:	27		
Base blocks:	1	Total blocks:	1		
Center points: 3					
Design Table (randomized)					
Run	Blk	A	B	C	D
1	1	0	-	0	-
2	1	0	0	0	0
3	1	0	-	+	0
4	1	0	-	-	0
5	1	+	+	0	0
6	1	-	0	-	0
7	1	-	0	+	0
8	1	+	0	0	-
9	1	0	0	-	+
10	1	+	0	0	+
11	1	0	+	0	-
12	1	0	0	-	-
13	1	+	-	0	0
14	1	+	0	+	0
15	1	-	0	0	+
16	1	+	0	-	0
17	1	0	0	0	0
18	1	-	-	0	0
19	1	0	+	-	0
20	1	-	+	0	0
21	1	0	+	+	0
22	1	-	0	0	-
23	1	0	0	+	-
24	1	0	+	0	+
25	1	0	-	0	+
26	1	0	0	+	+
27	1	0	0	0	0



Figure 9. Selection of the optimal design through STAT, DOE and RESPONSE SURFACE, to select the response variable, compressive strength (CS).

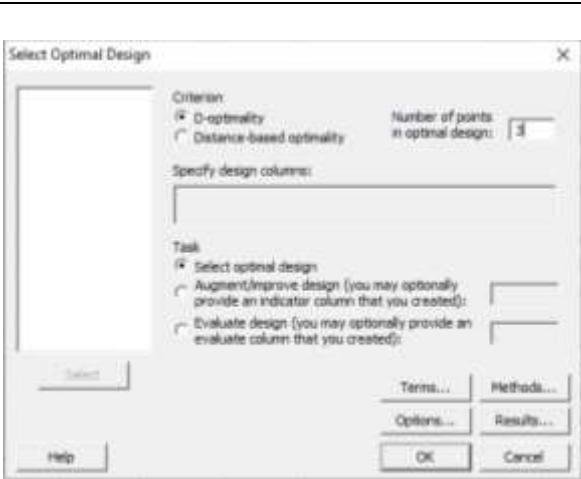


Figure 10. Selection of the optimal design from the Select Optimal Design dialog box.

Fig 3.3

3.6 DESIGN AND PLOT SELECTION CRITERIA:

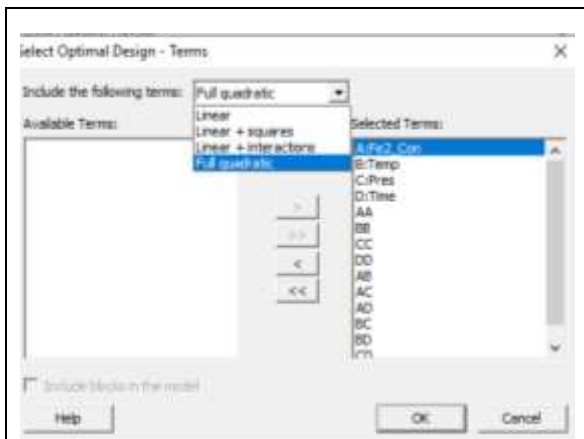


Figure 11. Selection of the optimal design probable model (Full Quadratic) from the Select Optimal Design-Terms dialog box.

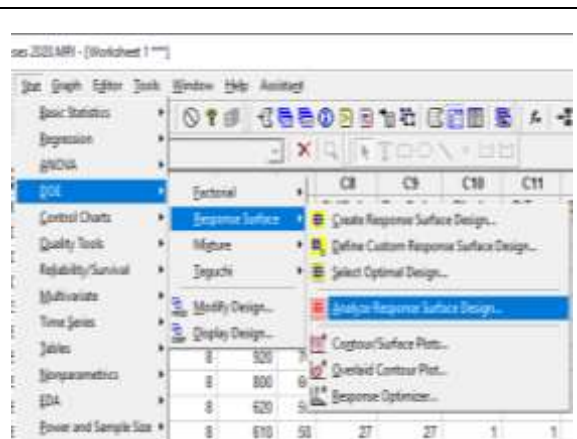


Figure 12. Selection of the analyse response design through STAT, DOE and RESPONSE SURFACE.

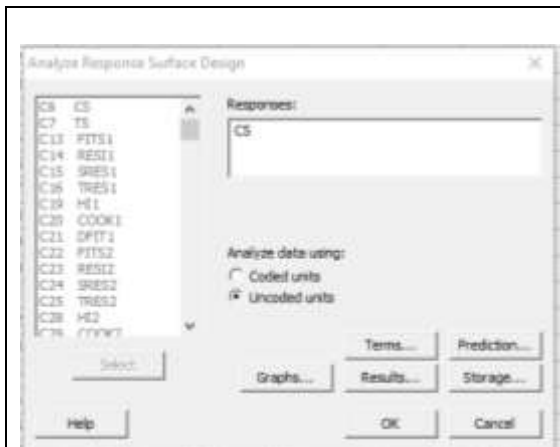


Figure 13. Selection of the response variable, CS from the Analyze Response Surface Design dialog box.

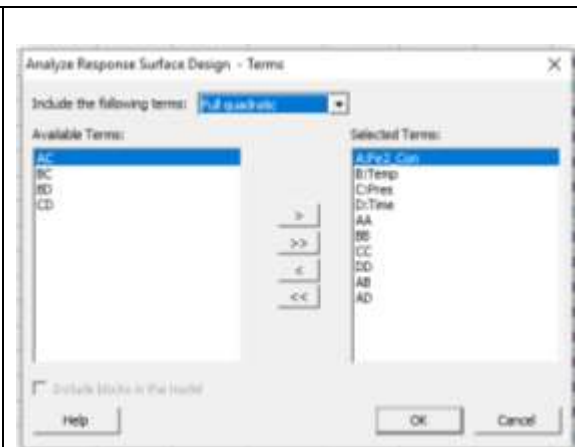
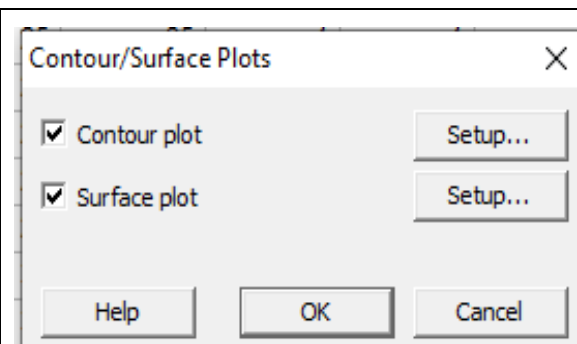


Figure 14. Selection of the optimal design probable model (Full Quadratic) from the Analyze Response Surface Design dialog box.



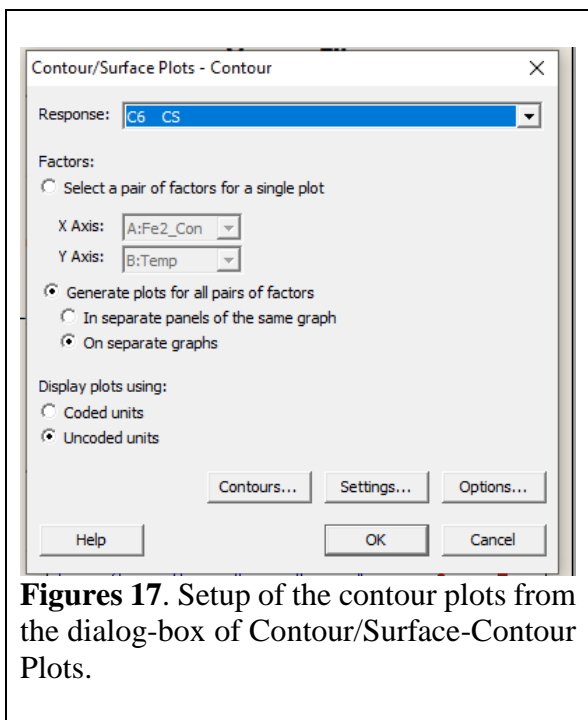
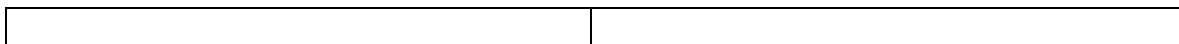
Figures 15. Selection of Contour/Surface Plots through STAT, DOE and RESPONSE SURFACE.



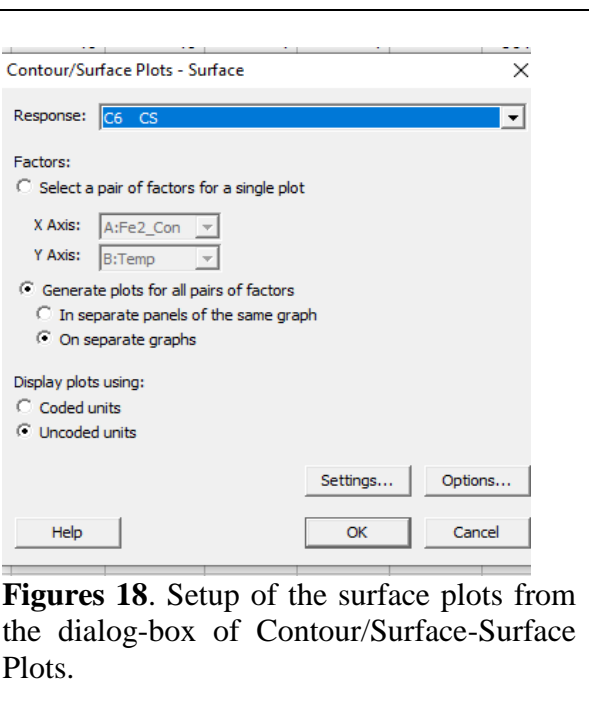
Figures 16. Setup of the contour/surface plots from the dialog-box of Contour/Surface Plots.

Fig 3.4

3.7 FINALISING PLOT CO-ORDINATES BEFORE OUTPUT:



Figures 17. Setup of the contour plots from the dialog-box of Contour/Surface-Contour Plots.



Figures 18. Setup of the surface plots from the dialog-box of Contour/Surface-Surface Plots.

Fig 3.5

3.8 Hierarchy

You can determine how Minitab enforces model hierarchy during a stepwise procedure.

The Hierarchy button is disabled if you specify a non-hierarchical model in the Model dialog box.

For example, a model that includes the interaction term $A*B*C$ is hierarchical if it includes these terms: A , B , C , $A*B$, $A*C$, and $B*C$.

Models can be non-hierarchical. Generally, you can remove lower order terms if they are insignificant, unless subject area knowledge suggests that you include them. Models that contain too many terms can be relatively imprecise and can reduce the ability to predict the values of new observations.

Consider the following tips:

- 1) Fit a hierarchical model first. You can remove insignificant terms later.
- 2) If you standardize your continuous predictors, fit a hierarchical model to produce an equation in uncoded (or natural) units.
- 3) If your model contains categorical variables, the results are easier to interpret if the categorical terms, at least, are hierarchical.

Fig 3.6

	C1-T	C2	C3	C4	C5	C6	C7	C8	C
	Labels	Group	Score						
1	ID1	1	40						
2	ID2	1	25						
3	ID3	1	29						
4	ID4	1	30						
5	ID5	1	34						
6	ID6	2	50						
7	ID7	2	39						
8	ID8	2	30						
9	ID9	2	34						
10	ID10	2	50						

3.9 Calculations

1. MATERIAL REMOVAL RATE

2. CHIP THICKNESS RATIO

3. SHEAR ANGLE

MRR(mm³/ min)

MRR = cutting speed * chip section

Chip section = chip thickness * axial depth of cut
* feed

$$\begin{aligned} \text{MRR} &= \pi * D_{\text{average}} * [\text{feed} * \text{depth of cut}] * N \\ &= [\pi * D_{\text{average}} * N] * f * d \\ &= V_{\text{cutting}} * f * d \end{aligned}$$

EN 8 dry condition (MRR)

1. $\text{MRR}(1) = \pi * 31.7 \text{ mm} * 200 \text{ rpm} * 0.5 * 1 = 9958.4 \text{ mm}^3/\text{min}$
2. $\text{MRR}(2) = \pi * 31.7 \text{ mm} * 200 \text{ rpm} * 0.5 * 1.5 = 14938.2 \text{ mm}^3/\text{min}$
3. $\text{MRR}(3) = \pi * 31.7 \text{ mm} * 200 \text{ rpm} * 1 * 1 = 19917.8 \text{ mm}^3/\text{min}$
4. $\text{MRR}(4) = \pi * 31.7 \text{ mm} * 200 \text{ rpm} * 1 * 1.5 = 29876.5 \text{ mm}^3/\text{min}$
5. $\text{MRR}(5) = \pi * 31.7 \text{ mm} * 500 \text{ rpm} * 0.5 * 1 = 24897.1 \text{ mm}^3/\text{min}$
6. $\text{MRR}(6) = \pi * 31.7 \text{ mm} * 500 \text{ rpm} * 0.5 * 1.5 = 37345.8 \text{ mm}^3/\text{min}$
7. $\text{MRR}(7) = \pi * 31.7 \text{ mm} * 500 \text{ rpm} * 1 * 1 = 49794.2 \text{ mm}^3/\text{min}$
8. $\text{MRR}(8) = \pi * 31.7 \text{ mm} * 500 \text{ rpm} * 1.5 * 1.5 = 74691.3 \text{ mm}^3/\text{min}$

EN 8 wet condition (MRR)

1. $\text{MRR}(1) = \pi * 30.2 \text{ mm} * 200 \text{ rpm} * 0.5 * 1 = 9487.6 \text{ mm}^3/\text{min}$
2. $\text{MRR}(2) = \pi * 30.2 \text{ mm} * 200 \text{ rpm} * 0.5 * 1.5 = 14231.41 \text{ mm}^3/\text{min}$
3. $\text{MRR}(3) = \pi * 30.2 \text{ mm} * 200 \text{ rpm} * 1 * 1 = 18975.21 \text{ mm}^3/\text{min}$
4. $\text{MRR}(4) = \pi * 30.2 \text{ mm} * 200 \text{ rpm} * 1 * 1.5 = 28462.82 \text{ mm}^3/\text{min}$
5. $\text{MRR}(5) = \pi * 30.2 \text{ mm} * 500 \text{ rpm} * 0.5 * 1 = 23719.02 \text{ mm}^3/\text{min}$
6. $\text{MRR}(6) = \pi * 30.2 \text{ mm} * 500 \text{ rpm} * 0.5 * 1.5 = 35578.53 \text{ mm}^3/\text{min}$
7. $\text{MRR}(7) = \pi * 30.2 \text{ mm} * 500 \text{ rpm} * 1 * 1 = 47438.04 \text{ mm}^3/\text{min}$
8. $\text{MRR}(8) = \pi * 30.2 \text{ mm} * 500 \text{ rpm} * 1.5 * 1.5 = 71157.07 \text{ mm}^3/\text{min}$

Chip thickness ratio (r.c) = a1 / a2

a1 = chip thickness before cutting

a2 = chip thickness after cutting

Chip thickness ratio for EN 8 dry condition

1. $r.c(1) = 0.43 / 8 = 0.0537$
2. $r.c(2) = 0.43 / 18 = 0.0239$
3. $r.c(3) = 0.866 / 6 = 0.1443$
4. $r.c(4) = 0.866 / 5 = 0.1732$
5. $r.c(5) = 0.43 / 9 = 0.0477$
6. $r.c(6) = 0.43 / 12 = 0.035$
7. $r.c(7) = 0.866 / 20 = 0.0433$
8. $r.c(8) = 0.866 / 7 = 0.1237$

Chip thickness ratio for EN 8 wet condition

1. $r.c(1) = 0.43 / 8 = 0.0537$
2. $r.c(2) = 0.43 / 12 = 0.0358$
3. $r.c(3) = 0.866 / 17 = 0.5094$
4. $r.c(4) = 0.866 / 9 = 0.0962$
5. $r.c(5) = 0.43 / 16 = 0.0268$
6. $r.c(6) = 0.43 / 8 = 0.0537$
7. $r.c(7) = 0.866 / 16 = 0.0541$
8. $r.c(8) = 0.866 / 8 = 0.1082$

Shear angle

$$\tan\theta = (r.c * \cos\alpha) / (1 - (r.c * \sin\alpha))$$

$$\theta = \tan^{-1} [(r.c * \cos\alpha) / (1 - (r.c * \sin\alpha))]$$

θ = shear angle

r.c = chip thickness ratio

α = rake angle (i.e $14^{\circ}30'$) [tool maker's microscope]

EN 8 wet (numerator):

$$\text{Numerator} = (r.c) * \cos\alpha$$

1. $[NU1] = 0.053 * \cos 14.5 = 0.051$
2. $[NU2] = 0.0239 * \cos 14.5 = 0.034$
3. $[NU3] = 0.1443 * \cos 14.5 = 0.493$
4. $[NU1] = 0.1732 * \cos 14.5 = 0.093$
5. $[NU1] = 0.0477 * \cos 14.5 = 0.02$
6. $[NU1] = 0.035 * \cos 14.5 = 0.051$
7. $[NU1] = 0.0433 * \cos 14.5 = 0.05$
8. $[NU1] = 0.1237 * \cos 14.5 = 0.10$

EN 8 wet (denominator):

1. $[DE1] = (1 - (0.53 * \sin 14.5)) = 0.98$
2. $[DE1] = (1 - (0.0239 * \sin 14.5)) = 0.99$
3. $[DE1] = (1 - (0.1443 * \sin 14.5)) = 0.87$
4. $[DE1] = (1 - (0.173 * \sin 14.5)) = 0.97$
5. $[DE1] = (1 - (0.047 * \sin 14.5)) = 0.99$
6. $[DE1] = (1 - (0.035 * \sin 14.5)) = 0.98$
7. $[DE1] = (1 - (0.043 * \sin 14.5)) = 0.98$
8. $[DE1] = (1 - (0.123 * \sin 14.5)) = 0.97$

Shear angle EN 8 wet:

$$\theta = \tan^{-1}[\text{NU} / \text{DE}]$$

$$\theta_1 = \tan^{-1}[0.0519 / 0.986] = 79.1^\circ$$

$$\theta_2 = \tan^{-1}[0.0346 / 0.991] = 74.01^\circ$$

$$\theta_3 = \tan^{-1}[0.493 / 0.872] = 88.9^\circ$$

$$\theta_4 = \tan^{-1}[0.093 / 0.975] = 84.01^\circ$$

$$\theta_5 = \tan^{-1}[0.025 / 0.99] = 69.02^\circ$$

$$\theta_6 = \tan^{-1}[0.051 / 0.98] = 79.23^\circ$$

$$\theta_7 = \tan^{-1}[0.052 / 0.98] = 79.31^\circ$$

EN 8 DRY (numerator):

$$\text{Numerator} = (\text{r.c}) * \cos\alpha$$

1. [NU1] = 0.053 * Cos14.5 = 0.0513
2. [NU2] = 0.023 * Cos14.5 = 0.0231
3. [NU3] = 0.144 * Cos14.5 = 0.1397
4. [NU4] = 0.173 * Cos14.5 = 0.1676
5. [NU5] = 0.047 * Cos14.5 = 0.0461
6. [NU6] = 0.035 * Cos14.5 = 0.0338
7. [NU7] = 0.0433 * Cos14.5 = 0.0419
8. [NU8] = 0.1237 * Cos14.5 = 0.1197

EN 8 DRY (denominator):

1. [DE1] = (1 - (0.53 * Sin14.5)) = 0.98
2. [DE2] = (1 - (0.0239 * Sin14.5)) = 0.994
3. [DE3] = (1 - (0.1443 * Sin14.5)) = 0.963
4. [DE4] = (1 - (0.173 * Sin14.5)) = 0.956
5. [DE5] = (1 - (0.047 * Sin14.5)) = 0.988
6. [DE6] = (1 - (0.043 * Sin14.5)) = 0.991
7. [DE7] = (1 - (0.035 * Sin14.5)) = 0.989
8. [DE8] = (1 - (0.123 * Sin14.5)) = 0.969

Shear angle EN 8 wet:

$$\theta = \tan^{-1}[\text{NU} / \text{DE}]$$

$$\theta_1 = \tan^{-1}[0.0519 / 0.986] = 79.1^\circ$$

$$\theta_2 = \tan^{-1}[0.0346 / 0.991] = 74.01^\circ$$

$$\theta_3 = \tan^{-1}[0.493 / 0.872] = 88.9^\circ$$

$$\theta_4 = \tan^{-1}[0.093 / 0.975] = 84.01^\circ$$

$$\theta_5 = \tan^{-1}[0.025 / 0.99] = 69.02^\circ$$

$$\theta_6 = \tan^{-1}[0.051 / 0.98] = 79.23^\circ$$

$$\theta_7 = \tan^{-1}[0.052 / 0.98] = 79.31^\circ$$

$$\theta_8 = \tan^{-1}[0.104 / 0.97] = 56.48^\circ$$

CHAPTER 4

EXPERIMENTAL SETUP AND MACHINING

The project was done in 3 stages.

- Design of experiments was done using full factorial method.
- Cycle time was calculated by machining the work piece on lathe machine
- Analysis of results was done using MINITAB 17.1.30.

4.1 Selection of process variables

- A total of three process variables and 3 levels are selected for the experimental procedure.
- The deciding process variables are
 - Speed
 - Feed
 - Depth of cut
- Speed of the spindle, i.e. the speed at which the spindle rotates the tool.
- Feed is the rate at which the material is removed from the work piece.
- Depth of cut is the depth up to which the tool is emerged in one cycle.

4.2 Selection of levels:

- Since it is a three level design by observing the parameters taken in various projects the levels of the factors are designed as follows

Table 4.1: Selection of process variables

FACTORS	LEVEL1	LEVEL2
S.SPEED(RPM)	200	500
FEED(MM/REV)	0.5	1.0
D.O.C(MM)	1.0	1.5

4.3 Design of Experiments

- Design of experiments was done using full factorial method.

- Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not.

4.4 Selection of material

By studying various projects EN-8 is selected for machining operation. The composition of EN-8 is:

- Silicon – 0.05 to 0.3%
- Carbon - 0.5 to 0.60%
- Manganese -0.5 to 0.80%

The dimensions of the workpiece used are length 50mm*16mmdia

4.5 Clamping of the work piece

The work piece is clamped to the machine by using standard 3 jaw chuck.

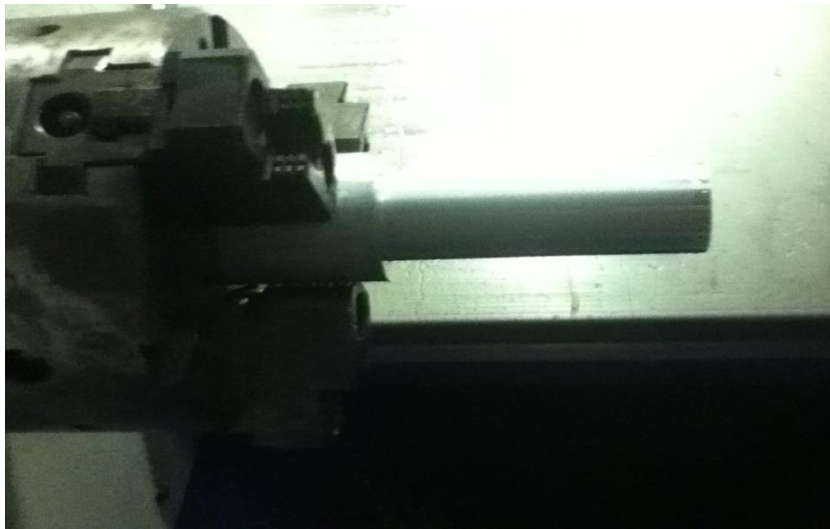


Fig 4.1: Clamping of the work piece

The tool used for turning is High Speed Steel. Initially these tool is fixed in the tool turret using tool holding fixture.

CHAPTER 5

ANALYSIS OF VARIANCE

5.1 ANALYSIS OF VARIANCE (ANOVA) USING MINITAB

ANOVA was developed by the English statistician, R.A. Fisher (1890-1962). Though initially dealing with agricultural data, this methodology has been applied to a vast array of other fields for data analysis. Despite its widespread use, some practitioners fail to recognize the need to check the validity of several key assumptions before applying an ANOVA to their data. It is the hope that this article may provide certain useful guidelines for performing basic analysis using such a software package.

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. Doing multiple two-sample *t*-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in comparing (testing) three, or more means (groups or variables) for statistical significance.

ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result (when a probability (*p*-value) is less than a threshold (significance level)) justifies the rejection of the null hypothesis.

The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. ANOVA is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is difficult to define concisely or precisely.

5.2 Characteristics of ANOVA

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations. In the era of mechanical calculation it was common to subtract a constant from all observations (when equivalent to dropping leading digits) to simplify data entry. This is an example of data coding.

Classical ANOVA for balanced data does three things at once:

1. As exploratory data analysis, an ANOVA is an organization of additive data decomposition, and its sums of squares indicate the variance of each component of the decomposition (or, equivalently, each set of terms of a linear model).
2. Comparisons of mean squares, along with F-tests ... allow testing of a nested sequence of models.
3. Closely related to the ANOVA is a linear model fit with coefficient estimates and standard errors.

In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

Additionally:

It is computationally elegant and relatively robust against violations to its assumptions.

4. ANOVA provides industrial strength (multiple sample comparison) statistically.
5. It has been adapted to the analysis of a variety of experimental designs.

CHAPTER-6

RESULTS AND DISCUSSIONS

6.1 Development of Mathematical Models

A Second -order polynomial is employed for developing the mathematical model for predicting weld pool geometry. If the response is well modelled by a linear function of the independent variables then the approximating function is the first order model as shown in Equation.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_x x_x + \epsilon$$

A mathematical regression equation is developed for cycle time in every tool path and the graphs are plotted.

$$Y = \beta_0 + \sum_{i=1}^k \beta_{0i} x_{0i} + \sum_{i=1}^k \beta_{ii} x_{i2} + \sum_{i < j} \beta_{ij} x_i x_j + \epsilon$$

- Y is the corresponding response
- X_i are the cutting parameters
- (1,2,...,k) are code levels of quantitative process variables
- The terms are the second order regression coefficients
- Second term is attribute to linear effect
- Third term corresponds to higher order effects
- Fourth term includes the interactive effects of the process parameters.
- And the last term indicates the experimental error.
- All the estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying Analysis Of Variance (ANOVA)) technique F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider===- adequate.

6.2 Different Terms used in Response Surface Methodology Regression table

1. P-values: P- Values (P) are used to determine which of the effects in the model are statistically significant.

- If the p-value is less than or equal to 0.5, conclude that the effect is significant.
- If the p-value is greater than 0.5, conclude that the effect is not significant.

2. Coefficients: Coefficients are used to construct an equation representing the relationship between the response and the factors.

3. R-squared: R and adjusted R represent the proportion of variation in the response that is explained by the model.

- R (R-Sq) describes the amount of variation in the observed responses that is explained by the model.
- Predicted R reflects how well the model will predict future data.
- Adjusted R is a modified R that has been adjusted for the number of terms in the model. If we include unnecessary terms, R can be artificially high. Unlike R, adjusted R may get smaller when we add terms to the model.

4. Analysis of variance table: P-values (P) are used in analysis of variance table to determine which of the effects in the model are statistically significant. The interaction effects in the model are observed first because a significant interaction will influence the main effects.

5. Estimated coefficients using uncoded units

- Minitab displays the coefficients in uncoded units in addition to coded units if the two units differ.
- For each term in the model, there is a coefficient. These coefficients are useful to construct an equation representing the relationship between the response and the factors.

6.3 Graphs Obtained

6.3.1 Contour Plots

- Contour and surface plots are useful for establishing desirable response values and operating conditions.
- A contour plot provides a two-dimensional view where all points that have the same response are connected to
- Produce contour lines of constant responses.
- A surface plot provides a three-dimensional view that may provide a clearer picture of the response surface.

Contour/Surface Plots – Contour – Setup

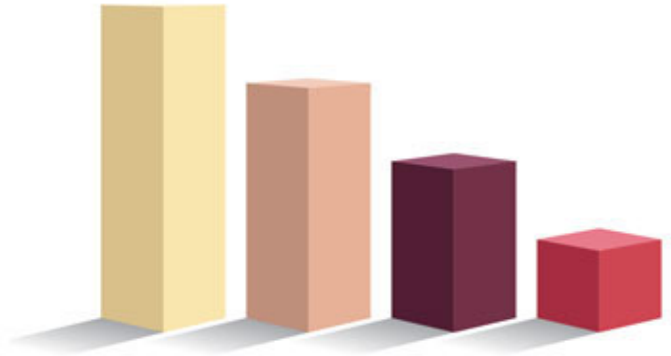
Stat > DOE > Factorial > Contour/Surface Plots > check Contour > Setup

- Generates a response surface contour plot for a single pair of factors or separate contour plots for all possible pairs of factors.
- Contour plots shows that as the lines are diverging towards spindle speed and feed, these two parameters have vital effect on machining process.
- A main effect occurs when the mean response changes across the levels of a factor main effect plots are used to compare the relative strength of the effects across factors.

6.3.1 OBSERVATION TABLE FOR HCS

A	B	C	D	E	F
(rpm)	feed(mm)	depth of cut(mm)	chip formation	temperature (°C)	mrr(mm ³ /min)
200	0.5	1	discontinuous	59	9956.84
200	0.5	1.5	discontinuous	46	14926.27
200	1	1	discontinuous	48	19917.69
200	1	1.5	discontinuous	43	29876.54
200	1	1.5	discontinuous	72	24897.12
500	0.5	1	discontinuous	63	37345.68
500	0.5	1.5	discontinuous	56	49794.24
500	1	1	discontinuous	67	74691.36
500	1	1.5			

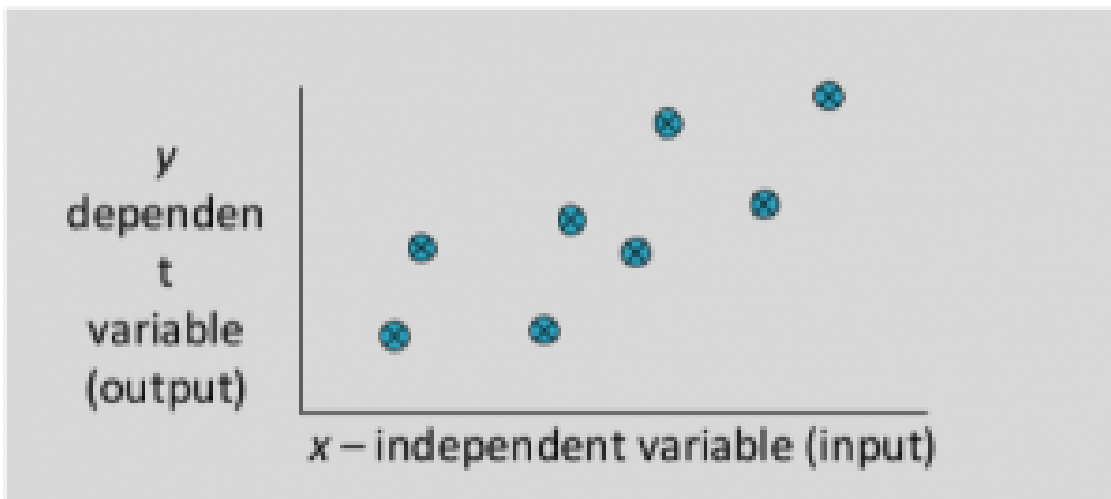
Minitab



6.4 REGRESSION MODEL ANALYSIS AND PLOTS:

Regression analysis is a form of predictive modelling technique which investigates the relationship between a dependent (target) and independent variable (s) (predictor). This technique is used for forecasting, time series modelling and finding the causal effect relationship between the variables.

Fig 6.1



6.5 REGRESSION ANALYSIS FOR EN-8(DRY CONDITION):

6.5.1 Response Surface Regression: temperature (°C) versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-
Value						
Model	6	895.50	87.49%	895.500	149.250	
1.17						
Linear	3	847.00	82.76%	847.000	282.333	
2.21						
Speed(rpm)	1	840.50	82.12%	840.500	840.500	
6.57						
feed(mm)	1	4.50	0.44%	4.500	4.500	
0.04						
depth of cut(mm)	1	2.00	0.20%	2.000	2.000	
0.02						
2-Way Interaction	3	48.50	4.74%	48.500	16.167	
0.13						
Speed(rpm)*feed(mm)	1	40.50	3.96%	40.500	40.500	
0.32						
Speed(rpm)*depth of cut(mm)	1	0.00	0.00%	0.000	0.000	
0.00						
feed(mm)*depth of cut(mm)	1	8.00	0.78%	8.000	8.000	
0.06						
Error	1	128.00	12.51%	128.000	128.000	
Total	7	1023.50	100.00%			

Source	P-Value
Model	0.610
Linear	0.451
Speed(rpm)	0.237
feed(mm)	0.882
depth of cut(mm)	0.921
2-Way Interaction	0.933
Speed(rpm)*feed(mm)	0.674
Speed(rpm)*depth of cut(mm)	1.000
feed(mm)*depth of cut(mm)	0.844
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
11.3137	87.49%	12.46%	8192	0.00%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Value						
Constant		54.25	4.00	(3.43, 105.07)	13.56	
0.047						
Speed(rpm)	20.50	10.25	4.00	(-40.57, 61.07)	2.56	
0.237 1.00						

feed(mm)	-1.50	-0.75	4.00	(-51.57, 50.07)	-0.19
0.882 1.00					
depth of cut(mm)	1.00	0.50	4.00	(-50.32, 51.32)	0.12
0.921 1.00					
Speed (rpm)*feed(mm)	-4.50	-2.25	4.00	(-53.07, 48.57)	-0.56
0.674 1.00					
Speed (rpm)*depth of cut(mm)	0.00	0.00	4.00	(-50.82, 50.82)	0.00
1.000 1.00					
feed(mm)*depth of cut(mm)	2.00	1.00	4.00	(-49.82, 51.82)	0.25
0.844 1.00					

Regression Equation in Uncoded Units

$$\begin{aligned} \text{temperature } (^{\circ}\text{C}) = & 29.3 + 0.113 \text{ Speed(rpm)} - 2.0 \text{ feed(mm)} - 10.0 \text{ depth of cut(mm)} \\ & - 0.060 \text{ Speed(rpm)*feed(mm)} + 0.000 \text{ Speed(rpm)*depth of cut(mm)} \\ & + 16.0 \text{ feed(mm)*depth of cut(mm)} \end{aligned}$$

6.5.2 Normplot of Residuals for temperature ($^{\circ}\text{C}$)

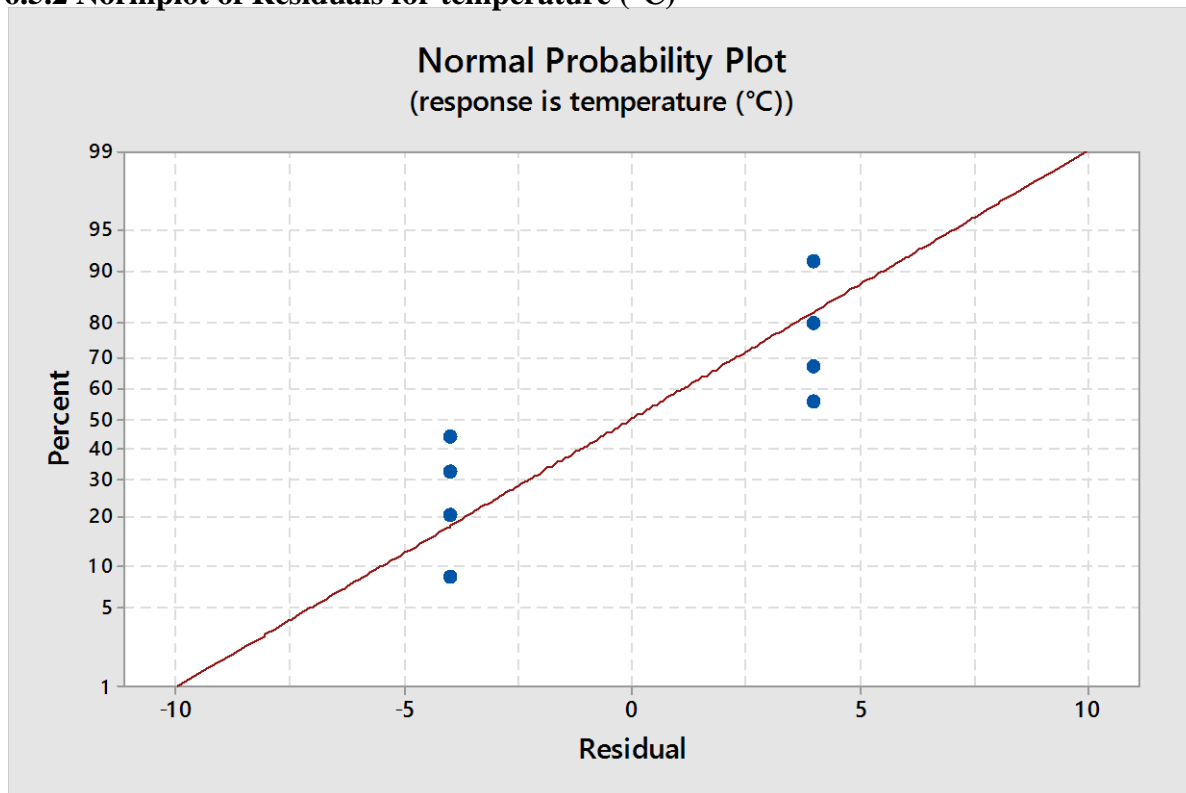
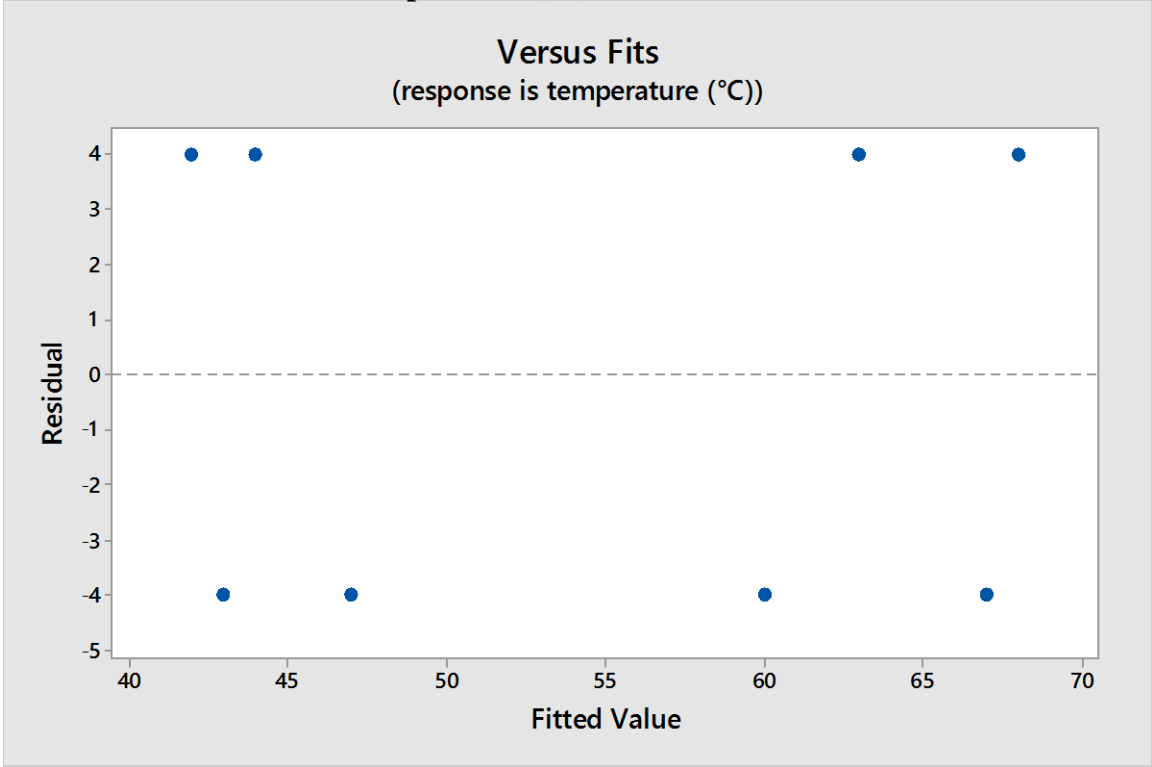


Fig 6.2

6.5.3 Residuals vs Fits for temperature (°C)



6.5.4 Residual Histogram for temperature (°C)

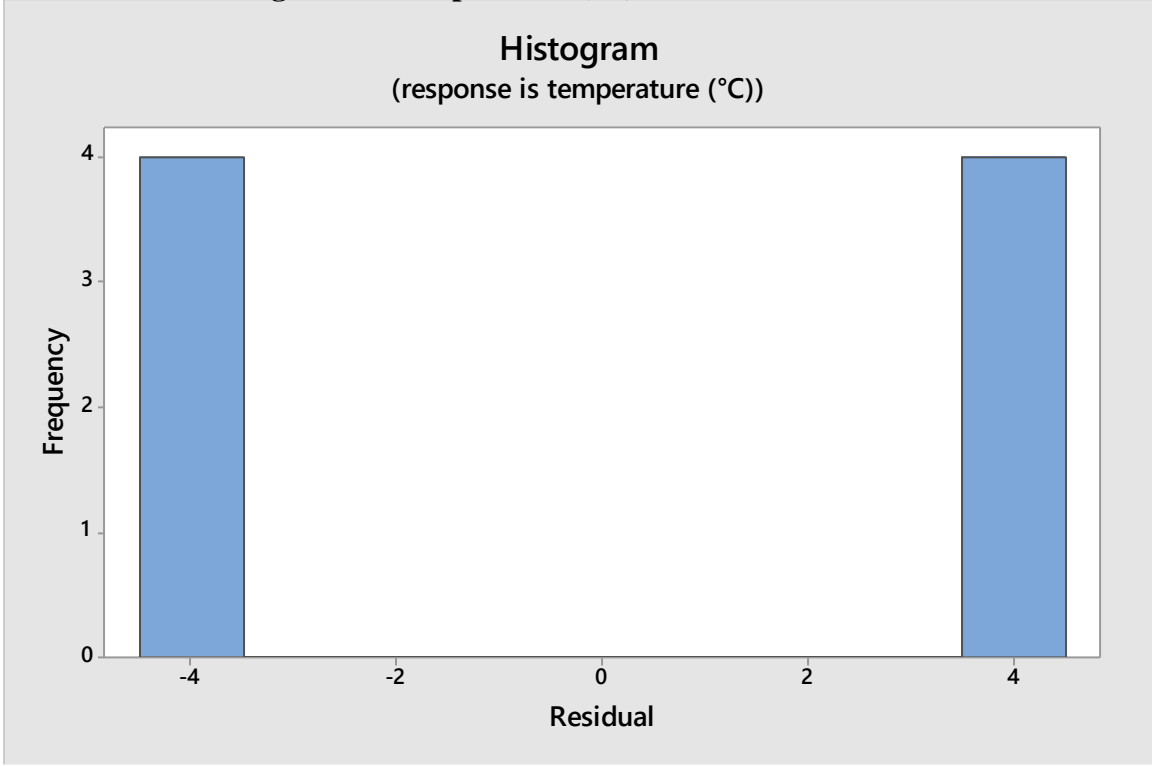
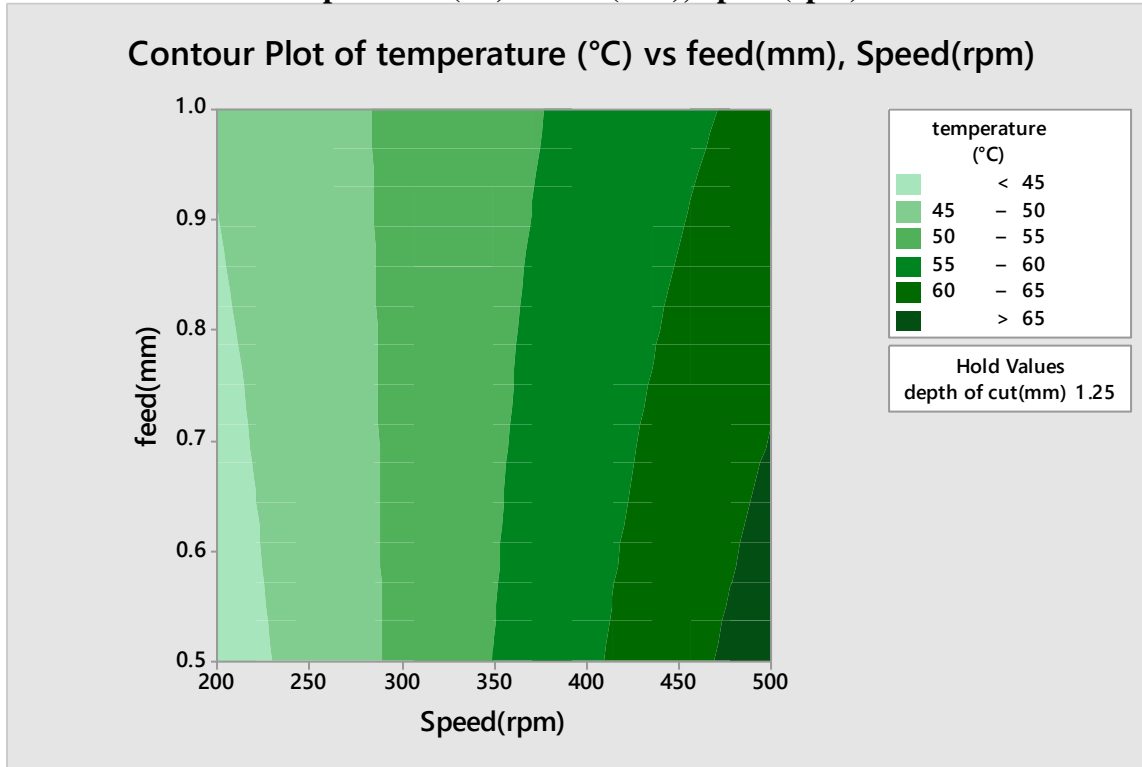


Fig 6.3

6.6 Contour Plot of temperature (°C) vs feed(mm), Speed(rpm)



Contour Plot of temperature (°C) vs depth of cut(mm), Speed(rpm)

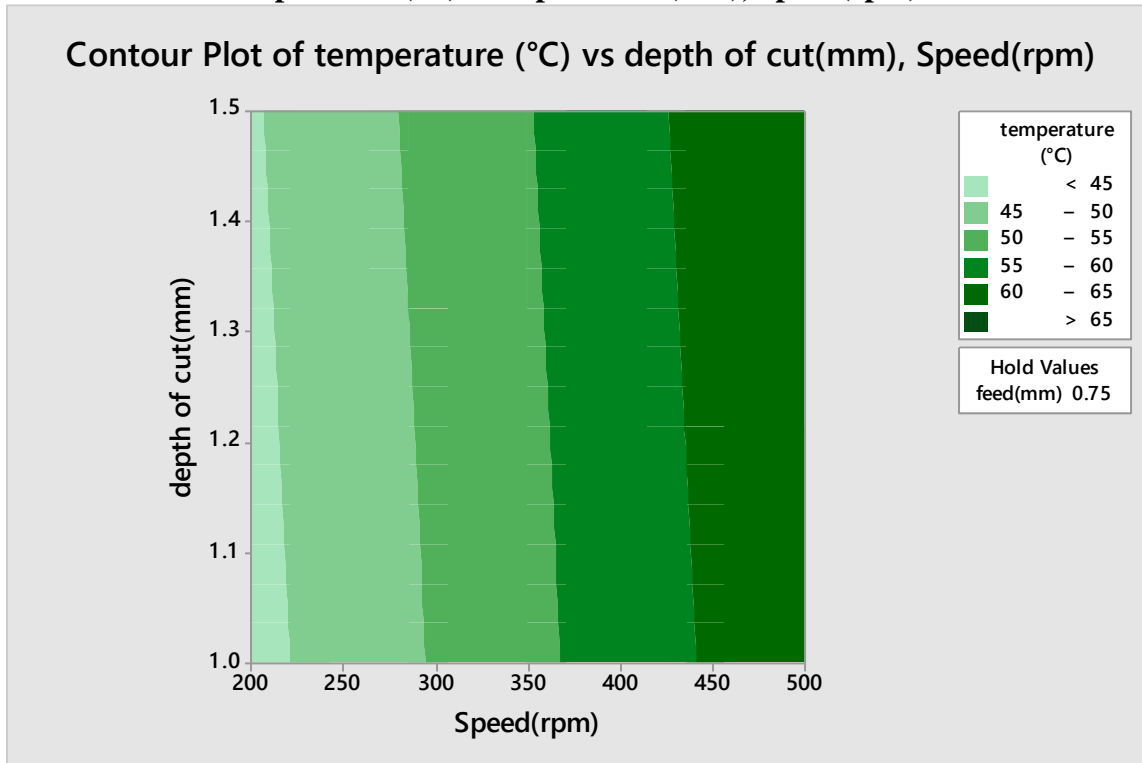
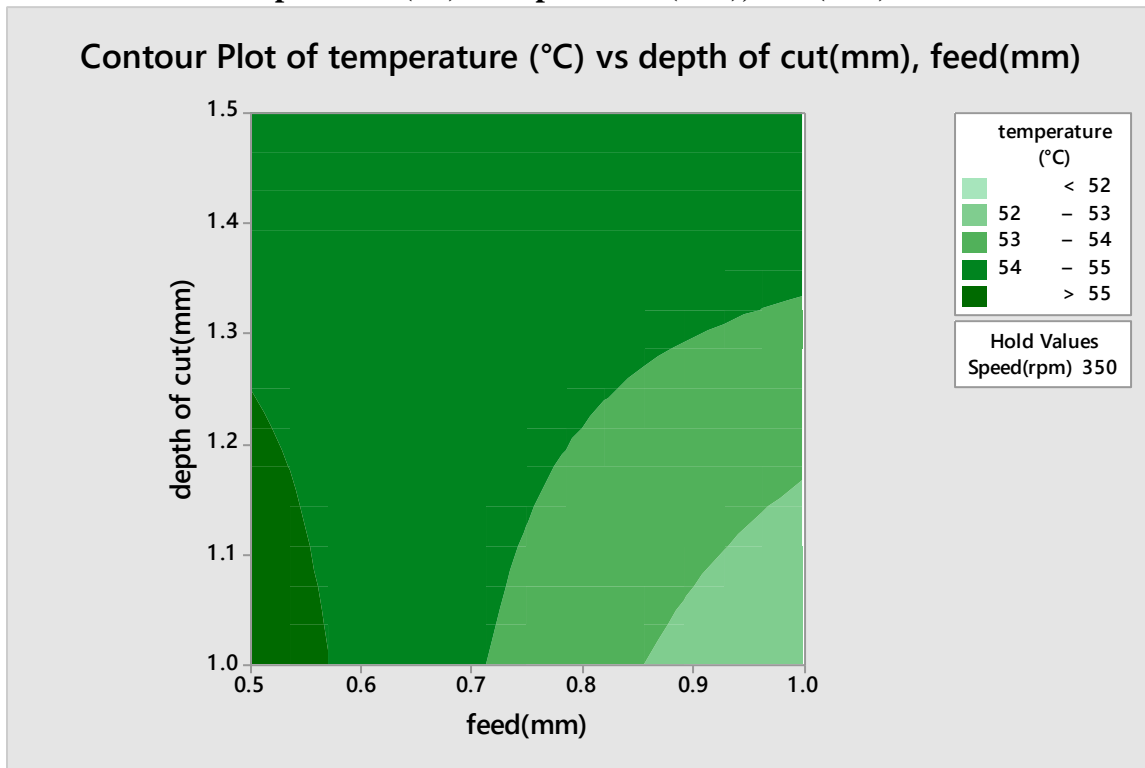


Fig 6.4

Contour Plot of temperature (°C) vs depth of cut(mm), feed(mm)



6.7 Surface Plot of temperature (°C) vs feed(mm), Speed(rpm)

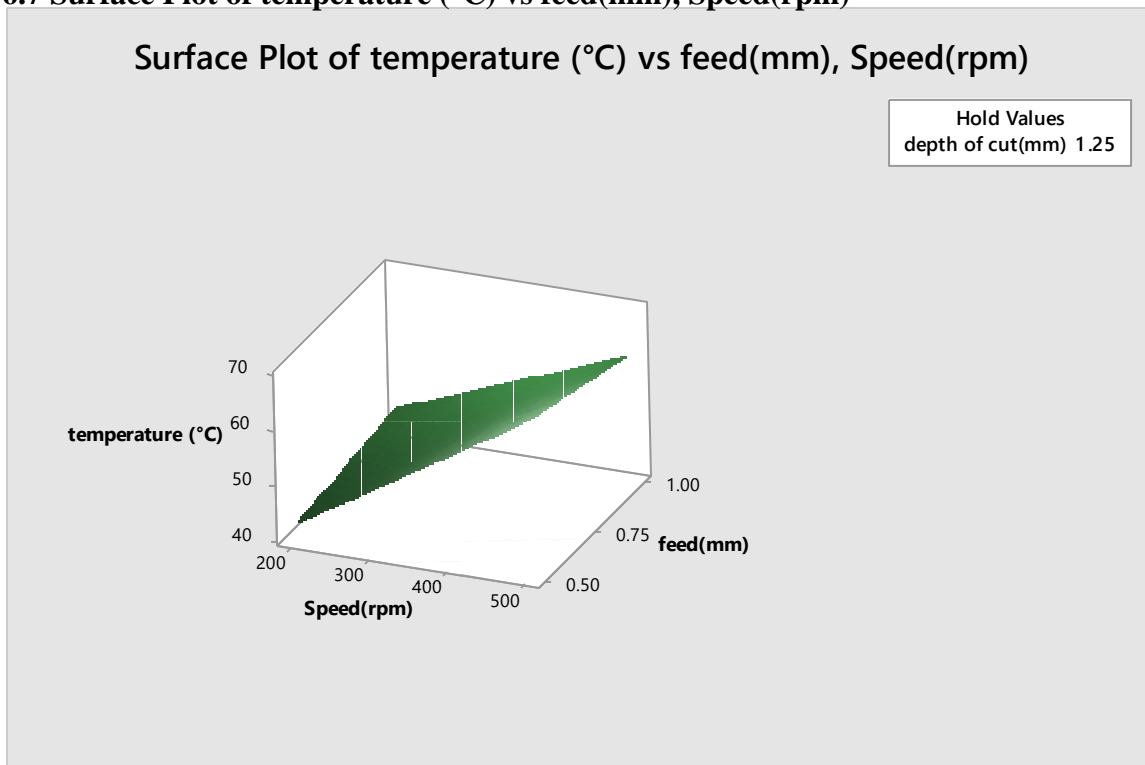
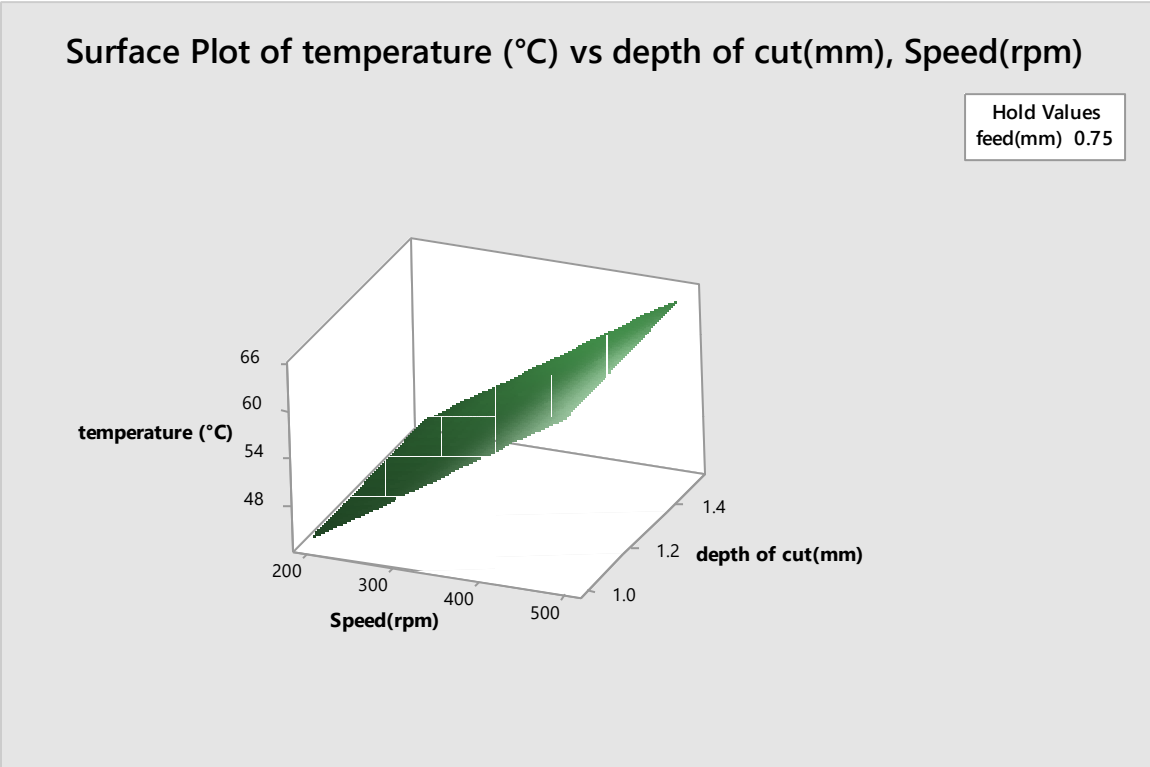


Fig 6.5

Surface Plot of temperature (°C) vs depth of cut(mm), Speed(rpm)



Surface Plot of temperature (°C) vs depth of cut(mm), feed(mm)

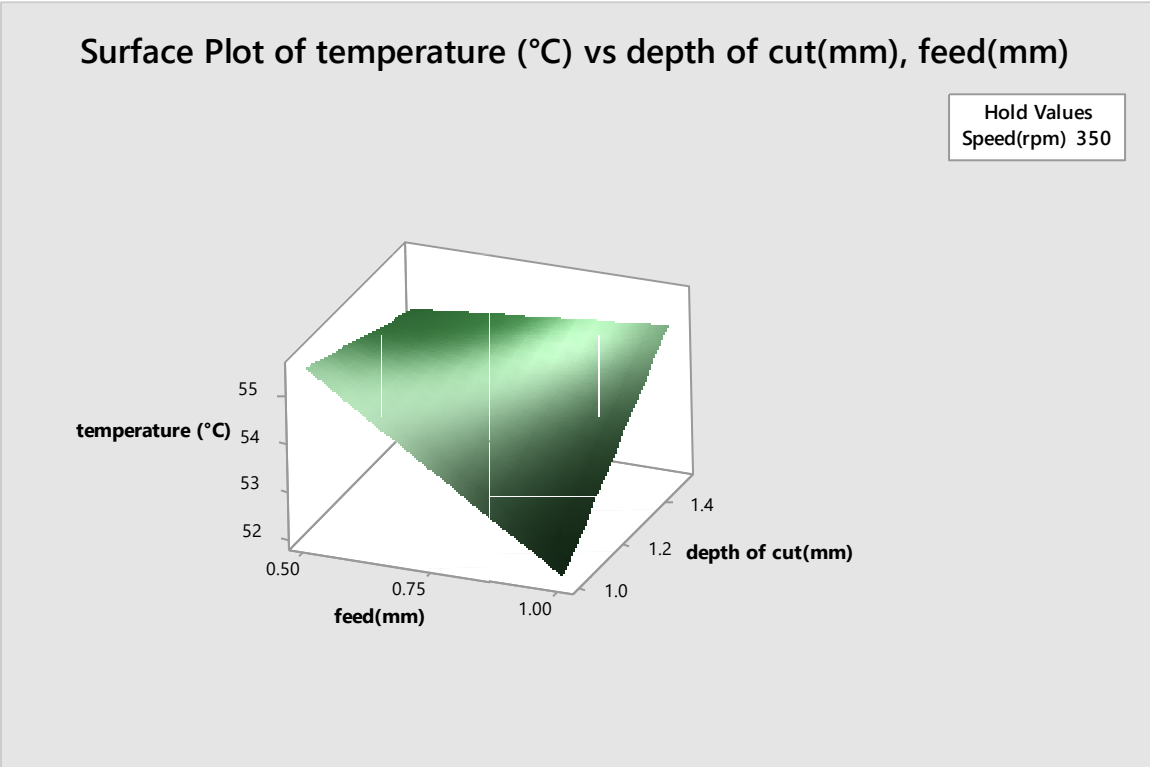


Fig 6.6

6.8 Response Surface Regression: chip thickness r versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-
Value						
Model	6	0.013514	71.79%	0.013514	0.002252	
0.42						
Linear	3	0.003791	20.14%	0.003791	0.001264	
0.24						
Speed(rpm)	1	0.001990	10.57%	0.001990	0.001990	
0.37						
feed(mm)	1	0.000876	4.65%	0.000876	0.000876	
0.16						
depth of cut(mm)	1	0.000925	4.92%	0.000925	0.000925	
0.17						
2-Way Interaction	3	0.009724	51.66%	0.009724	0.003241	
0.61						
Speed(rpm)*feed(mm)	1	0.002372	12.60%	0.002372	0.002372	
0.45						
Speed(rpm)*depth of cut(mm)	1	0.003754	19.94%	0.003754	0.003754	
0.71						
feed(mm)*depth of cut(mm)	1	0.003597	19.11%	0.003597	0.003597	
0.68						
Error	1	0.005310	28.21%	0.005310	0.005310	
Total	7	0.018824	100.00%			

Source	P-Value
Model	0.824
Linear	0.867
Speed(rpm)	0.650
feed(mm)	0.754
depth of cut(mm)	0.748
2-Way Interaction	0.709
Speed(rpm)*feed(mm)	0.625
Speed(rpm)*depth of cut(mm)	0.555
feed(mm)*depth of cut(mm)	0.562
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.0728674	71.79%	0.00%	0.339818	0.00%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Value						
Constant		0.0504	0.0258	(-0.2770, 0.3777)	1.95	
0.301						
Speed(rpm)	-0.0315	-0.0158	0.0258	(-0.3431, 0.3116)	-0.61	
0.650						

feed (mm)	0.0209	0.0105	0.0258	(-0.3169, 0.3378)	0.41
0.754					
depth of cut (mm)	0.0215	0.0108	0.0258	(-0.3166, 0.3381)	0.42
0.748					
Speed (rpm) * feed (mm)	-0.0344	-0.0172	0.0258	(-0.3446, 0.3101)	-0.67
0.625					
Speed (rpm) * depth of cut (mm)	-0.0433	-0.0217	0.0258	(-0.3490, 0.3057)	-0.84
0.555					
feed (mm) * depth of cut (mm)	0.0424	0.0212	0.0258	(-0.3061, 0.3485)	0.82
0.562					

Term	VIF
Constant	
Speed (rpm)	1.00
feed (mm)	1.00
depth of cut (mm)	1.00
Speed (rpm) * feed (mm)	1.00
Speed (rpm) * depth of cut (mm)	1.00
feed (mm) * depth of cut (mm)	1.00

Regression Equation in Uncoded Units

$$\begin{aligned} \text{chip thickness ratio} = & -0.053 + 0.00096 \text{ Speed (rpm)} - 0.222 \text{ feed (mm)} - \\ & 0.009 \text{ depth of cut (mm)} - 0.000459 \text{ Speed (rpm) * feed (mm)} - \\ & 0.000578 \text{ Speed (rpm) * depth of cut (mm)} + \\ & 0.339 \text{ feed (mm) * depth of cut (mm)} \end{aligned}$$

6.8.1 Normplot of Residuals for chip thickness ratio

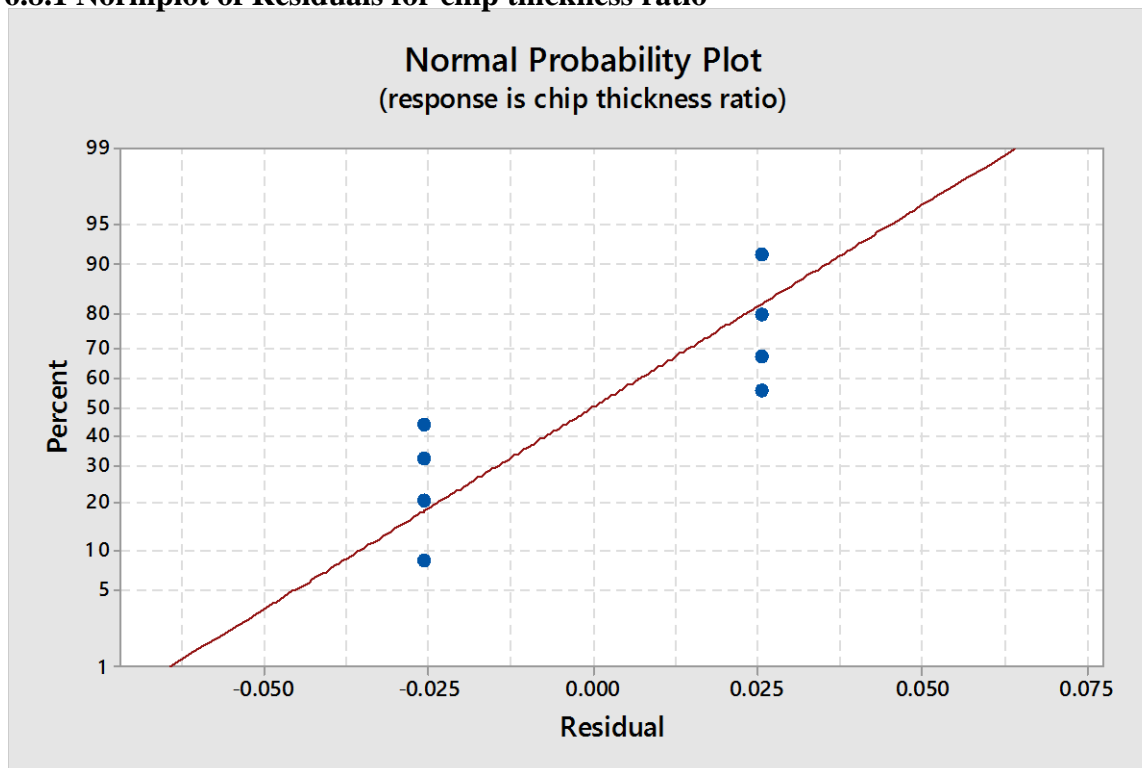
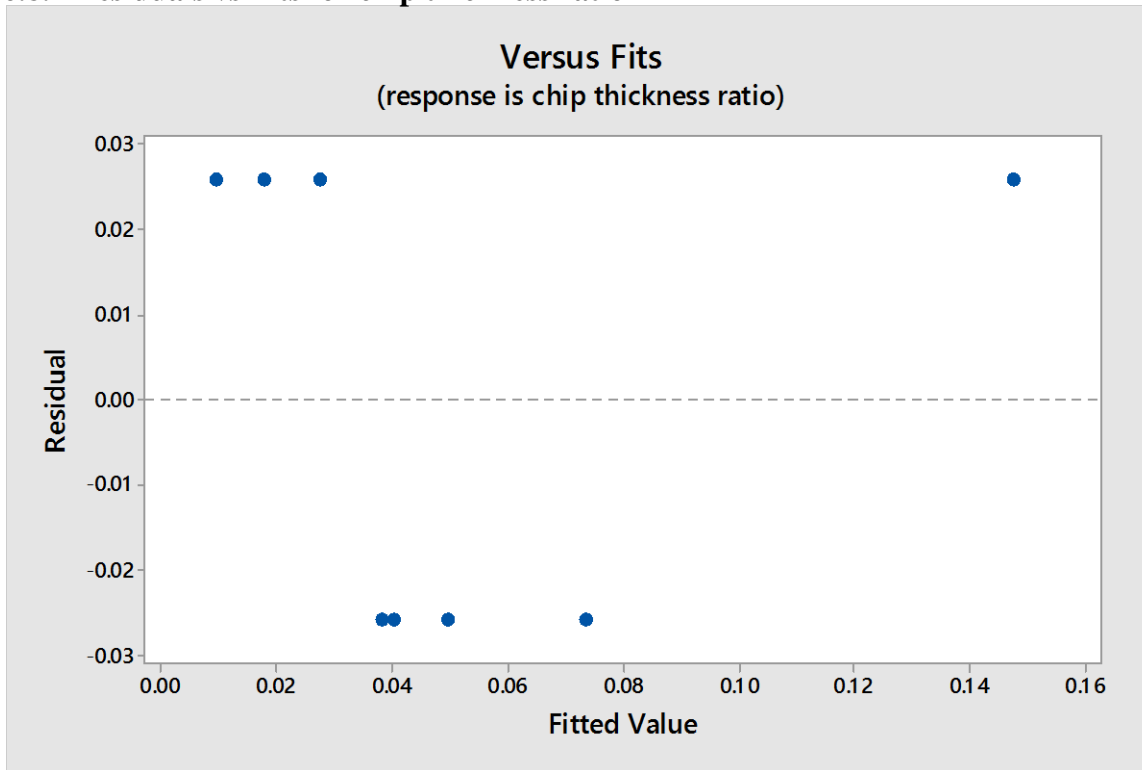


Fig 6.7

6.8.2 Residuals vs Fits for chip thickness ratio



6.8.3 Residual Histogram for chip thickness ratio

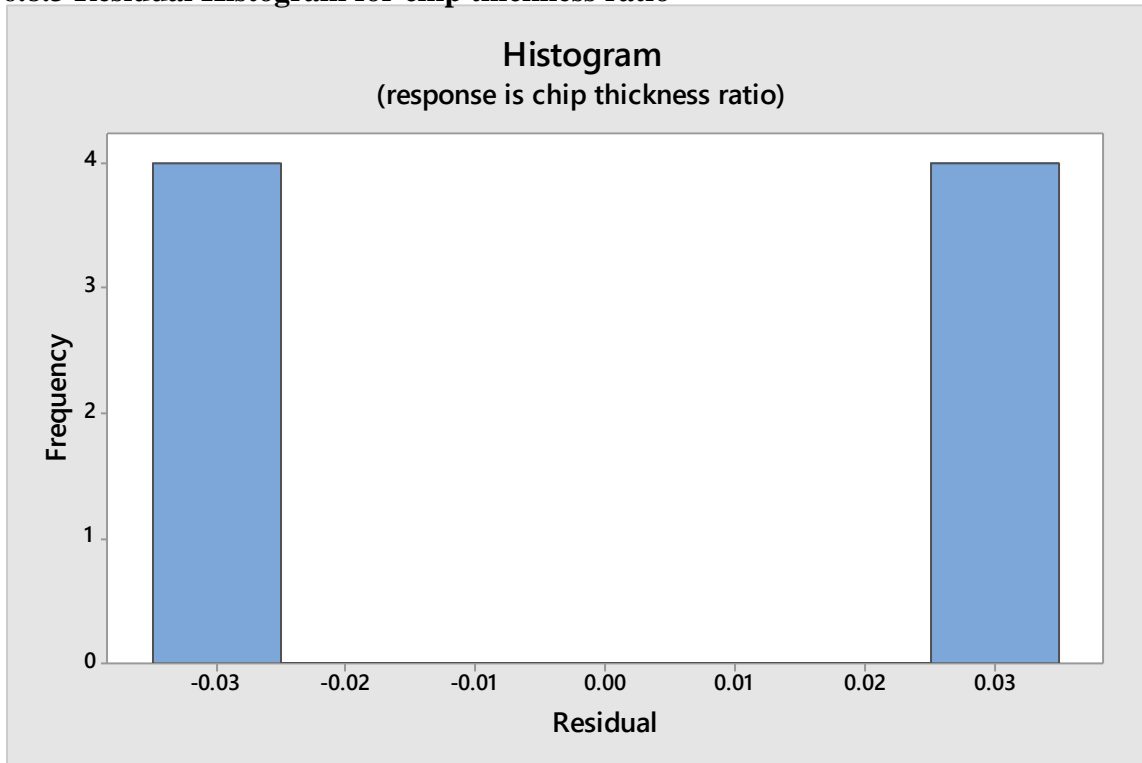
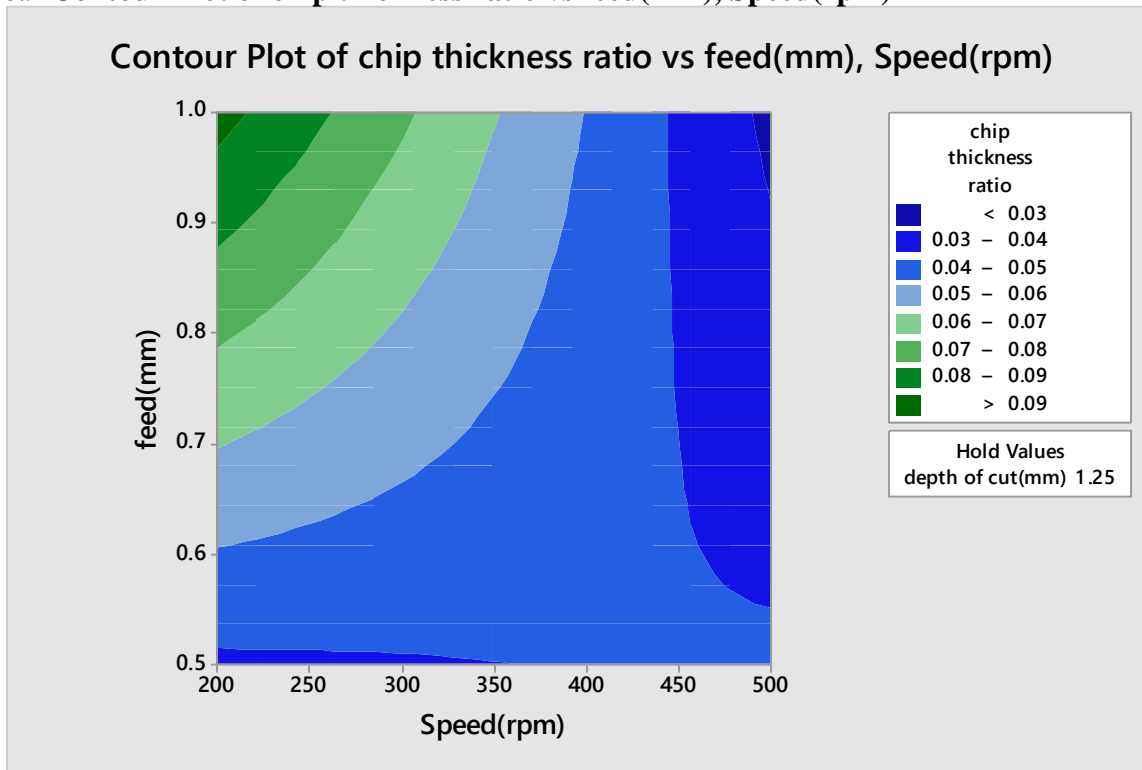


Fig 6.8

6.9 Contour Plot of chip thickness ratio vs feed(mm), Speed(rpm)



Contour Plot of chip thickness ratio vs depth of cut(mm), Speed(rpm)

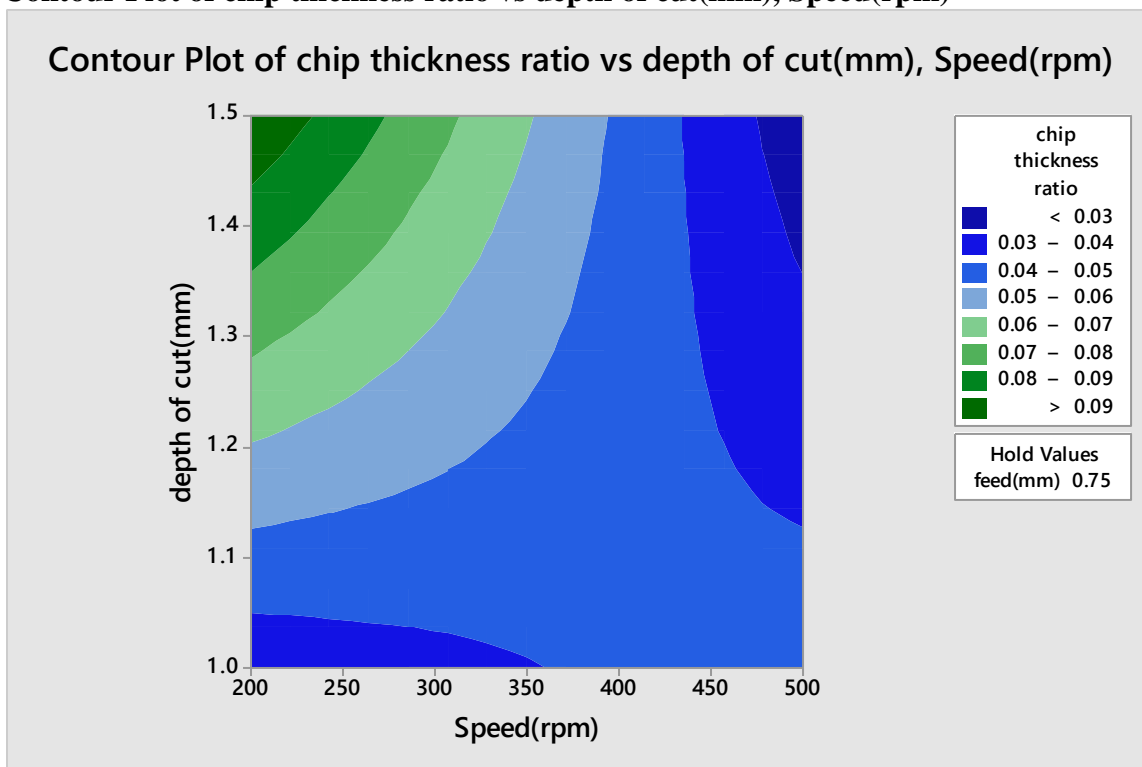
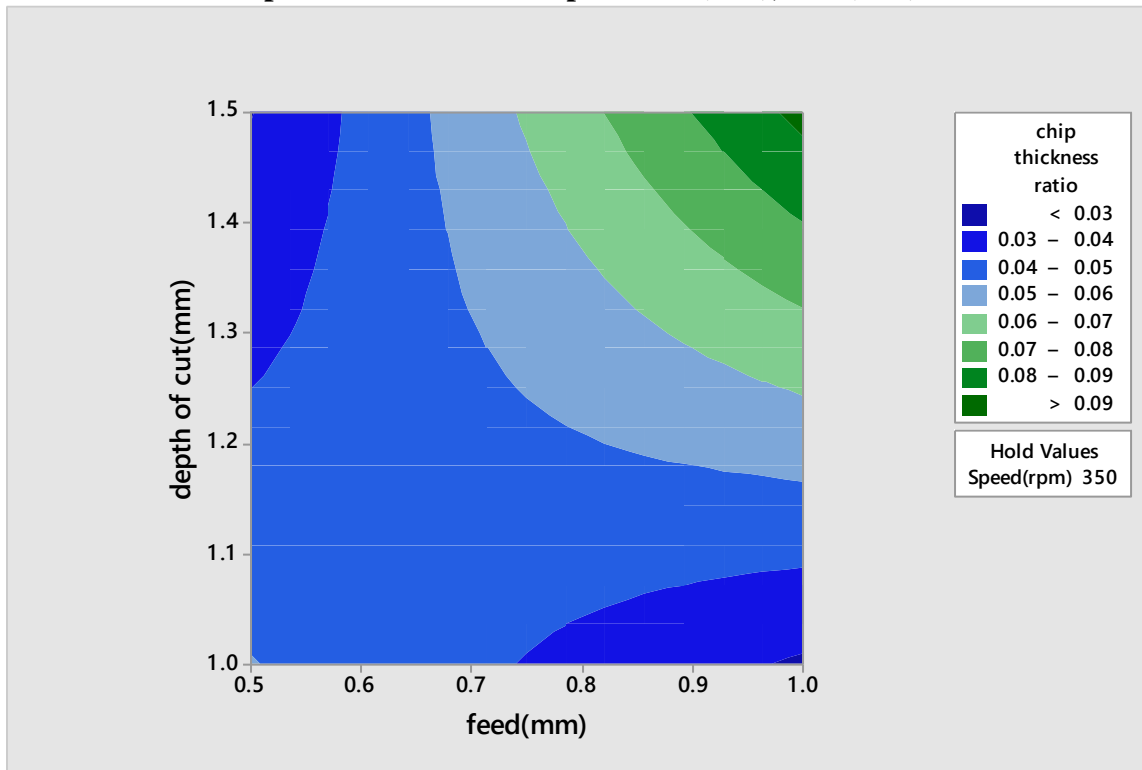


Fig 6.9

Contour Plot of chip thickness ratio vs depth of cut(mm), feed(mm)



6.10 Surface Plot of chip thickness ratio vs feed(mm), Speed(rpm)

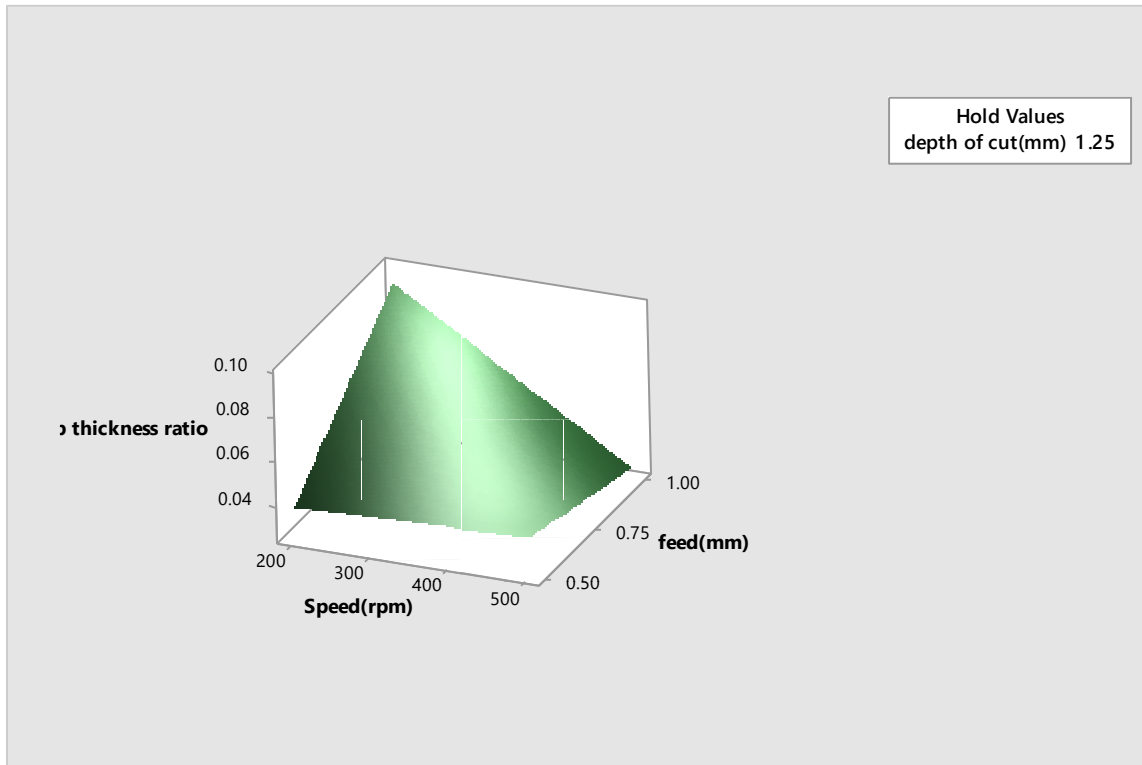
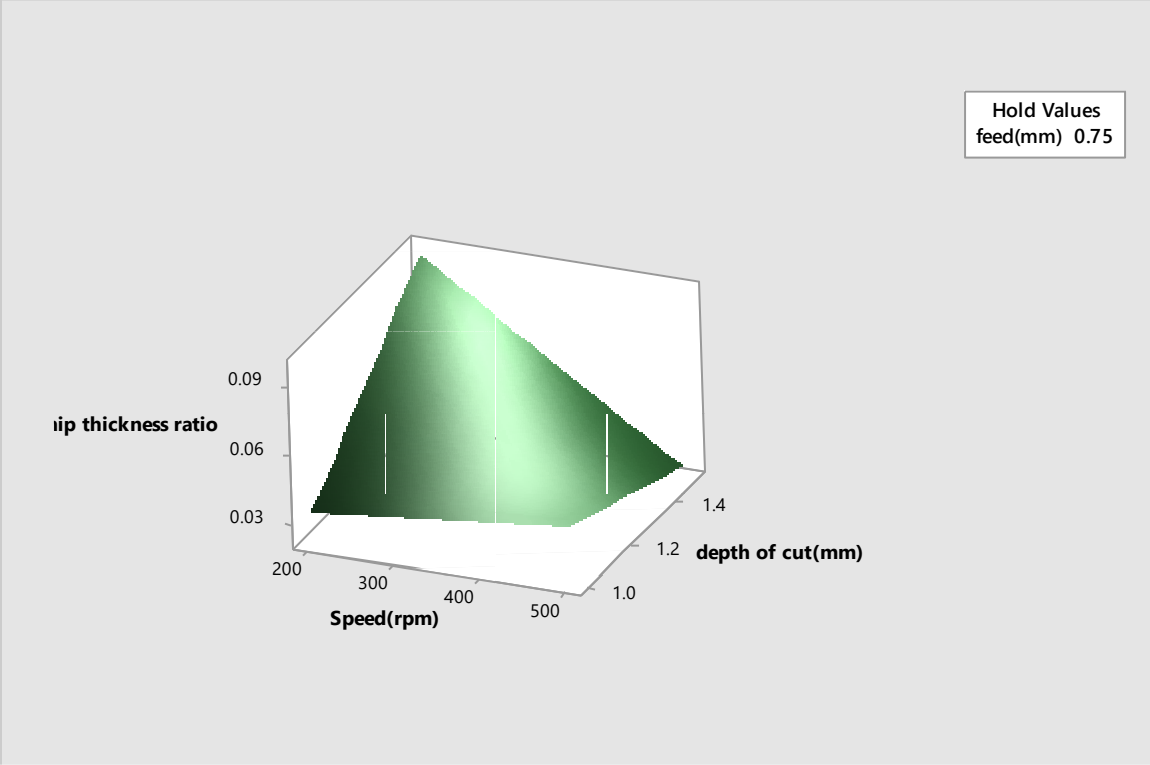


Fig 6.10

Surface Plot of chip thickness ratio vs depth of cut(mm), Speed(rpm)



Surface Plot of chip thickness ratio vs depth of cut(mm), feed(mm)

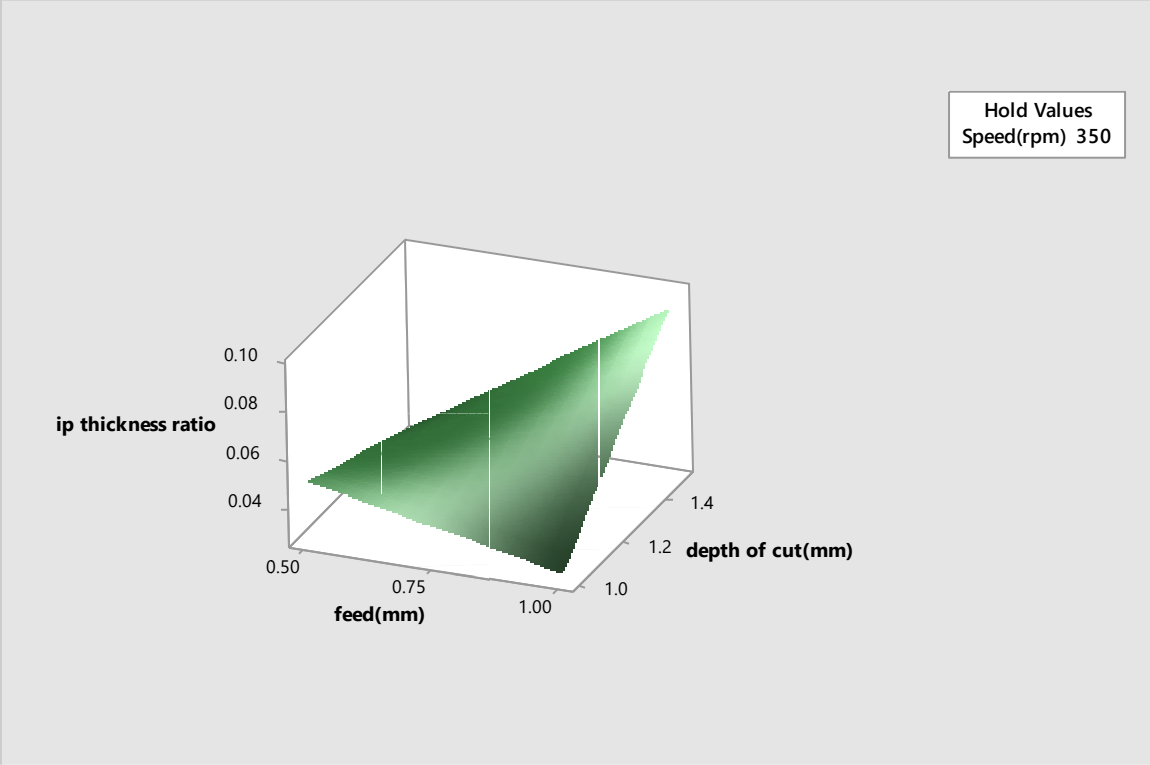


Fig 6.11

6.11 Response Surface Regression: shear angle versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Model	6	322.655	99.78%	322.655	53.776	75.31
Linear	3	163.864	50.67%	163.864	54.621	76.50
Speed (rpm)	1	1.118	0.35%	1.118	1.118	1.57
feed (mm)	1	159.222	49.24%	159.222	159.222	223.00
depth of cut (mm)	1	3.525	1.09%	3.525	3.525	4.94
2-Way Interaction	3	158.791	49.11%	158.791	52.930	74.13
Speed (rpm) *feed (mm)	1	43.013	13.30%	43.013	43.013	60.24
Speed (rpm) *depth of cut (mm)	1	43.478	13.45%	43.478	43.478	60.89
feed (mm) *depth of cut (mm)	1	72.300	22.36%	72.300	72.300	101.26
Error	1	0.714	0.22%	0.714	0.714	
Total	7	323.369	100.00%			

Source	P-Value
Model	0.088
Linear	0.084
Speed (rpm)	0.429
feed (mm)	0.043
depth of cut (mm)	0.269
2-Way Interaction	0.085
Speed (rpm) *feed (mm)	0.082
Speed (rpm) *depth of cut (mm)	0.081
feed (mm) *depth of cut (mm)	0.063
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.844993	99.78%	98.45%	45.6968	85.87%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Value						
Constant		79.206	0.299	(75.410, 83.002)	265.13	
0.002						
Speed (rpm)	-0.747	-0.374	0.299	(-4.170, 3.422)	-1.25	
0.429						
feed (mm)	8.922	4.461	0.299	(0.665, 8.257)	14.93	
0.043						
depth of cut (mm)	-1.327	-0.664	0.299	(-4.460, 3.132)	-2.22	
0.269						
Speed (rpm) *feed (mm)	-4.638	-2.319	0.299	(-6.115, 1.477)	-7.76	
0.082						
Speed (rpm) *depth of cut (mm)	4.662	2.331	0.299	(-1.465, 6.127)	7.80	
0.081						
feed (mm) *depth of cut (mm)	6.012	3.006	0.299	(-0.790, 6.802)	10.06	
0.063						

Term	VIF
Constant	
Speed (rpm)	1.00
feed (mm)	1.00
depth of cut (mm)	1.00
Speed (rpm) * feed (mm)	1.00
Speed (rpm) * depth of cut (mm)	1.00
feed (mm) * depth of cut (mm)	1.00

Regression Equation in Uncoded Units

$$\begin{aligned} \text{shear angle} = & 126.07 - 0.0338 \text{ Speed (rpm)} - 20.64 \text{ feed (mm)} - 60.49 \text{ depth of cut (mm)} \\ & - 0.06183 \text{ Speed (rpm) * feed (mm)} + 0.06217 \text{ Speed (rpm) * depth of cut (mm)} \\ & + 48.10 \text{ feed (mm) * depth of cut (mm)} \end{aligned}$$

6.11.1 Normplot of Residuals for shear angle

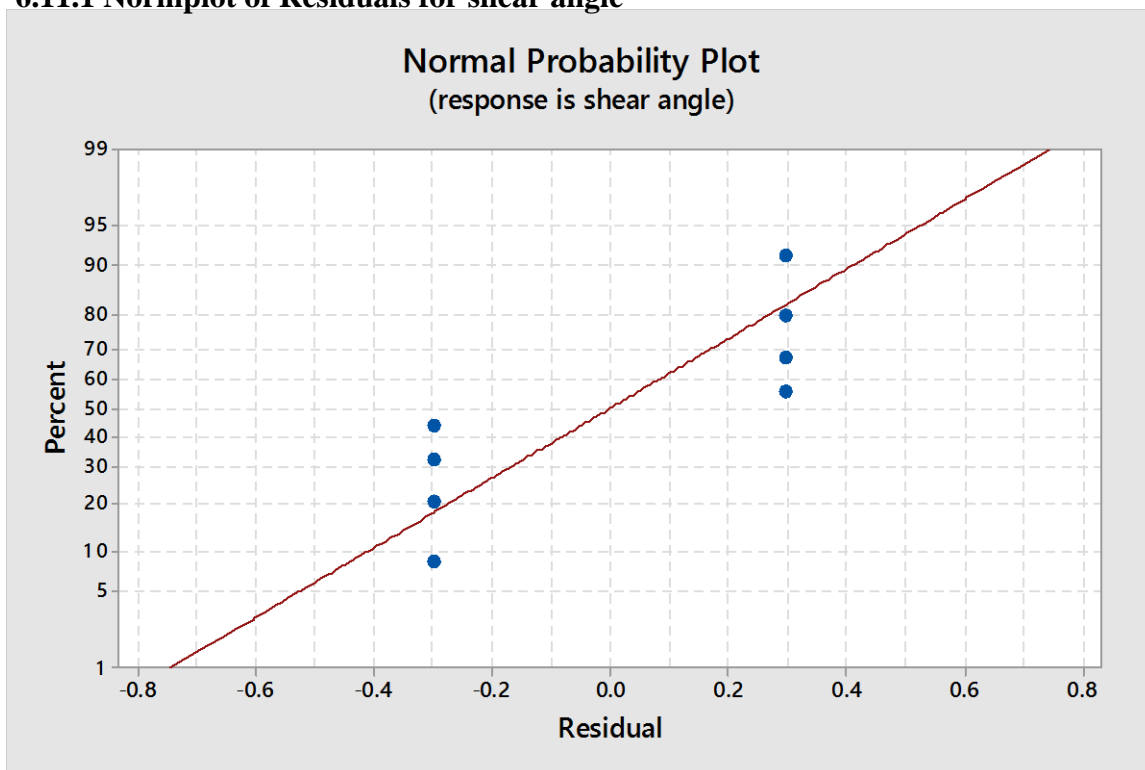
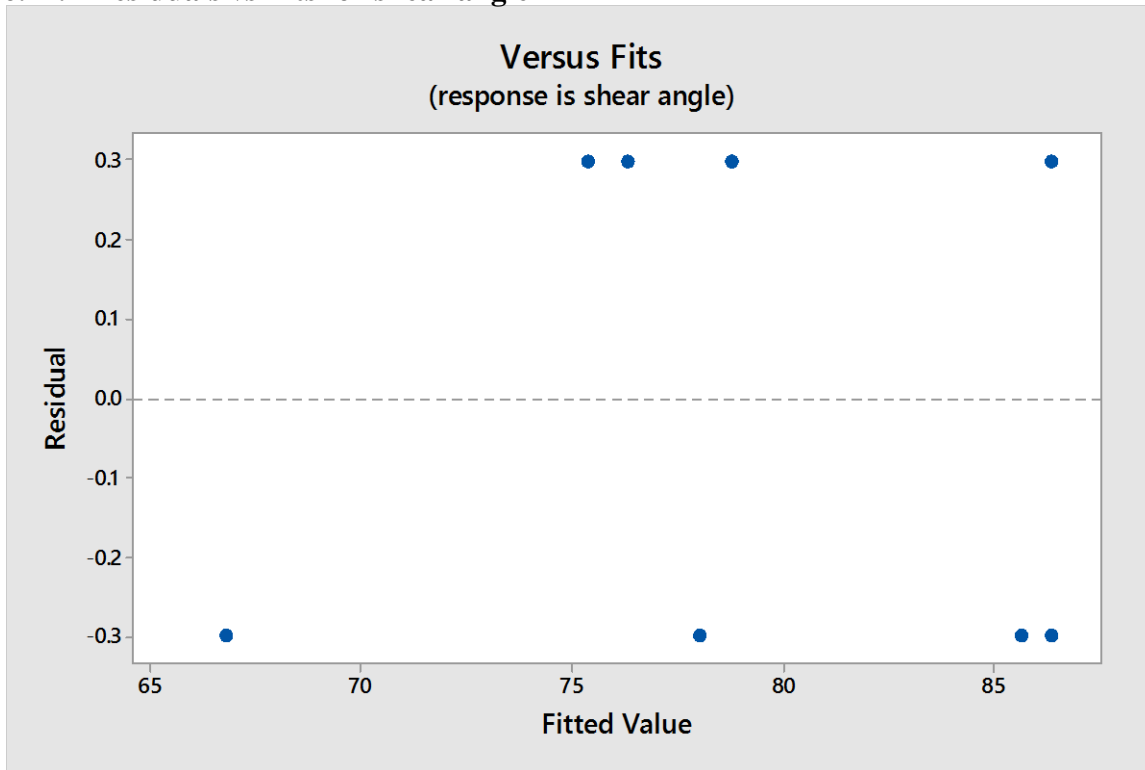


Fig 6.12

6.11.2 Residuals vs Fits for shear angle



6.11.3 Residual Histogram for shear angle

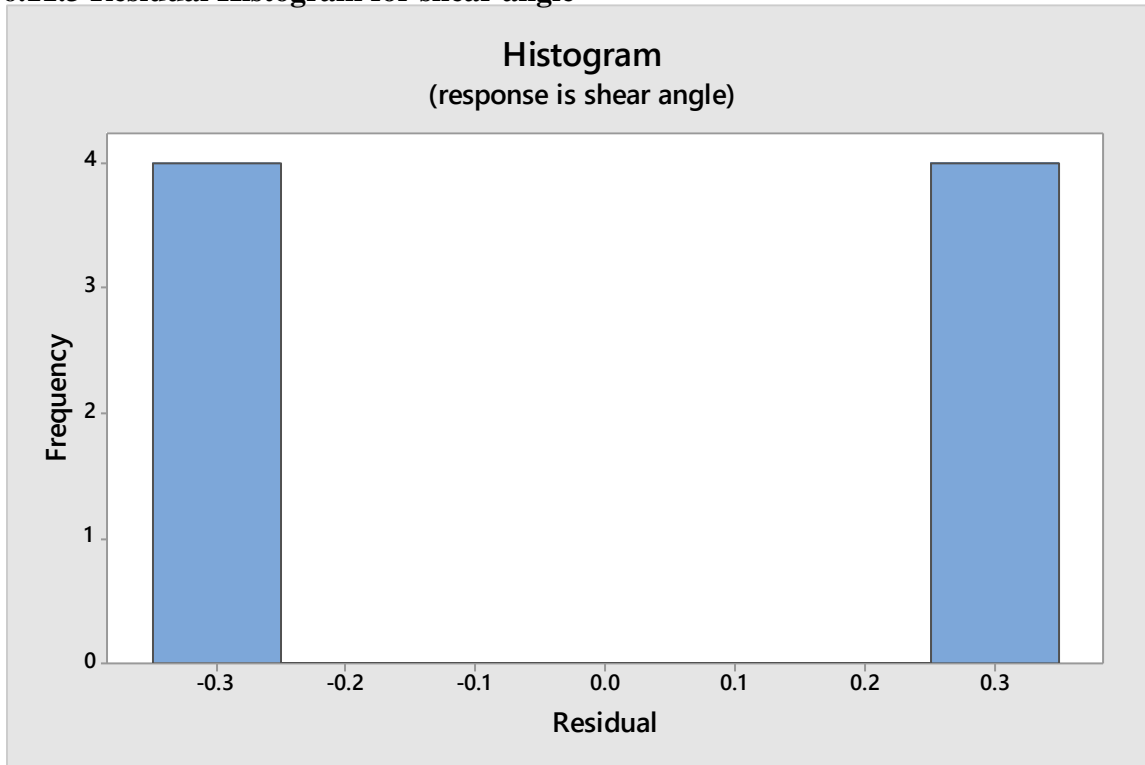
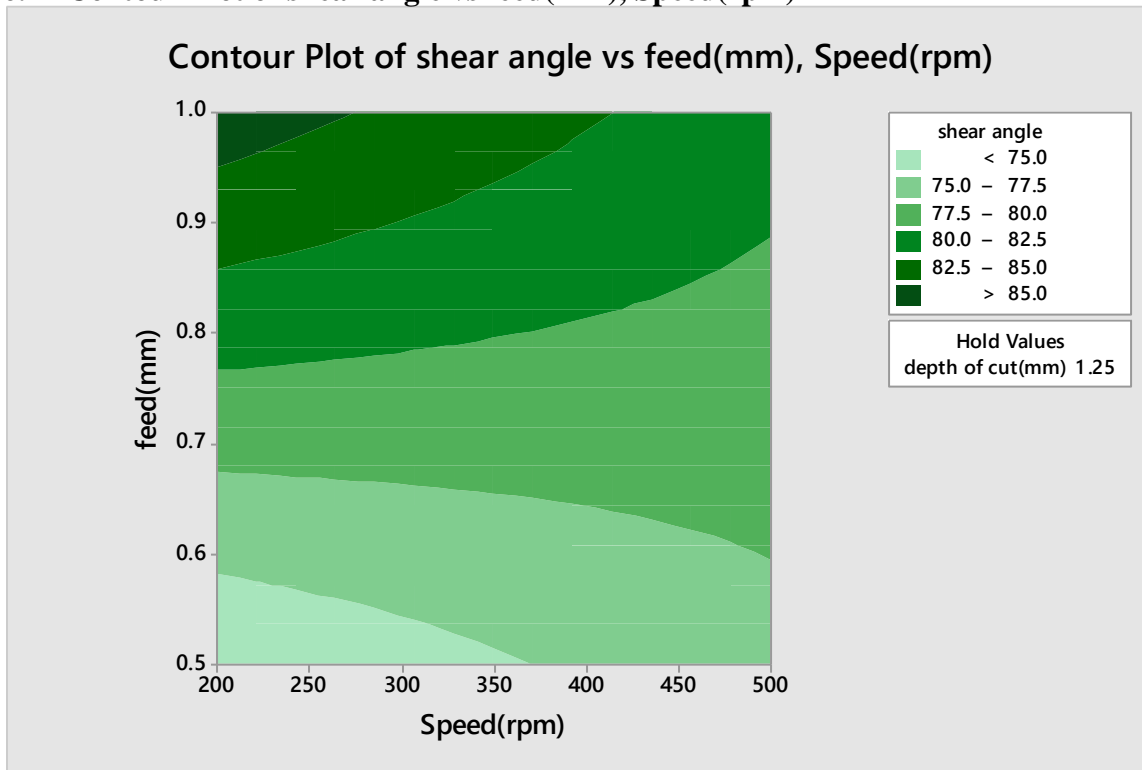


Fig 6.13

6.12 Contour Plot of shear angle vs feed(mm), Speed(rpm)



Contour Plot of shear angle vs depth of cut(mm), Speed(rpm)

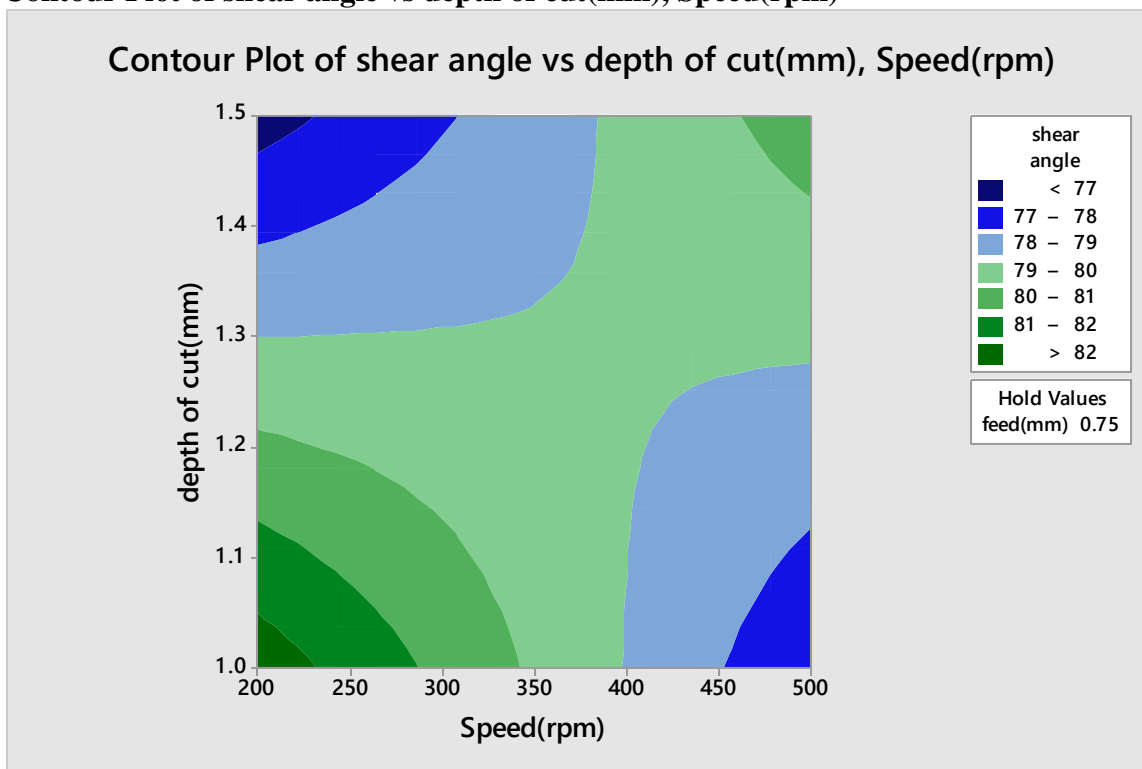
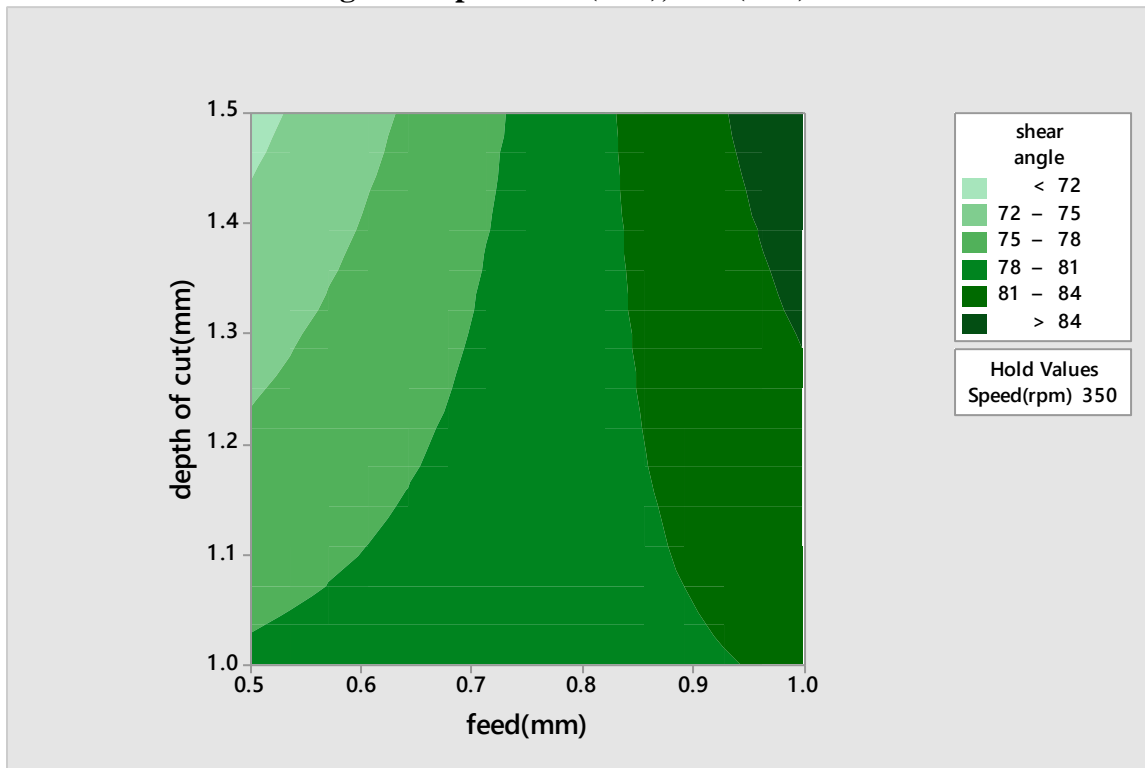


Fig 6.14

Contour Plot of shear angle vs depth of cut(mm), feed(mm)



6.13 Surface Plot of shear angle vs feed(mm), Speed(rpm)

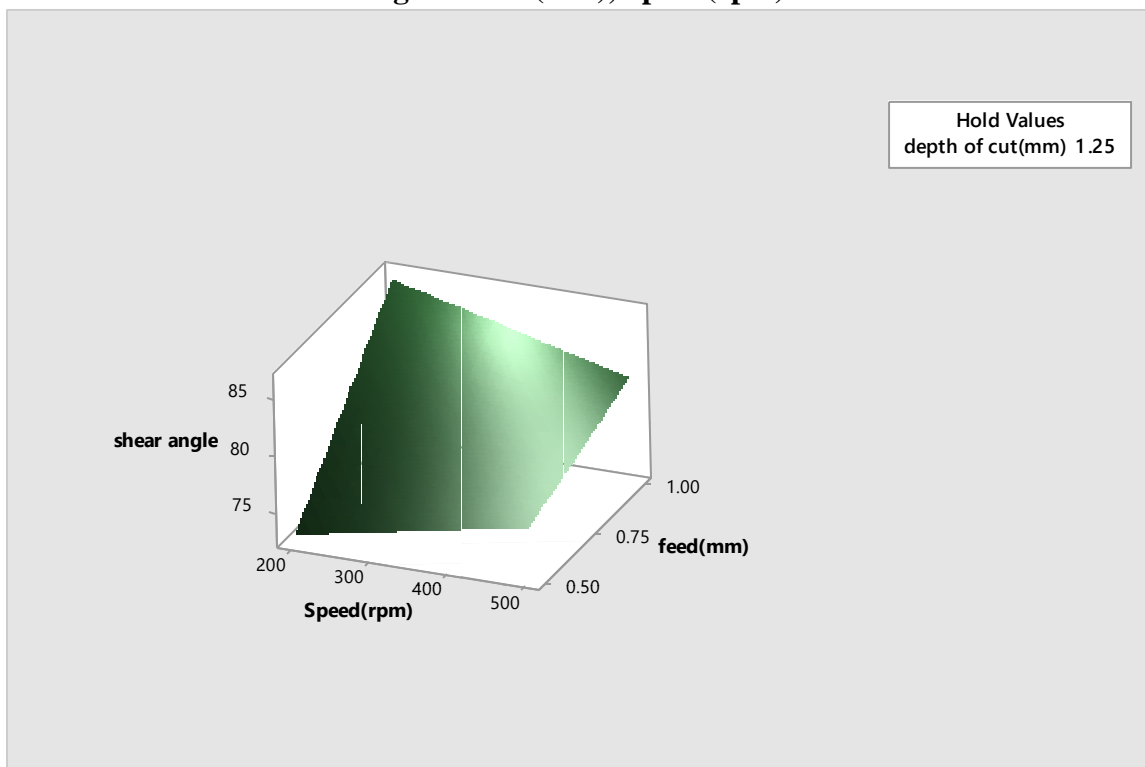
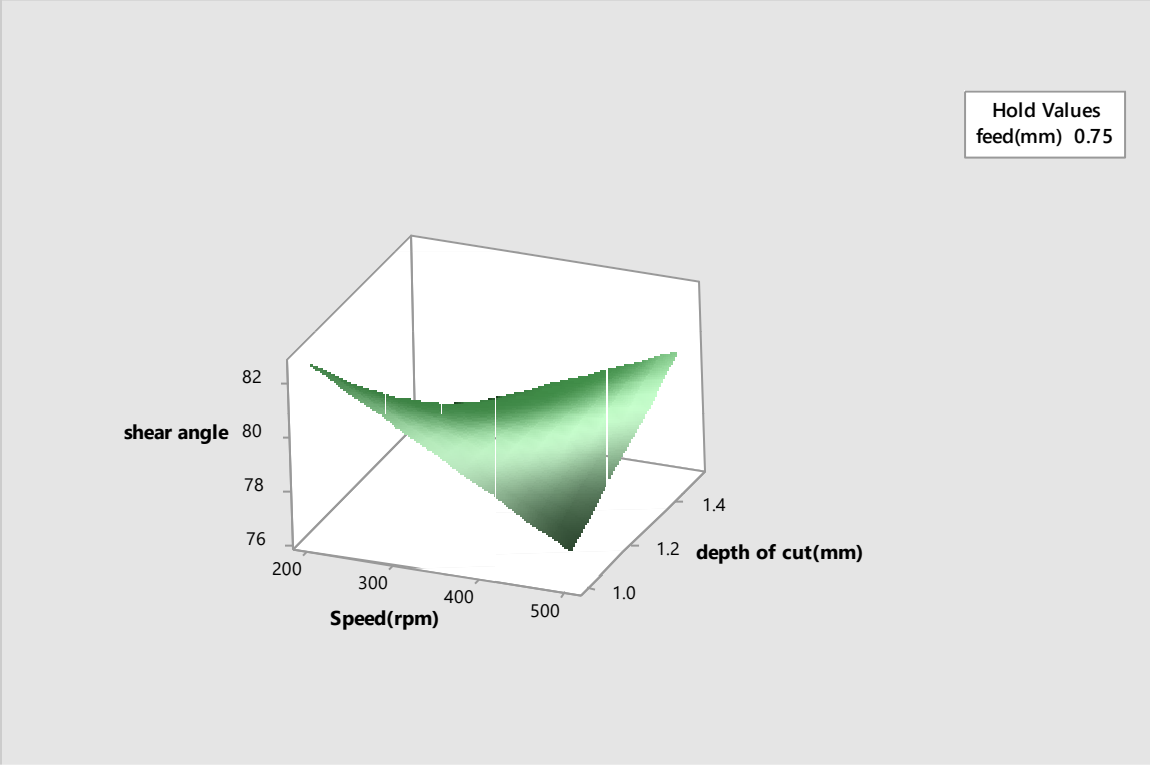


Fig 6.15

Surface Plot of shear angle vs depth of cut(mm), Speed(rpm)



Surface Plot of shear angle vs depth of cut(mm), feed(mm)

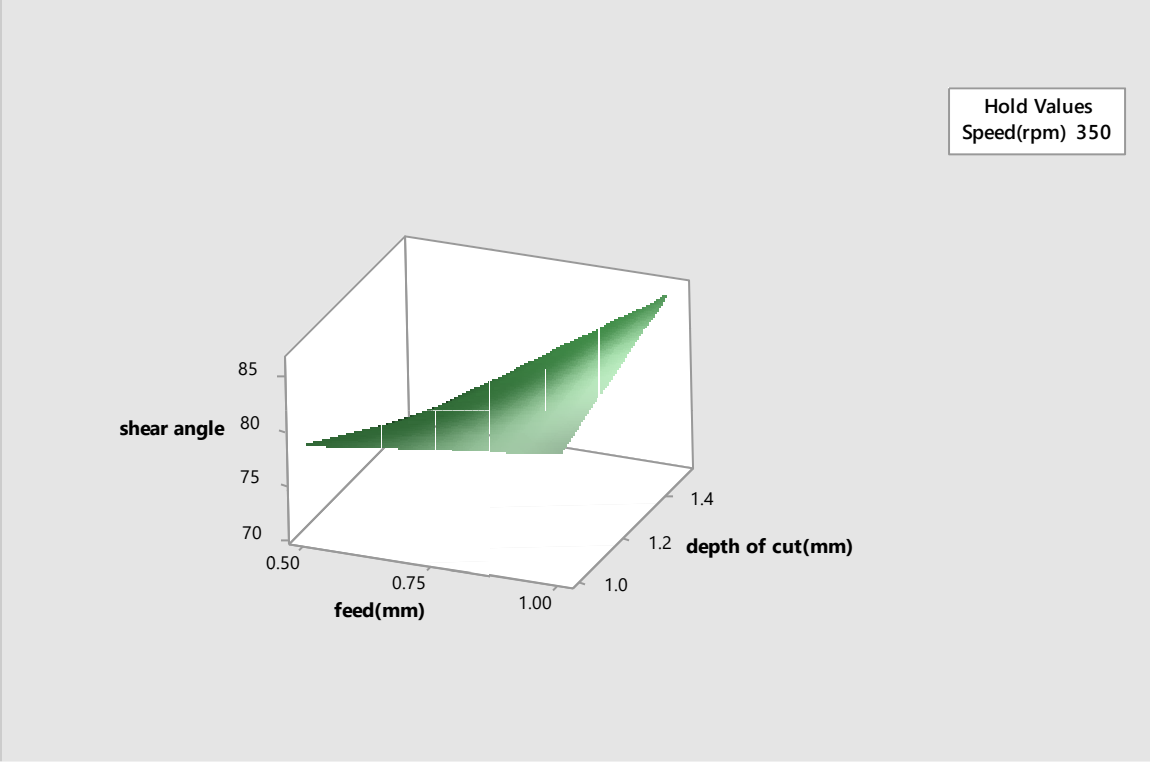


Fig 6.16

6.14 Response Optimization: shear angle, chip thickness ratio, temperature (°C)

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
shear angle	Maximum	66.5000	86.6700		1	1
chip thickness ratio	Maximum	0.0124	0.1732		1	1
temperature (°C)	Minimum		39.0000	72	1	1

Solution

Composite Solution Desirability	Speed (rpm)	feed (mm)	depth of cut (mm)	shear angle	chip thickness ratio	temperature (°C)
1	200	1	1.5	86.3713	0.147438	47

Multiple Response Prediction

Variable	Setting
Speed (rpm)	200
feed (mm)	1
depth of cut (mm)	1.5

Response	Fit	SE Fit	95% CI	95% PI
shear angle	86.371	0.790	(76.328, 96.414)	(71.669, 101.073)
chip thickness ratio	0.1474	0.0682	(-0.7186, 1.0135)	(-1.1204, 1.4152)
temperature (°C)	47.0	10.6	(-87.5, 181.5)	(-149.8, 243.8)

6.14.1 Optimization Plot

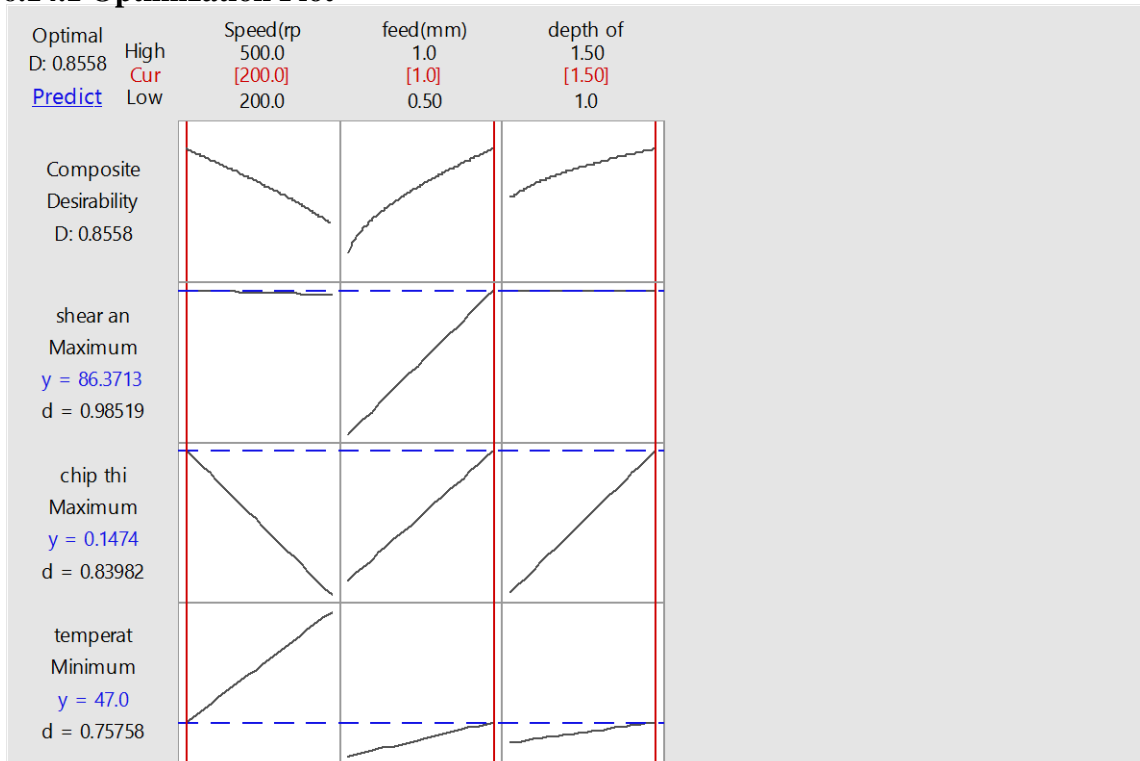


Fig 6.17

6.15 Response Surface Regression: temperature (°C) versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Model	6	2128.64	99.78%	2128.64	354.77	76.27
Linear	3	1725.15	80.87%	1725.15	575.05	123.63
Speed (rpm)	1	1202.95	56.39%	1202.95	1202.95	258.63
feed (mm)	1	393.40	18.44%	393.40	393.40	84.58
depth of cut (mm)	1	128.80	6.04%	128.80	128.80	27.69
2-Way Interaction	3	403.48	18.91%	403.48	134.49	28.92
Speed (rpm) *feed (mm)	1	396.21	18.57%	396.21	396.21	85.18
Speed (rpm) *depth of cut (mm)	1	2.31	0.11%	2.31	2.31	0.50
feed (mm) *depth of cut (mm)	1	4.96	0.23%	4.96	4.96	1.07
Error	1	4.65	0.22%	4.65	4.65	
Total	7	2133.29	100.00%			

Source	P-Value
Model	0.087
Linear	0.066
Speed (rpm)	0.040
feed (mm)	0.069
depth of cut (mm)	0.120
2-Way Interaction	0.136
Speed (rpm) *feed (mm)	0.069
Speed (rpm) *depth of cut (mm)	0.609
feed (mm) *depth of cut (mm)	0.490
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
2.15668	99.78%	98.47%	297.68	86.05%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Value						
Constant		47.788	0.762	(38.099, 57.476)	62.67	
0.010						
Speed (rpm)	24.525	12.263	0.763	(2.574, 21.951)	16.08	
0.040						
feed (mm)	14.025	7.013	0.762	(-2.676, 16.701)	9.20	
0.069						
depth of cut (mm)	8.025	4.013	0.762	(-5.676, 13.701)	5.26	
0.120						
Speed (rpm) *feed (mm)	14.075	7.037	0.762	(-2.651, 16.726)	9.23	
0.069						
Speed (rpm) *depth of cut (mm)	1.075	0.538	0.763	(-9.151, 10.226)	0.70	
0.609						
feed (mm) *depth of cut (mm)	1.575	0.788	0.763	(-8.901, 10.476)	1.03	
0.490						

Term	VIF
Constant	
Speed (rpm)	1.00
feed (mm)	1.00
depth of cut (mm)	1.00
Speed (rpm) * feed (mm)	1.00
Speed (rpm) * depth of cut (mm)	1.00
feed (mm) * depth of cut (mm)	1.00

Regression Equation in Uncoded Units

$$\begin{aligned} \text{temperature } (^{\circ}\text{C}) = & 45.4 - 0.0769 \text{ Speed (rpm)} - 53.4 \text{ feed (mm)} + 1.6 \text{ depth of cut (mm)} \\ & + 0.1877 \text{ Speed (rpm) * feed (mm)} + 0.0143 \text{ Speed (rpm) * depth of cut (mm)} \\ & + 12.6 \text{ feed (mm) * depth of cut (mm)} \end{aligned}$$

6.15.1 Normplot of Residuals for temperature ($^{\circ}\text{C}$)

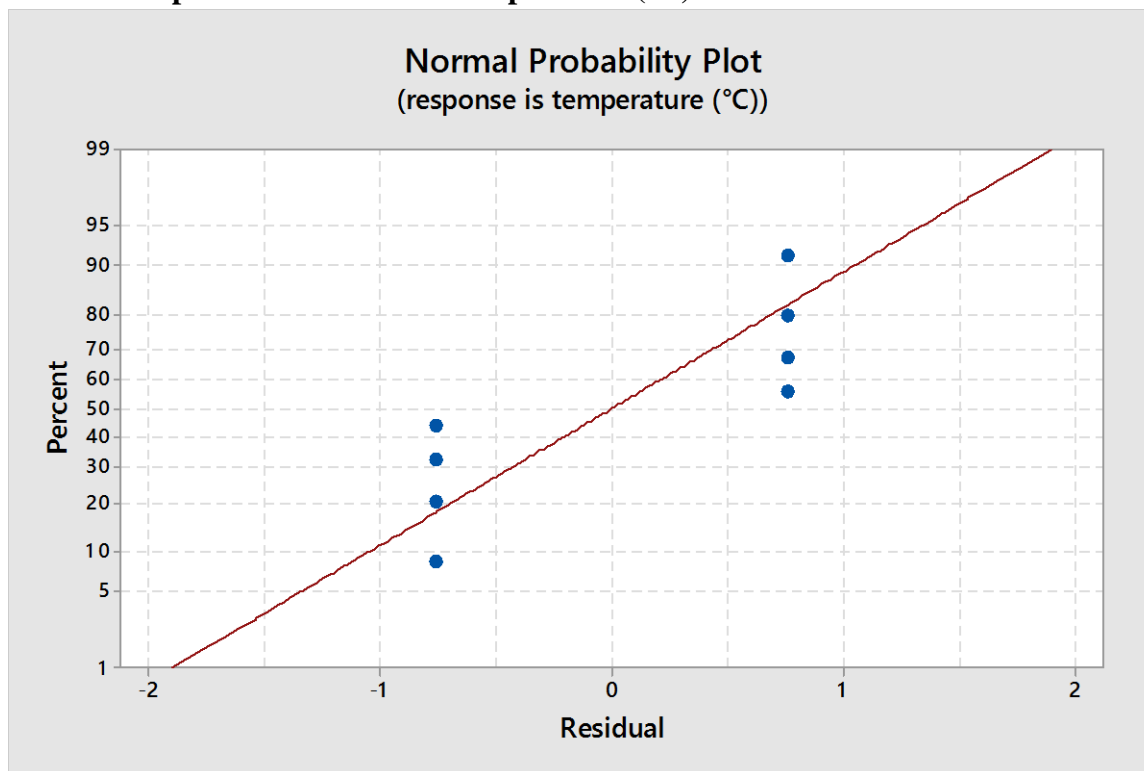
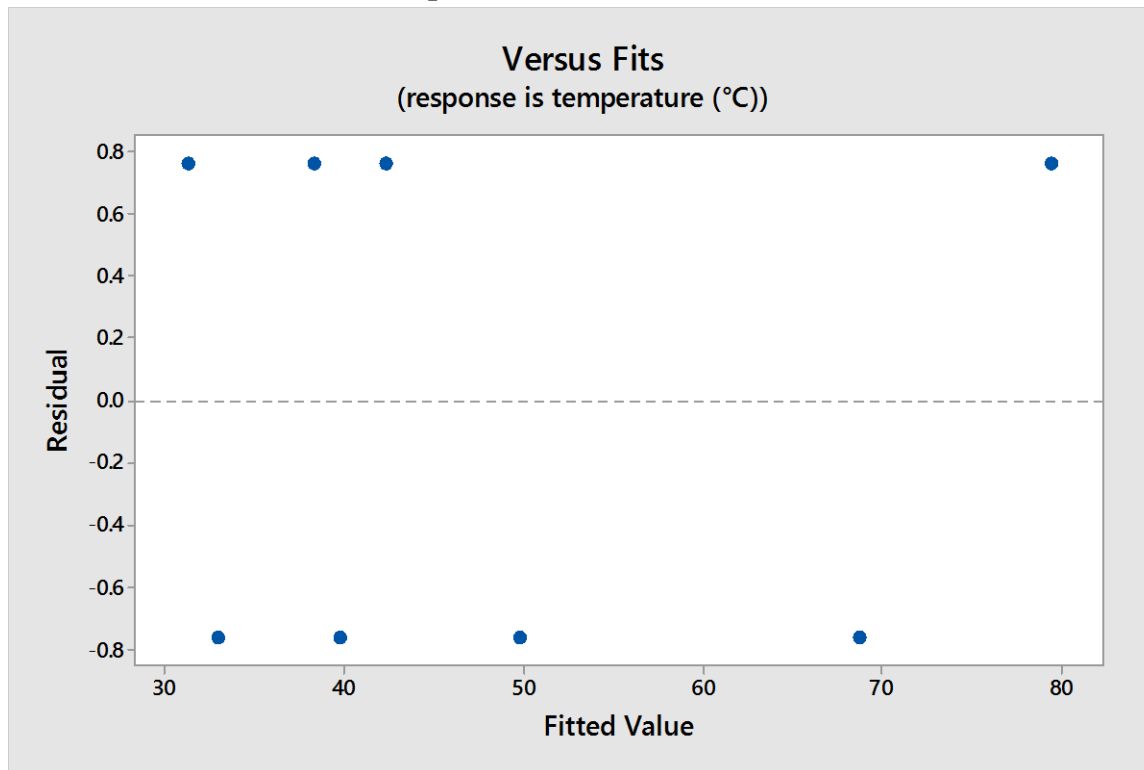


Fig 6.18

6.15.2 Residuals vs Fits for temperature (°C)



6.15.3 Residual Histogram for temperature (°C)

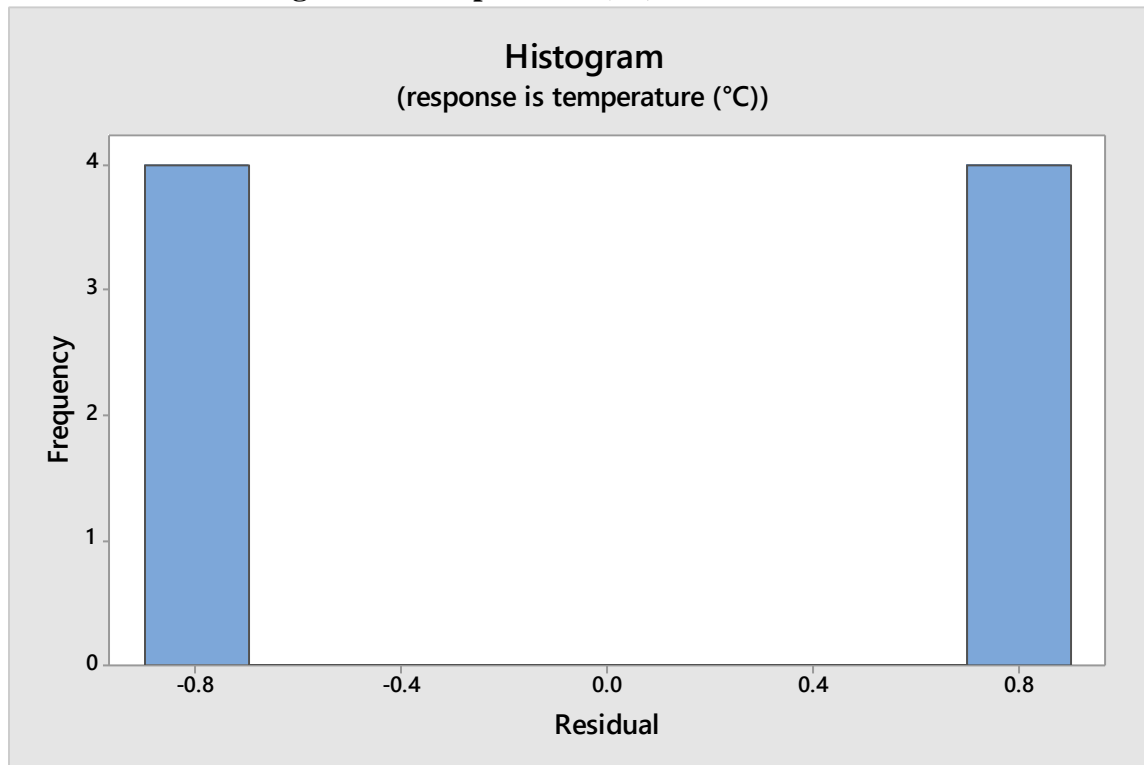
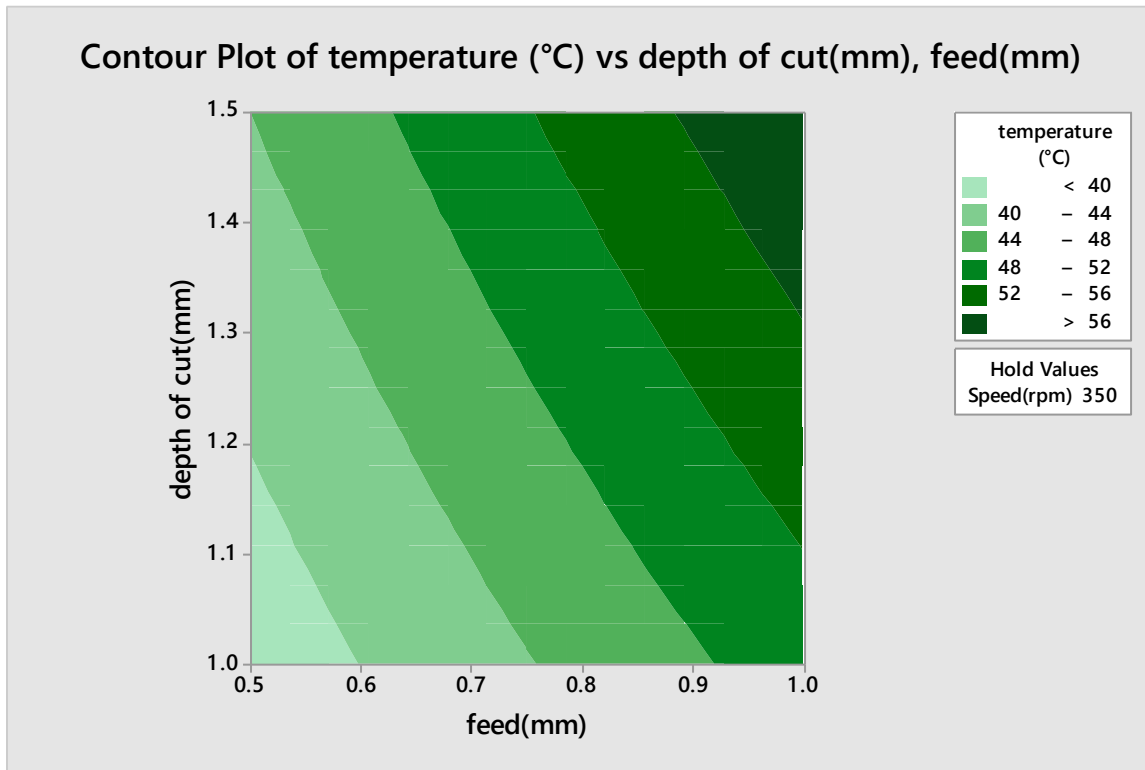


Fig 6.19

6.16 Contour Plot of temperature (°C) vs feed(mm), Speed(rpm)



Contour Plot of temperature (°C) vs depth of cut(mm), Speed(rpm)

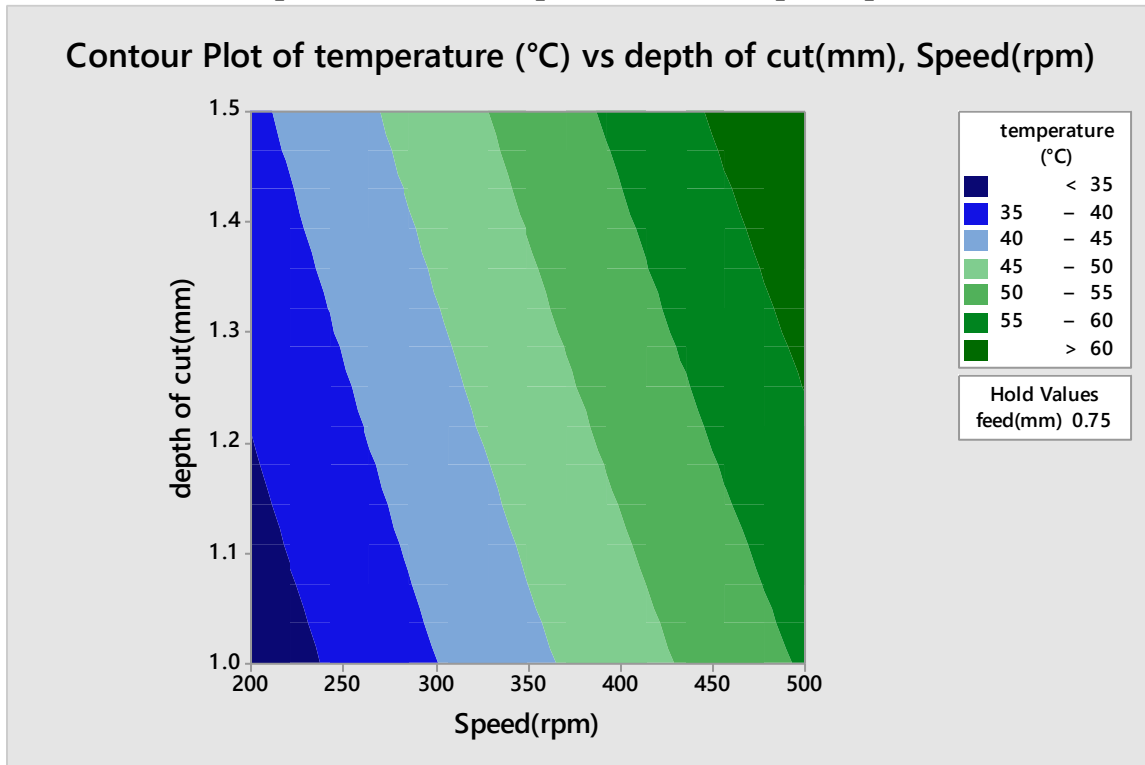
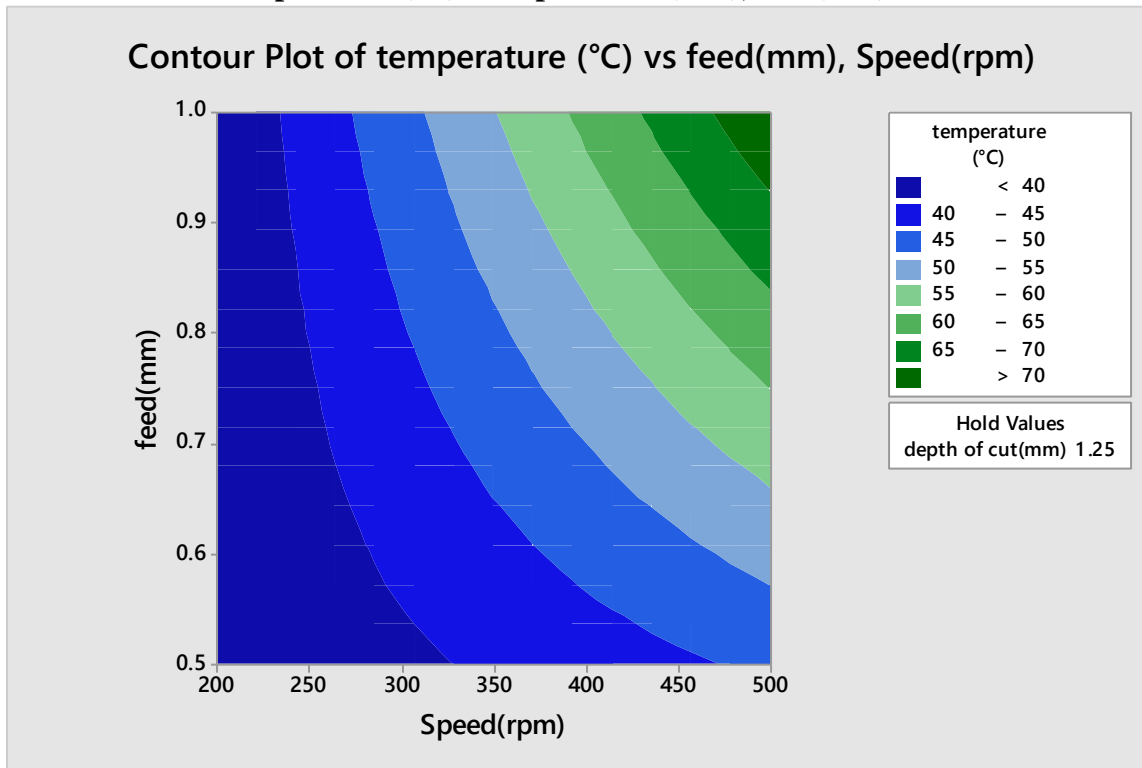


Fig 6.20

Contour Plot of temperature (°C) vs depth of cut(mm), feed(mm)



6.17 Surface Plot of temperature (°C) vs feed(mm), Speed(rpm)

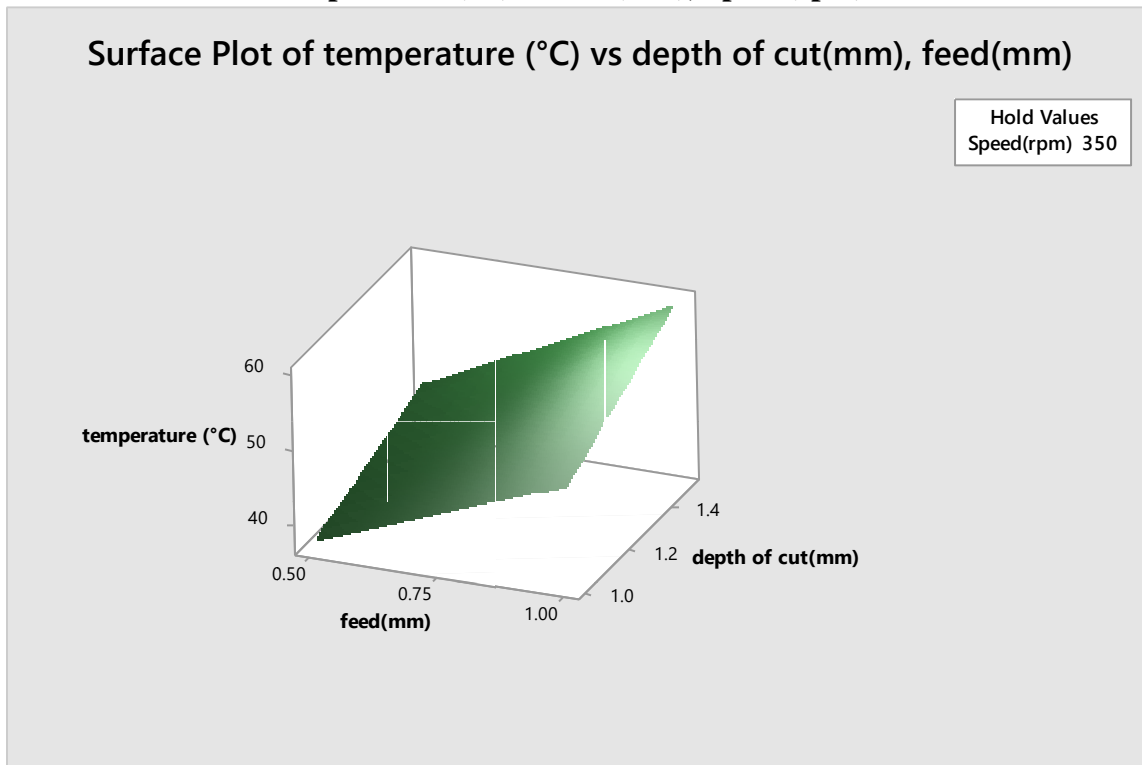
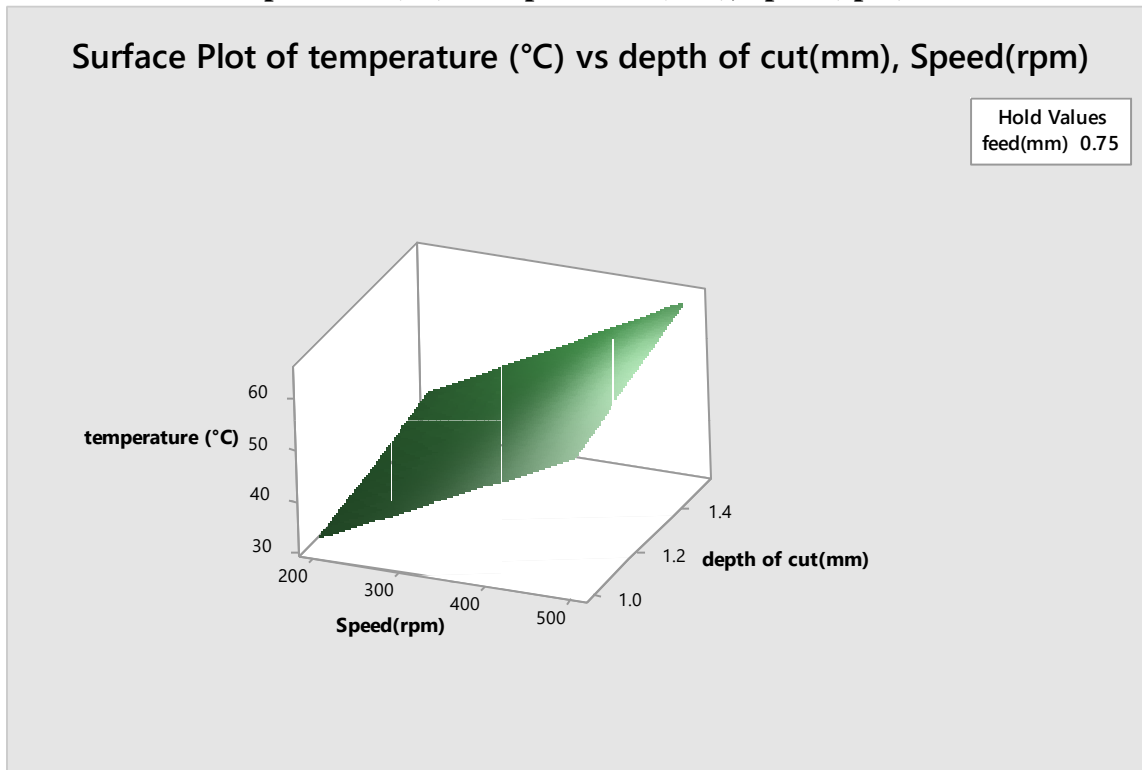


Fig 6.21

Surface Plot of temperature (°C) vs depth of cut(mm), Speed(rpm)



Surface Plot of temperature (°C) vs depth of cut(mm), feed(mm)

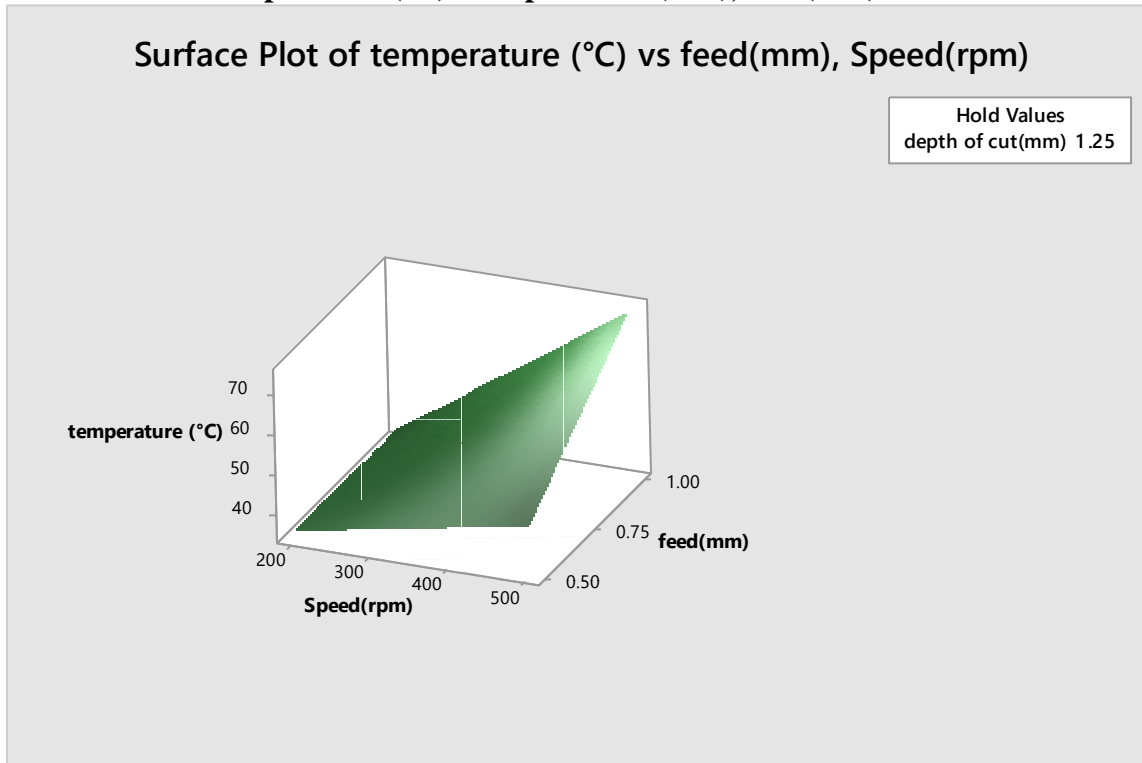


Fig 6.22

6.18 Response Surface Regression: chip thickness r versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Model	6	0.15887	87.68%	0.15887	0.02648	1.19
Linear	3	0.08558	47.23%	0.08558	0.02853	1.28
Speed (rpm)	1	0.02557	14.11%	0.02557	0.02557	1.15
feed (mm)	1	0.04469	24.66%	0.04469	0.04469	2.00
depth of cut (mm)	1	0.01532	8.46%	0.01532	0.01532	0.69
2-Way Interaction	3	0.07330	40.45%	0.07330	0.02443	1.09
Speed (rpm) *feed (mm)	1	0.02358	13.01%	0.02358	0.02358	1.06
Speed (rpm) *depth of cut (mm)	1	0.03278	18.09%	0.03278	0.03278	1.47
feed (mm) *depth of cut (mm)	1	0.01694	9.35%	0.01694	0.01694	0.76
Error	1	0.02231	12.32%	0.02231	0.02231	
Total	7	0.18119	100.00%			

Source	P-Value
Model	0.606
Linear	0.558
Speed (rpm)	0.478
feed (mm)	0.392
depth of cut (mm)	0.559
2-Way Interaction	0.590
Speed (rpm) *feed (mm)	0.491
Speed (rpm) *depth of cut (mm)	0.439
feed (mm) *depth of cut (mm)	0.544
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
0.149376	87.68%	13.79%	1.42805	0.00%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Value						
Constant		0.1172	0.0528	(-0.5538, 0.7883)	2.22	
0.269						
Speed (rpm)	-0.1131	-0.0565	0.0528	(-0.7276, 0.6145)	-1.07	
0.478						
feed (mm)	0.1495	0.0747	0.0528	(-0.5963, 0.7458)	1.42	
0.392						
depth of cut (mm)	-0.0875	-0.0438	0.0528	(-0.7148, 0.6273)	-0.83	
0.559						
Speed (rpm) *feed (mm)	-0.1086	-0.0543	0.0528	(-0.7253, 0.6168)	-1.03	
0.491						
Speed (rpm) *depth of cut (mm)	0.1280	0.0640	0.0528	(-0.6070, 0.7351)	1.21	
0.439						
feed (mm) *depth of cut (mm)	-0.0920	-0.0460	0.0528	(-0.7171, 0.6250)	-0.87	
0.544						

Term	VIF
Constant	
Speed (rpm)	1.00
feed (mm)	1.00
depth of cut (mm)	1.00
Speed (rpm) * feed (mm)	1.00
Speed (rpm) * depth of cut (mm)	1.00
feed (mm) * depth of cut (mm)	1.00

Regression Equation in Uncoded Units

$$\begin{aligned} \text{chip thickness ratio} = & -0.08 - 0.00142 \text{ Speed (rpm)} + 1.73 \text{ feed (mm)} - \\ & 0.220 \text{ depth of cut (mm)} \\ & - 0.00145 \text{ Speed (rpm) * feed (mm)} \\ + & 0.00171 \text{ Speed (rpm) * depth of cut (mm)} \\ & - 0.736 \text{ feed (mm) * depth of cut (mm)} \end{aligned}$$

6.18.1 Normplot of Residuals for chip thickness ratio

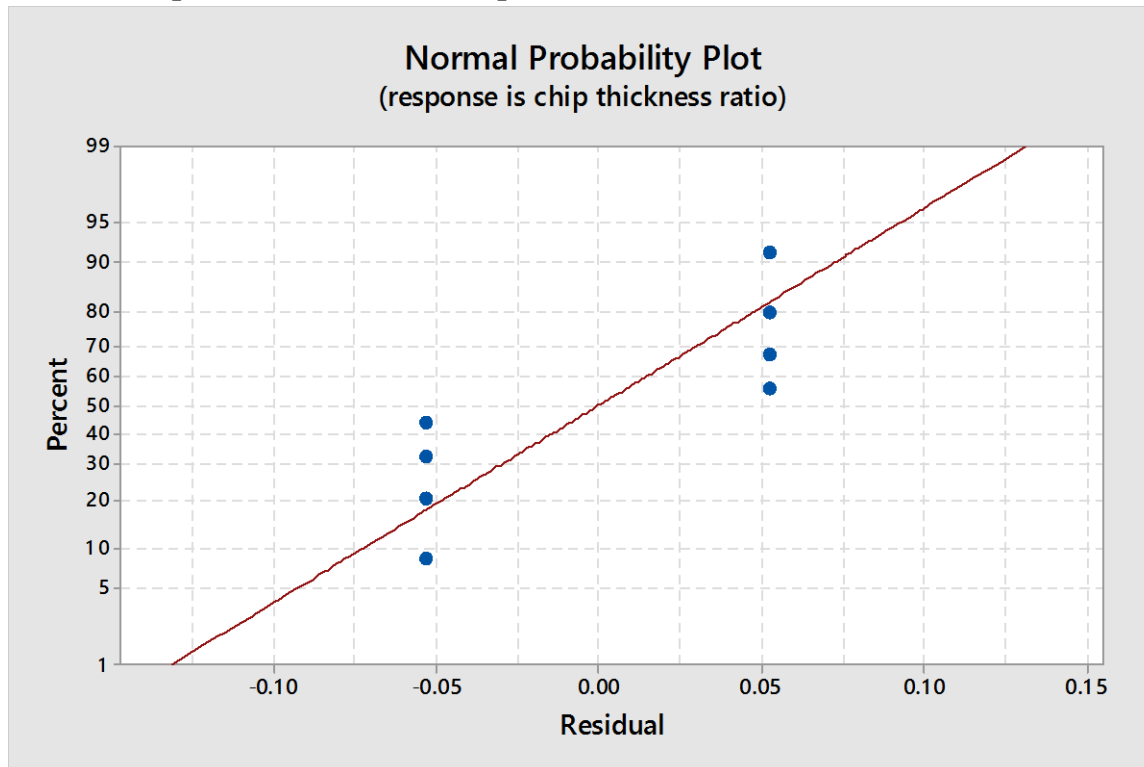
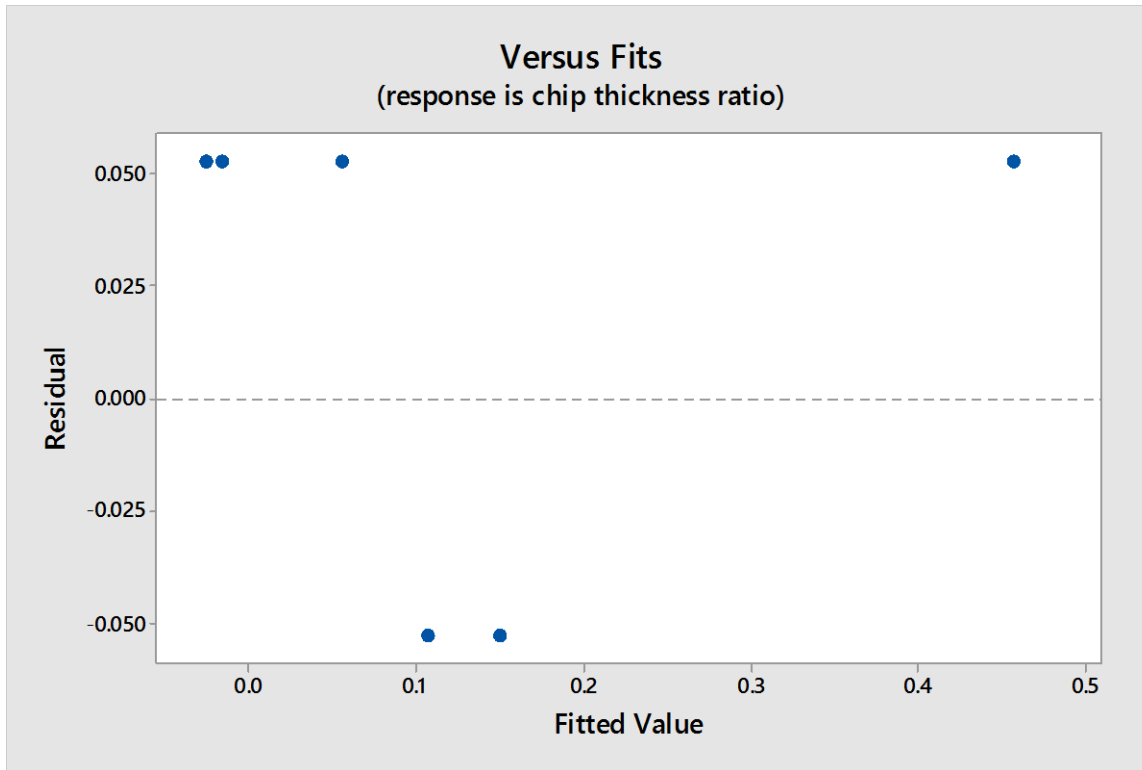


Fig 6.23

6.18.2 Residuals vs Fits for chip thickness ratio



6.18.3 Residual Histogram for chip thickness ratio

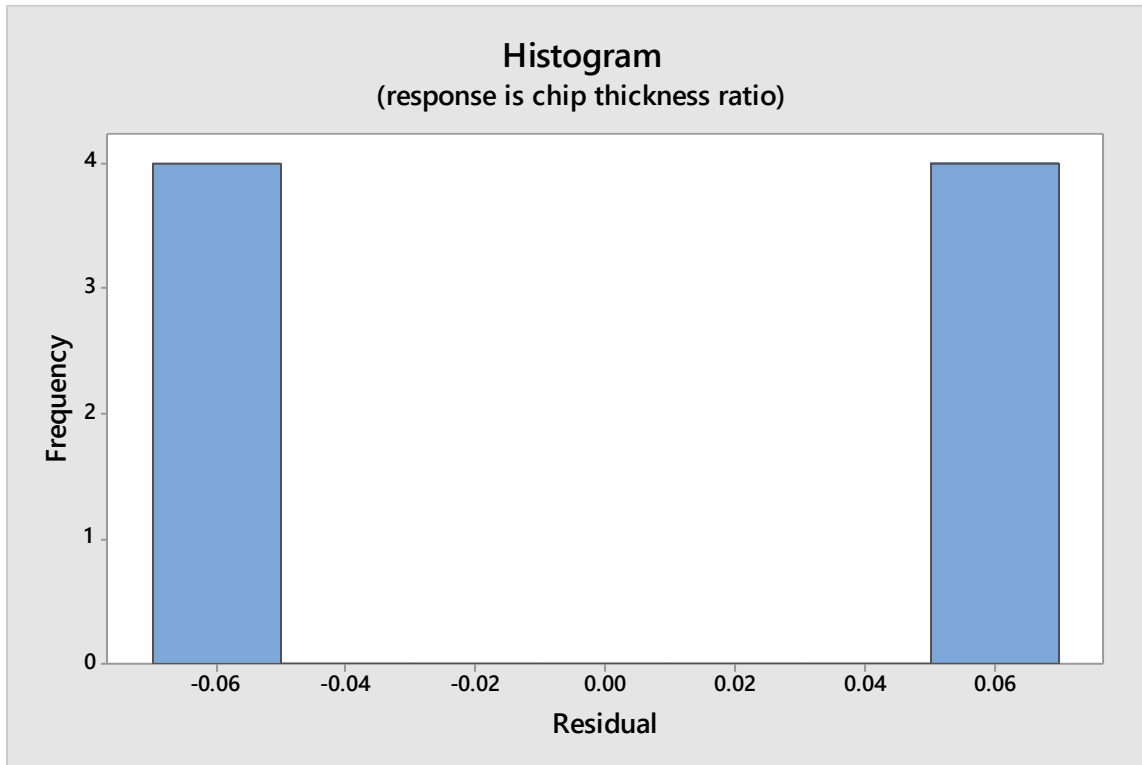
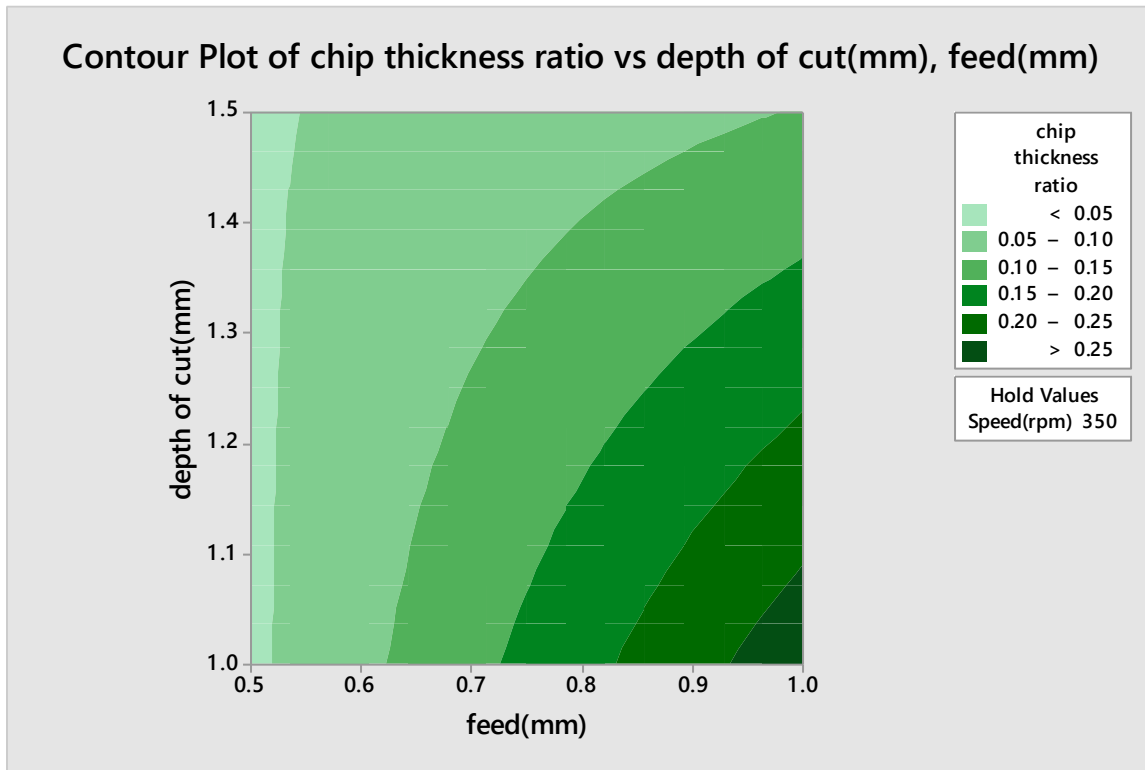


Fig 6.24

6.19 Contour Plot of chip thickness ratio vs feed(mm), Speed(rpm)



Contour Plot of chip thickness ratio vs depth of cut(mm), Speed(rpm)

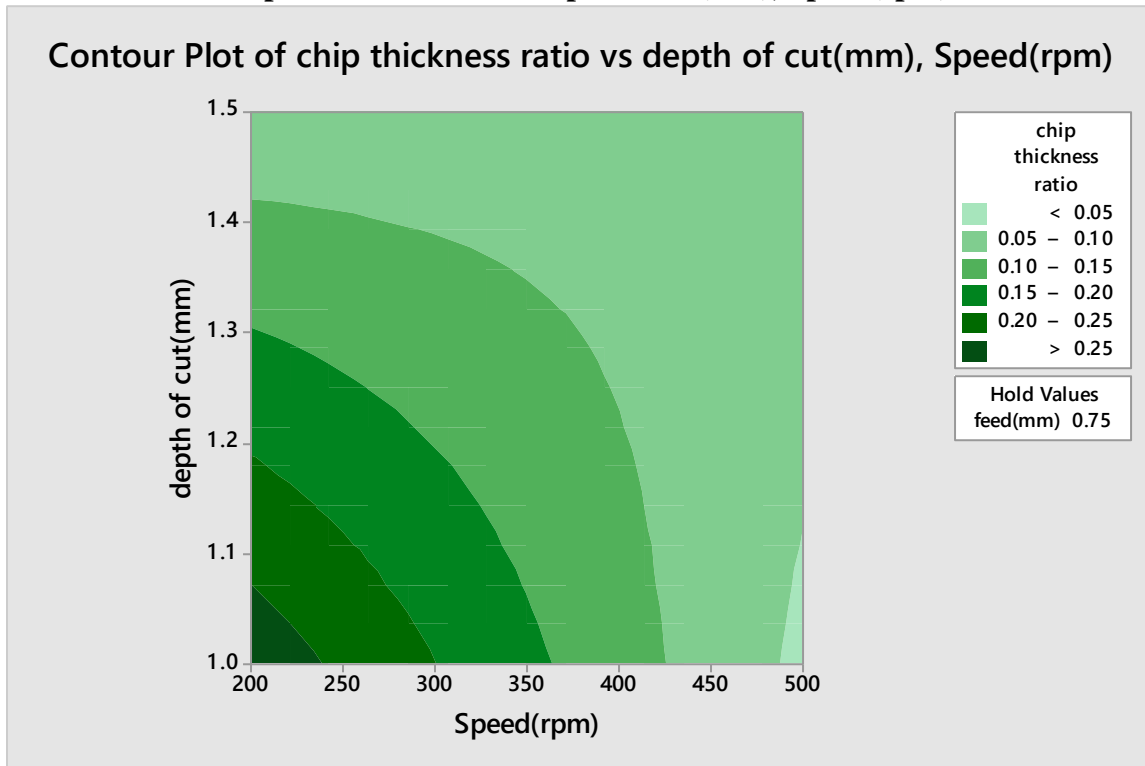
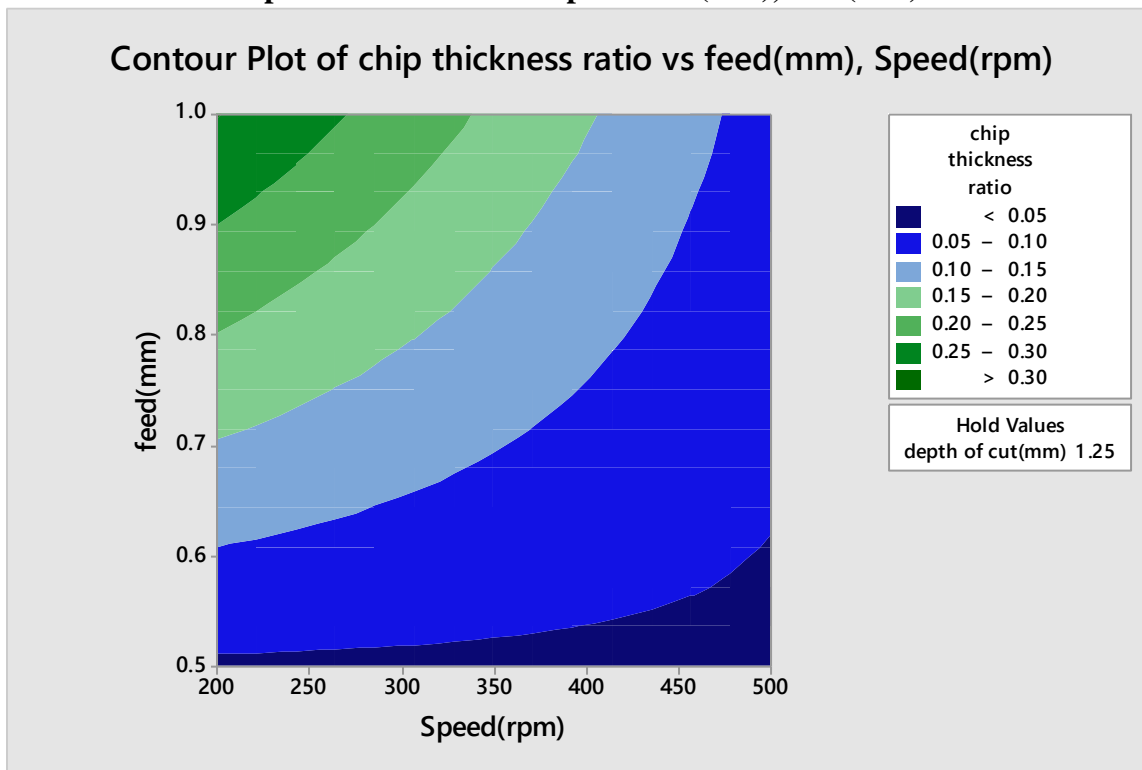


Fig 6.25

Contour Plot of chip thickness ratio vs depth of cut(mm), feed(mm)



6.20 Surface Plot of chip thickness ratio vs feed(mm), Speed(rpm)

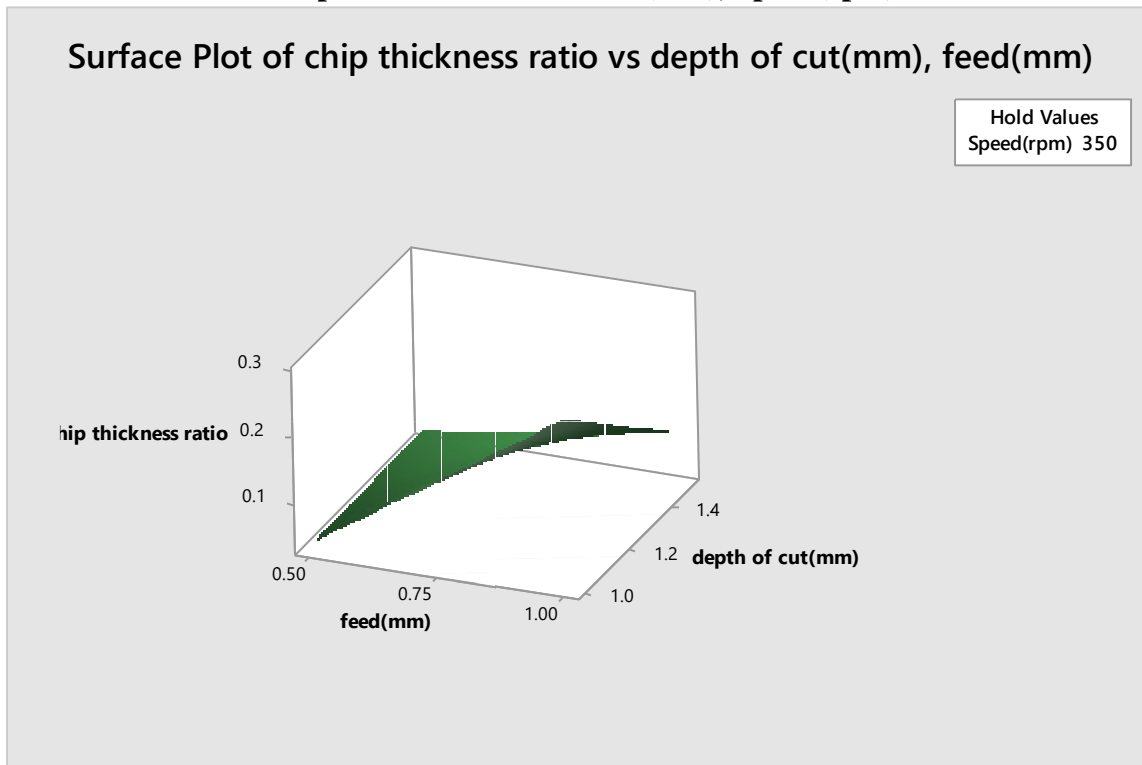
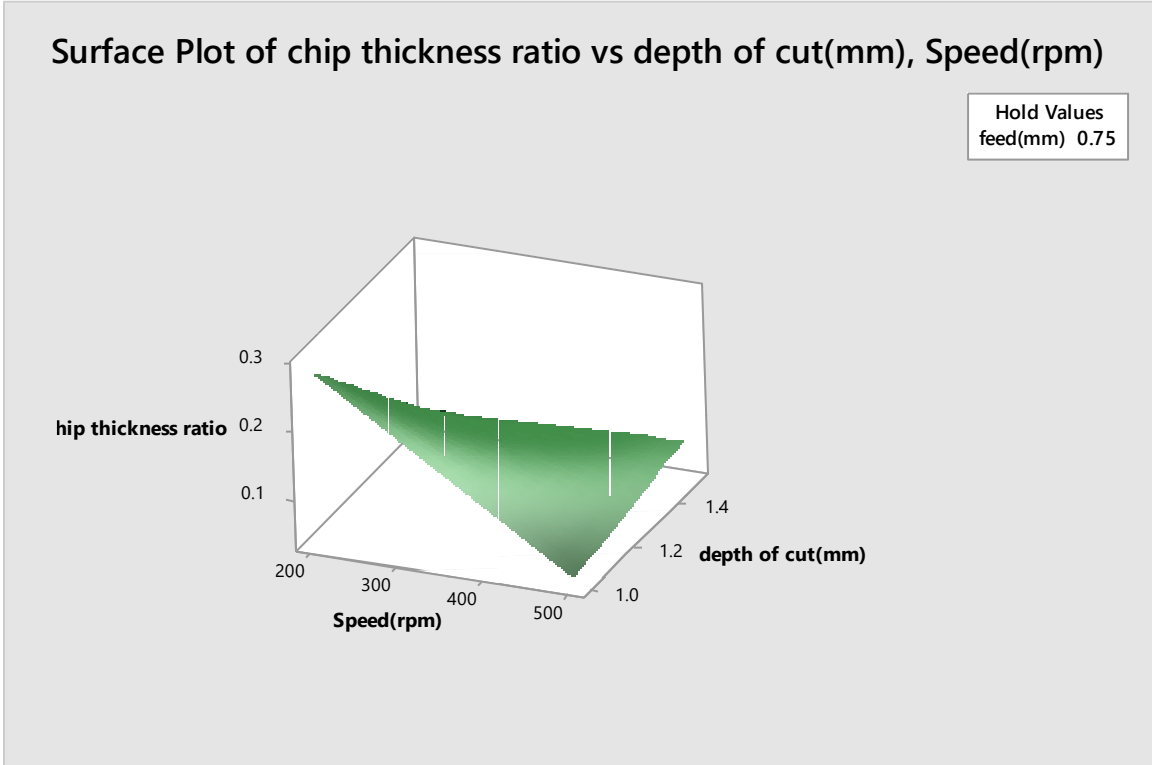


Fig 6.26

Surface Plot of chip thickness ratio vs depth of cut(mm), Speed(rpm)



Surface Plot of chip thickness ratio vs depth of cut(mm), feed(mm)

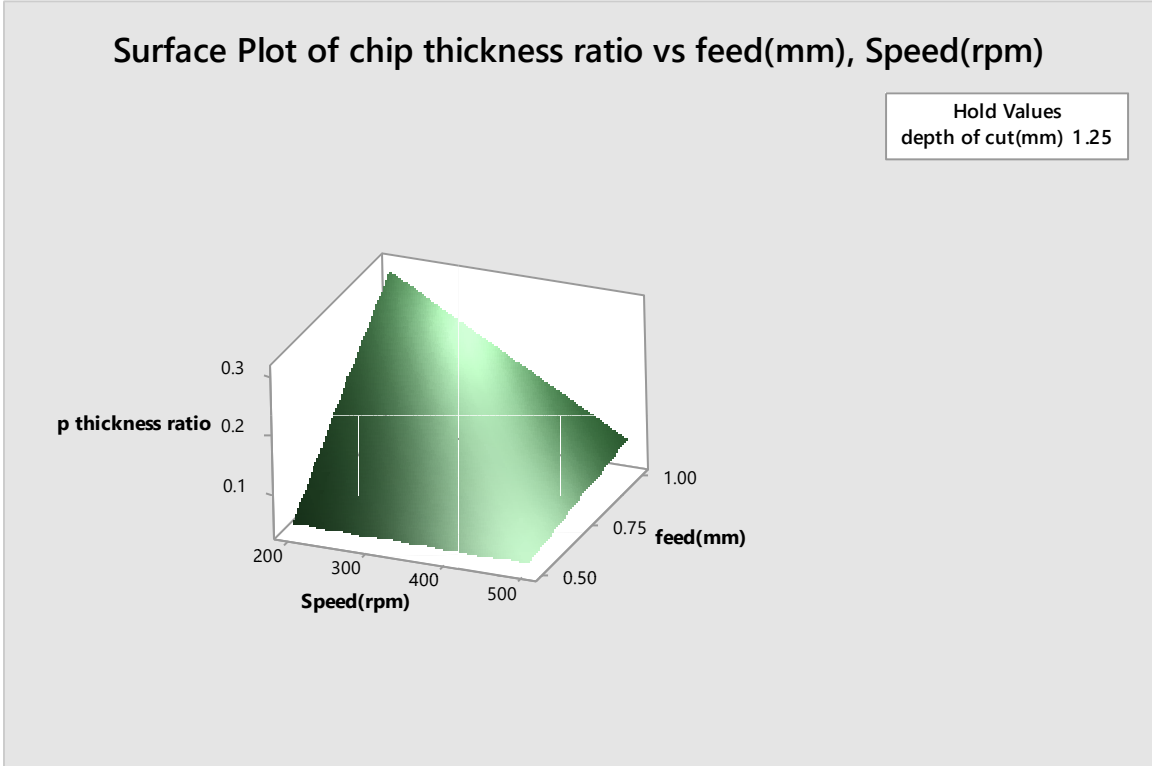


Fig 6.27

6.21 Response Surface Regression: shear angle versus Speed(rpm), feed(mm), depth of cut(mm)

The following terms cannot be estimated and were removed:

Speed(rpm)*Speed(rpm), feed(mm)*feed(mm), depth of cut(mm)*depth of cut(mm)

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Model	6	556.637	80.12%	556.637	92.773	0.67
Linear	3	290.870	41.87%	290.870	96.957	0.70
Speed (rpm)	1	220.290	31.71%	220.290	220.290	1.60
feed (mm)	1	6.734	0.97%	6.734	6.734	0.05
depth of cut (mm)	1	63.845	9.19%	63.845	63.845	0.46
2-Way Interaction	3	265.768	38.25%	265.768	88.589	0.64
Speed (rpm) * feed (mm)	1	130.088	18.72%	130.088	130.088	0.94
Speed (rpm) * depth of cut (mm)	1	0.871	0.13%	0.871	0.871	0.01
feed (mm) * depth of cut (mm)	1	134.808	19.40%	134.808	134.808	0.98
Error	1	138.112	19.88%	138.112	138.112	
Total	7	694.750	100.00%			

Source	P-Value
Model	0.732
Linear	0.682
Speed (rpm)	0.426
feed (mm)	0.862
depth of cut (mm)	0.620
2-Way Interaction	0.700
Speed (rpm) * feed (mm)	0.510
Speed (rpm) * depth of cut (mm)	0.950
feed (mm) * depth of cut (mm)	0.504
Error	
Total	

Model Summary

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
11.7521	80.12%	0.00%	8839.18	0.00%

Coded Coefficients

Term	Effect	Coef	SE Coef	95% CI	T-Value	P-
Constant		76.26	4.15	(23.46, 129.05)	18.35	
Speed (rpm)	-10.50	-5.25	4.16	(-58.04, 47.55)	-1.26	
feed (mm)	1.84	0.92	4.15	(-51.88, 53.71)	0.22	
depth of cut (mm)	-5.65	-2.82	4.15	(-55.62, 49.97)	-0.68	
Speed (rpm) * feed (mm)	-8.07	-4.03	4.15	(-56.83, 48.76)	-0.97	
Speed (rpm) * depth of cut (mm)	-0.66	-0.33	4.16	(-53.12, 52.46)	-0.08	
feed (mm) * depth of cut (mm)	-8.21	-4.11	4.16	(-56.90, 48.69)	-0.99	

Regression Equation in Uncoded Units

$$\begin{aligned} \text{shear angle} = & 6.2 + 0.057 \text{ Speed(rpm)} + 123.4 \text{ feed(mm)} + 41.0 \text{ depth of cut(mm)} \\ & - 0.108 \text{ Speed(rpm)*feed(mm)} - 0.009 \text{ Speed(rpm)*depth of cut(mm)} - \\ & 65.7 \text{ feed(mm)} \\ & \quad * \text{depth of cut(mm)} \end{aligned}$$

6.21.1 Normplot of Residuals for shear angle

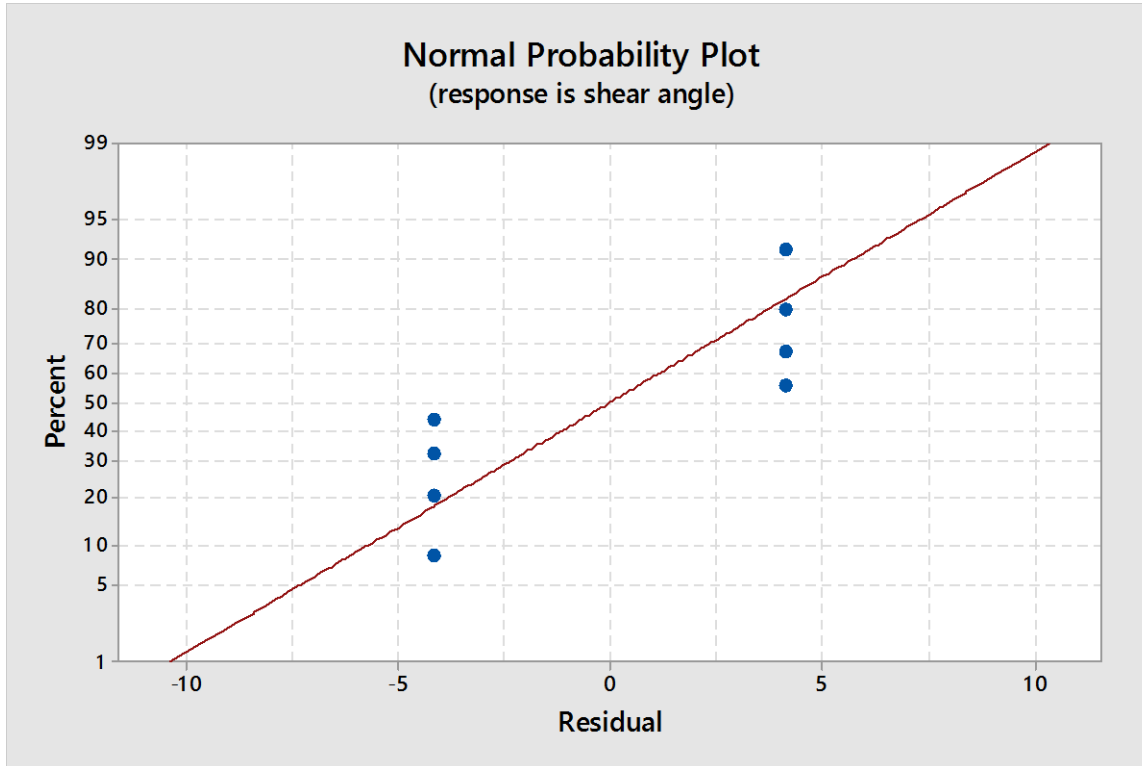
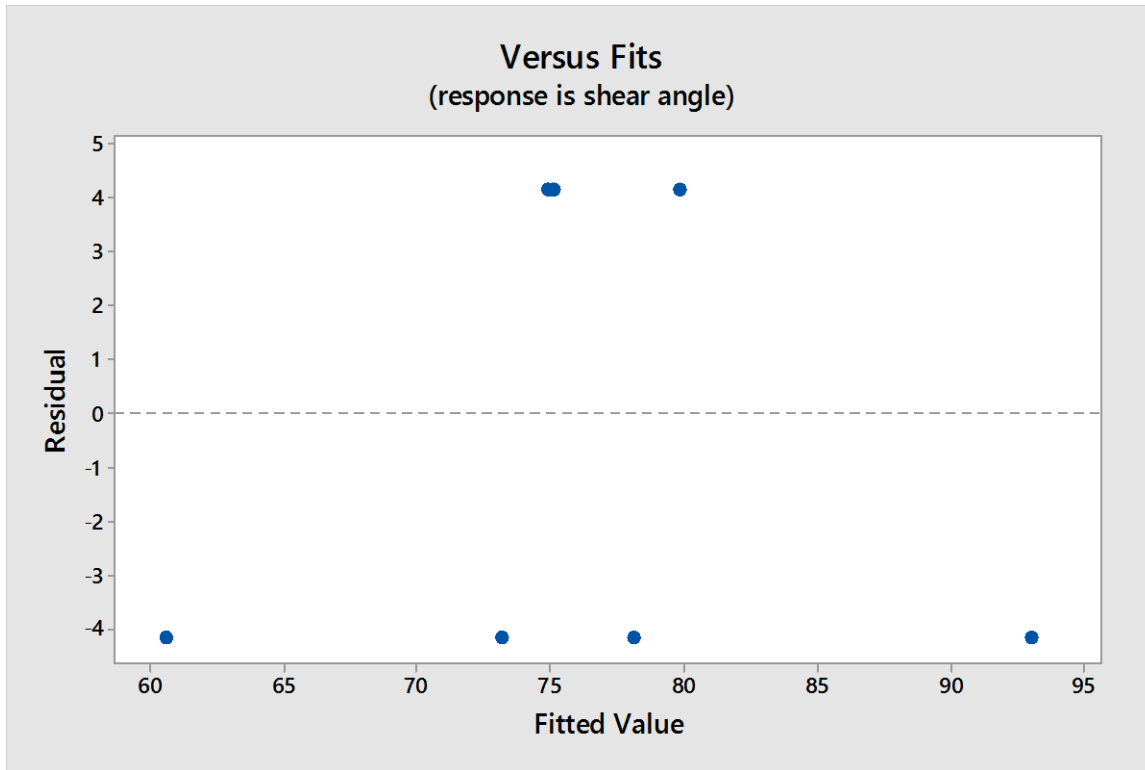


Fig 6.28

6.21.2 Residuals vs Fits for shear angle



6.21.3 Residual Histogram for shear angle

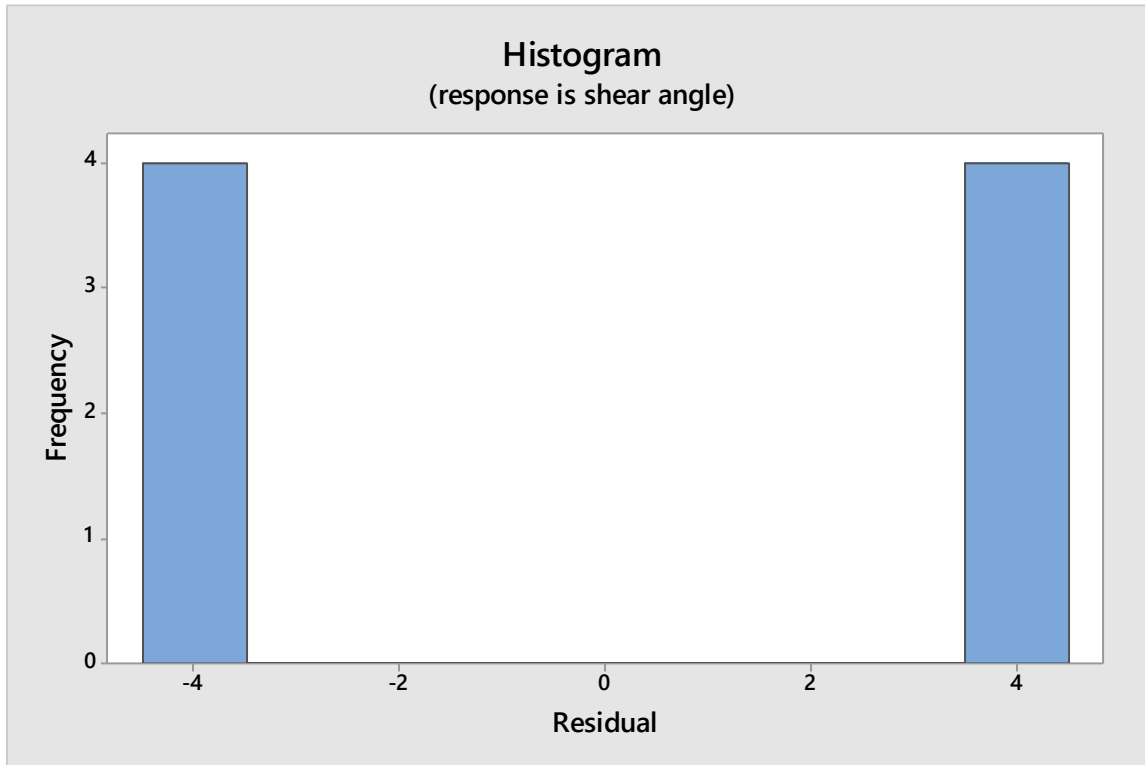
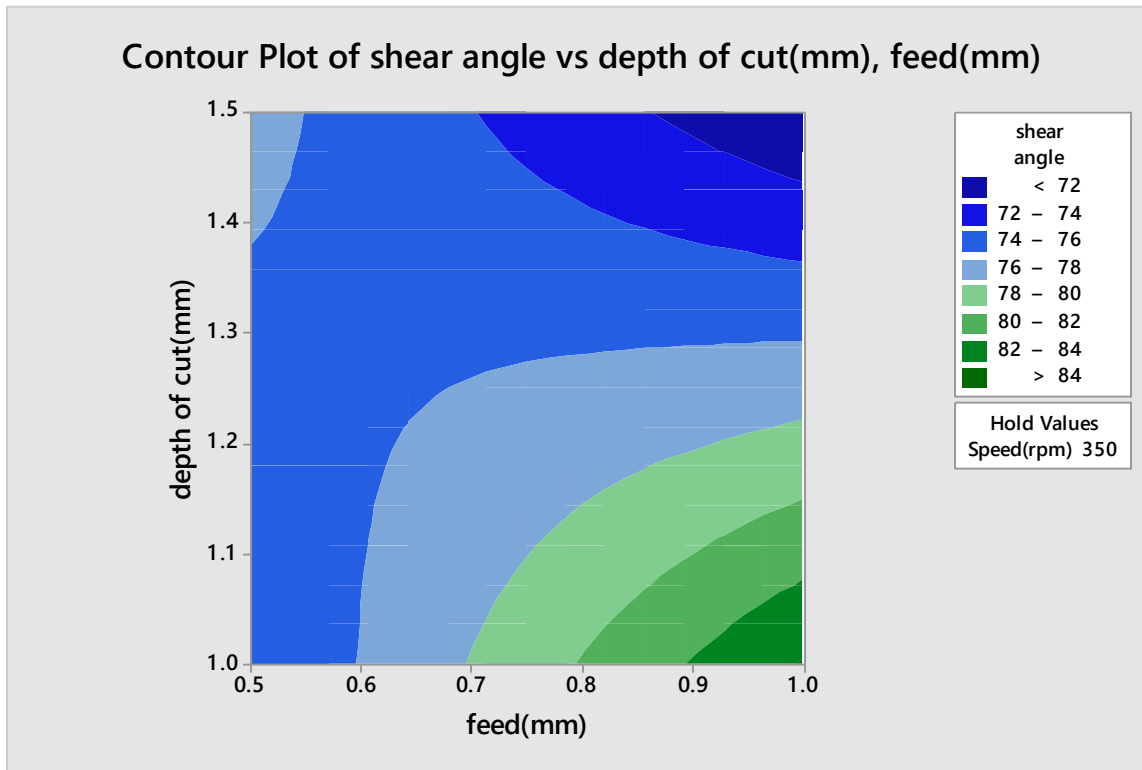


Fig 6.29

6.22 Contour Plot of shear angle vs feed(mm), Speed(rpm)



Contour Plot of shear angle vs depth of cut(mm), Speed(rpm)

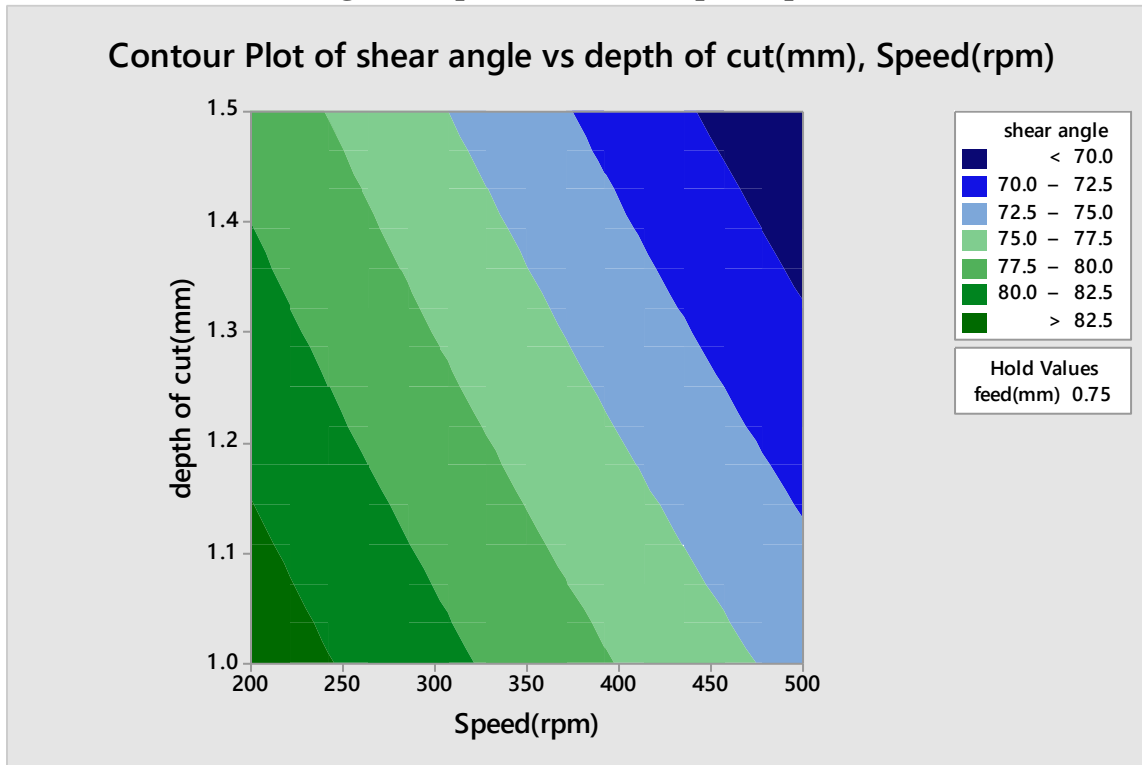
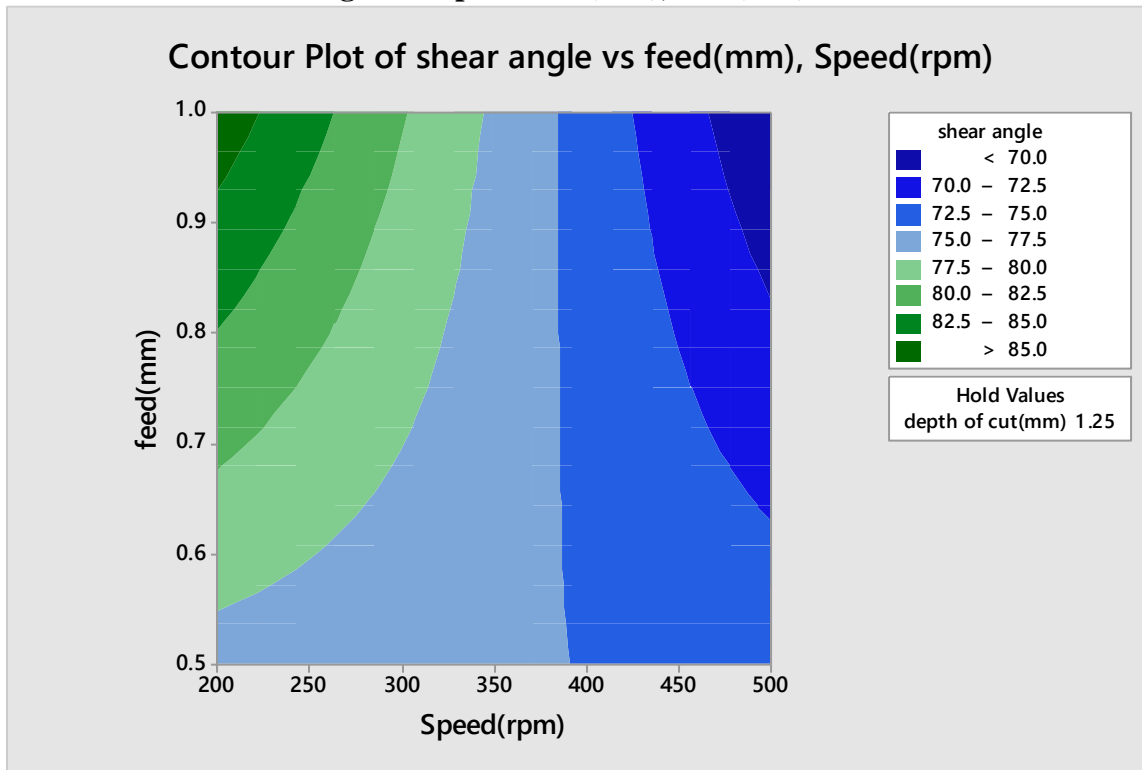


Fig 6.30

Contour Plot of shear angle vs depth of cut(mm), feed(mm)



6.23 Surface Plot of shear angle vs feed(mm), Speed(rpm)

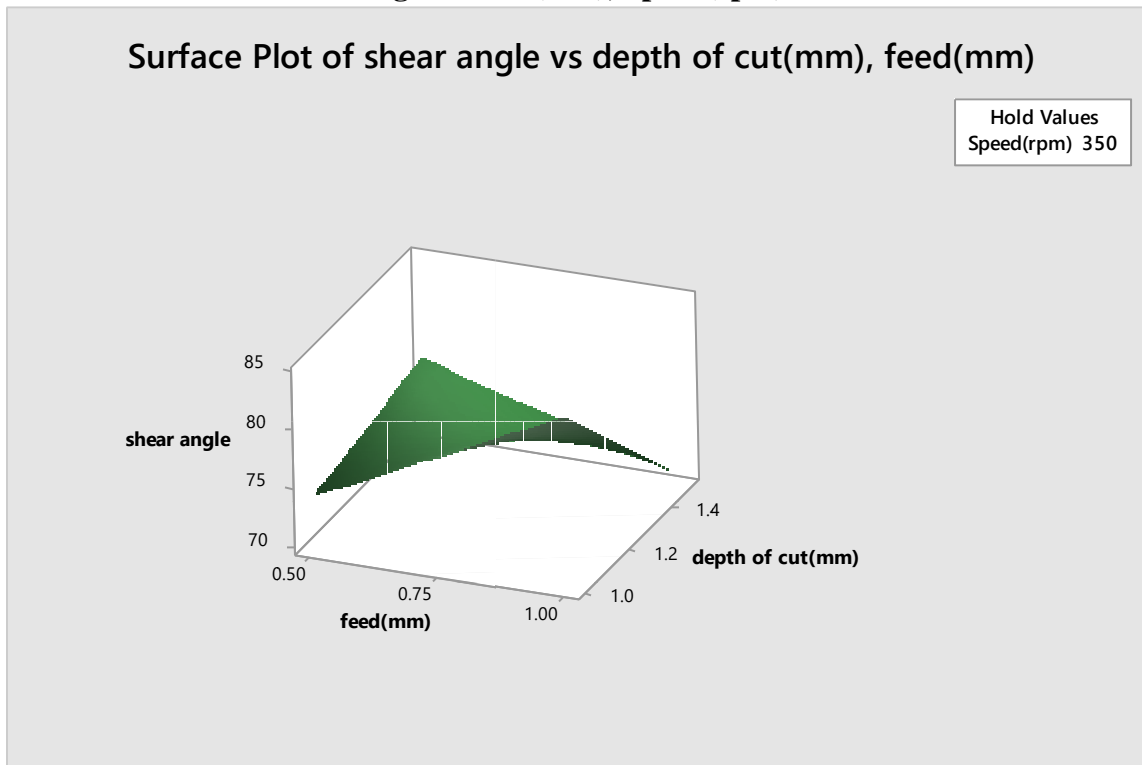
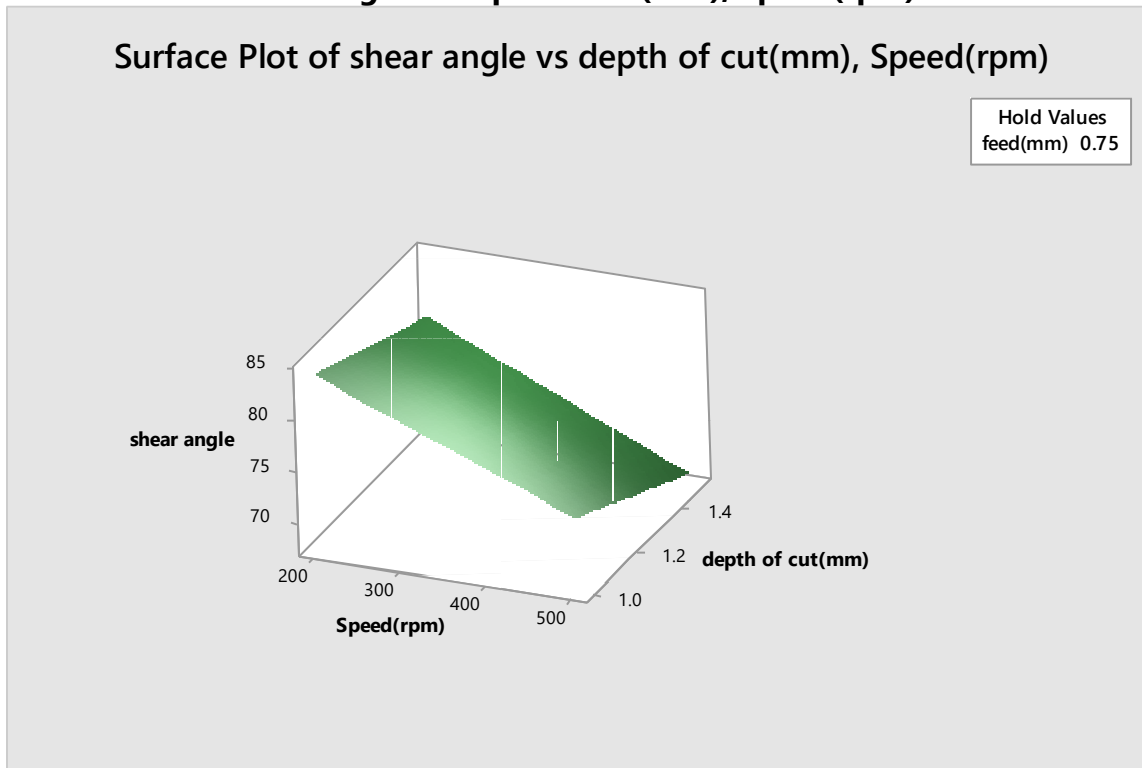


Fig 6.31

Surface Plot of shear angle vs depth of cut(mm), Speed(rpm)



Surface Plot of shear angle vs depth of cut(mm), feed(mm)

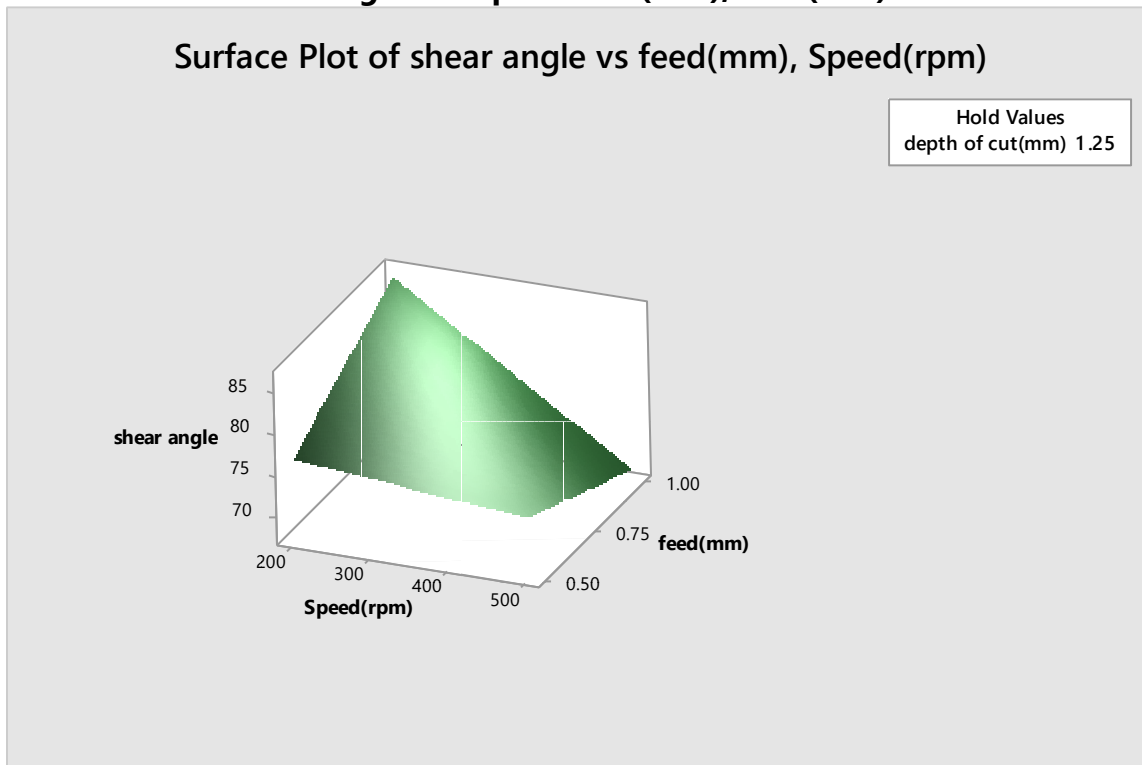


Fig 6.32

6.24 Response Optimization: shear angle, chip thickness ratio, temperature (°C)

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
shear angle	Maximum	56.4800	88.9000		1	1
chip thickness ratio	Maximum	0.0268	0.5094		1	1
temperature (°C)	Minimum		32.0000	80.2	1	1

Solution

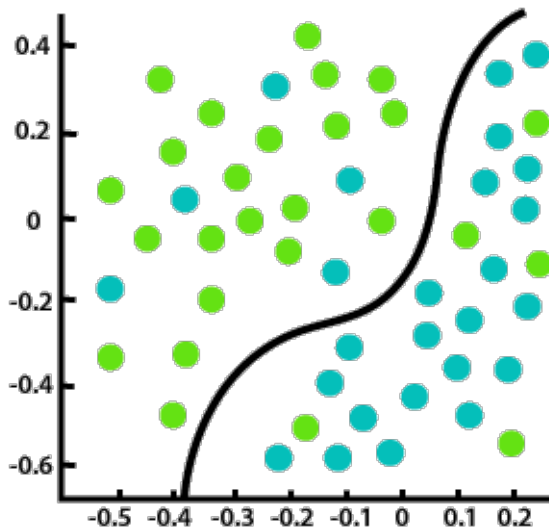
Solution	Speed (rpm)	feed (mm)	depth of cut (mm)	shear angle Fit	chip thickness ratio Fit	temperature (°C) Fit	Composite Desirability
1	200	1	1	93.055	0.456588	31.2375	0.962104

Multiple Response Prediction

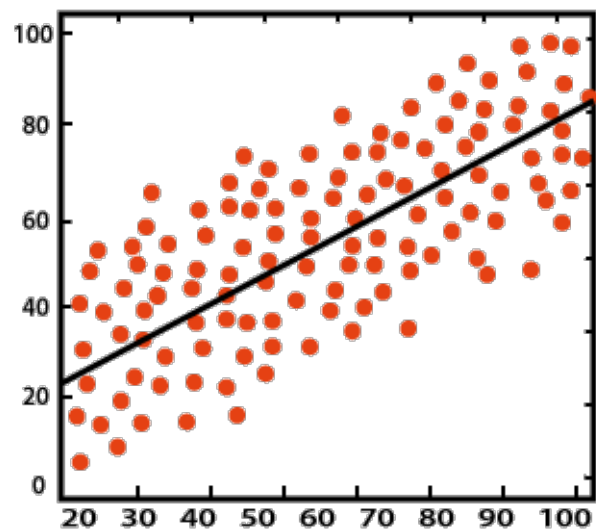
Variable	Setting
Speed (rpm)	200
feed (mm)	1
depth of cut (mm)	1

Response	Fit	SE Fit	95% CI	95% PI
shear angle	93.1	11.0	(-46.6, 232.7)	(-111.4, 297.5)
chip thickness ratio	0.457	0.140	(-1.319, 2.232)	(-2.142, 3.056)
temperature (°C)	31.24	2.02	(5.60, 56.87)	(-6.29, 68.76)

CORRELATION BETWEEN CLASSIFICATION AND REGRESSION:



Classification



Regression

6.24.1 Optimization Plot

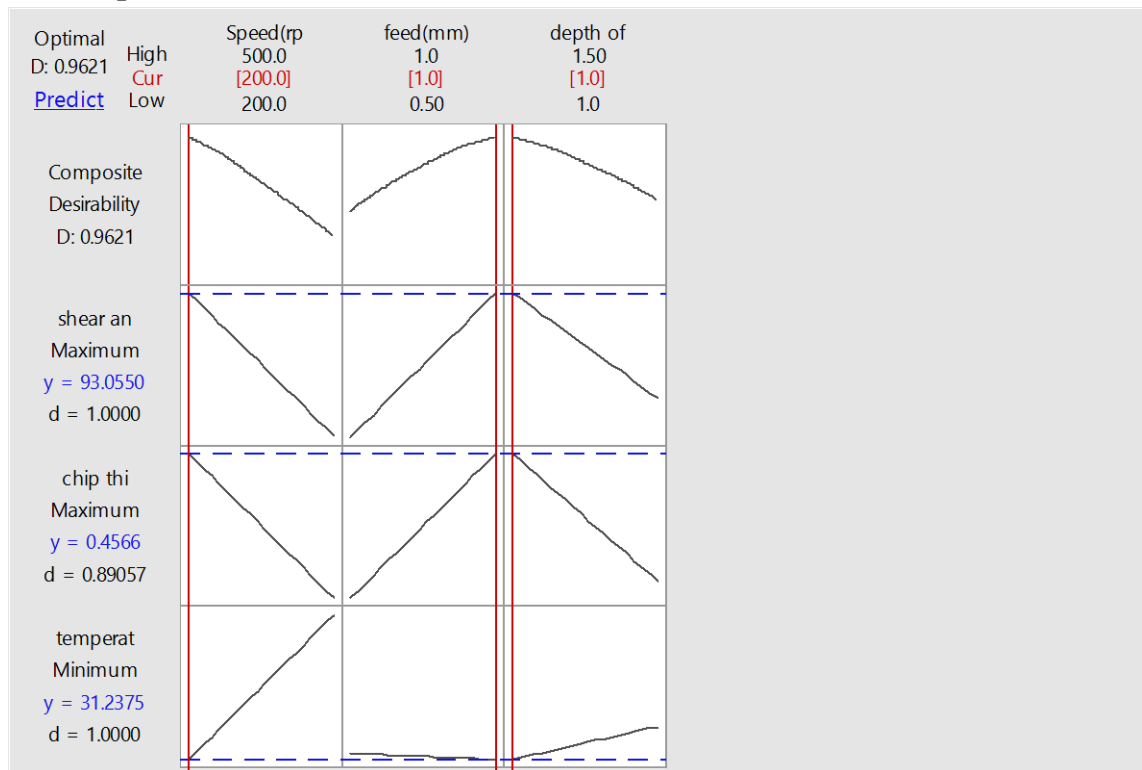


Fig 6.33

An optimization plot is a Minitab Response Optimizer tool that shows how different experimental settings affect the predicted responses for a stored model.

Minitab calculates an optimal solution and draws the plot. The optimal solution serves as the initial point for the plot — you can modify the settings interactively to determine how different setting affect responses. For factorial and response surface designs, you can adjust the factor levels. For mixture designs, you can adjust component, process variable, and amount variable settings. You might want to change these variable settings on the optimization plot for many reasons, including:

- 1) To search for variable settings with a higher composite (user-specified) desirability
- 2) To search for lower-cost variable settings with near optimal properties
- 3) To explore the sensitivity of response variables to changes in the design variables
- 4) To "calculate" the predicted responses for a variable setting of interest
- 5) To explore variable settings in the neighborhood of a local solution

CHAPTER 7

CONCLUSIONS

- From the optimisation plot it is clear that while machining an EN-8 material a HCS tool is to be used .
- Mini Tab produces a direct equation with the combination of controlled parameters which can be used in industries to know the Values of material removal rate, cutting forces both on x and y directions and cutting temperature.
- This paper produces a direct equation with the combination of controlled parameters which can be used in industries to know the Values of chip thickness ratio and shear angle along with optimum temperature.
- The optimal solution for composite desirability in dry condition of machining is 85.58% and the optimal solution for composite desirability in wet condition of machining EN-8 is 95.39% hence due to lubrication the wet condition is preferable at certain rates of speeds, feeds, depth of cuts.

CHAPTER 8

FUTURE SCOPE OF WORK

- By using carbide tool with the workpiece of EN-8 can also measure cutting forces.
- Can also measure material removal rate.
- The tool life can also be predicted under wet and dry conditions by using carbide tool with the machining of EN-8 workpiece.
- The tool wear can also be measured when continuously machined under wet and dry conditions.
- The adequacy of the developed model is checked using response surface method.
- An optimization plot is a Minitab Response Optimizer tool that shows how different experimental settings affect the Composite Desirability.

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