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RSM: A Key to Optimize Machining

Multi-Response Optimization of CNC Turning with Al-7020 Alloy

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Prof. Bikram Jit Singh
Prof. H.S. Sodhi

PREFACE

In present manufacturing scenario quality and quantity are two challenging aspects which are to be looked upon. Quality is important according to customer point of view, whereas quantity is required from the industrial point of view to maximize profit earnings. Both of these aspects are negatively co related with each other. For the sustainability of machining industry in today's world there should be an optimized path which should be followed to satisfy both aspects.

This book gives rise to an optimization problem which should identify best combinations of various parametric variables. In a single objective optimization the output is only governed by a single parameter, whereas in multiple objective optimizations there are two or more conflicting variables which made further the optimization of responses, much difficult to achieve. The present study is done for optimization of turning parameters of a CNC turning center for Aluminium-7020 by using Response Surface Method (RSM). Tool used in the study is uncoated carbide tool 'Taegutech TNMG 160408-GM-TT.3500'.

As the main response parameters considered here are Material Removal Rate (MRR) and Surface Finish (Ra) which mainly depends upon parameters such as Cutting Speed, Feed Rate and Depth of Cut. All these control parameters are directly or inversely related to each other. If the depth of cut is increased MRR increases at the same time we get poor surface finish. Increase in the cutting speed has positive impact on both material removal rate and surface finish. It employs that all the parameters are conflicting so we have to select the optimized parameters for the enhancement of the performance. Further the optimized results are verified by using ANOVA. This book indicates towards the practical feasibility of optimized turning in multi response conditions.

In chapter-1, an overview of machining technology has been provided. Introduction to Machining and its various common Machining Operations have been chalked out, suitably. Main focus is put on CNC machining With Lathe Turner. Light is put on machine actually being utilized during present case study along with its specifications. Various concerned process parameters (like; feed, dept of cut and cutting speed etc.) have been elaborated. At end of chapter rough plan of given book has been mentioned.

Chapter-2 highlights information about cutting tool by defining different tool geometry variables. It not only describes about stages included in metal cutting process but also signifies about the concept of tool wear in detail. Next chapter-3 emphasizes mainly on Aluminium and its alloys. It also demonstrates broad classification of Al alloys with its relevant applications. Chapter-4 discusses about Response Surface Methodology (RSM) in length. It shares the information about selected design of RSM in present case and elaborates Analysis of Variance (ANOVA) tool as a statistical tool being used during study, to further verify the achieved optimization of machining parameters. This also deals with the multiple responses (like; MRR and Ra) under consideration and talk about the need of present study in existing machining SMEs (especially in developing nations).

Chapter-5 represents the retrospective review of literature concerning Machining, CNC Machining, Non-Ferrous Machining and its respective Optimization, tried by different practitioners, engineers and machinists with time. Next chapter-6 describes the methodology adopted to optimize the present CNC machining through RSM for Al-7020 alloy. A comprehensive information regarding; CNC Machining of non ferrous alloy, RSM, actual experimentation performed and corresponding statistical analysis of RSM by 'Minitab-16 Release' software have been quoted, strategically in chapter-7. It also demonstrates the way to validate the achieved 'Optimized Machine Settings' with the help of ANOVA, appropriately. Conclusions have been made and future scope of such a work has been briefed in chapter-8. A complete list of references and web sources (as cited in book text) has been pasted at end of book for future consultation of readers.

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CHAPTER 1

MACHINING AND CNC MACHINING

1.1 Machining: An Introduction

Machining is a process in which a piece of raw material is cut into a desired final shape and size through a controlled material-removal activity. Traditional machining processes consist of turning, boring, drilling, milling, broaching, sawing, shaping, planning, reaming and tapping. In these "traditional" or "conventional" machining processes, machine tools like; lathes, milling machines, drill presses, or others, are used with a cutting tool to remove material and achieve a desired geometry (Oberg. 2004). The new technologies include; electrical discharge machining (EDM), electrochemical machining (ECM), electron beam machining (EBM), photochemical machining and ultrasonic machining etc. In current usage, the term "machining" usually implies the traditional machining processes that may be performed on conventional or CNC machines.

Machining is used to manufacture many metal products and further can also be used on materials such as wood, plastic, ceramic and composites. A person well versed in machining is known as a machinist. A room, building or company where machining is executed is called a machine shop. Much of modern day machining is performed out through computer numerical control (CNC), in which computers are used to monitor and control the movement or operation of the mills, lathes and other cutting machines.

1.2 Machining Operations

The major three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous category include; shaping, planning, boring, broaching and sawing (Groover, 2007). Turning operations are one that rotates the work piece against the cutting tool. Lathes are the principal machine- tool used in turning. Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving linearly while the work piece rotates. The tool's axes of movement may be literally a straight line or they may be along some set of curves or angles, but they are essentially linear (in the non-mathematical sense). Usually the term "turning" is reserved for the generation of external surfaces by cutting action, whereas this same essential cutting action when applied to internal surfaces (that is, holes, of one kind or another) is known as "boring". Thus the phrase "turning and boring" categorizes the larger family of (essentially similar) operations. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, named as "facing", and may be lumped into either category as a subset.

Turning can be performed manually, in a traditional form by lathe, which frequently requires continuous supervision by the operator or by using an automated lathe, which does not. Today the most common type of such automation is computer numerical control, better known as CNC. (CNC is usually used with many other types of machining besides turning). When turning a piece of relatively rigid material (such as wood, metal, plastic or stone) is rotated and a cutting tool is traversed along axes of motion to produce precise diameters and depths. Lathes could even be used to manufacture complex geometric figures but since the advent of CNC it has become unusual to use non-computerized tool path control for this purpose.

The turning operations are typically carried out on a lathe, considered to be the oldest machine tools and can be of four different types such as straight turning, taper turning, profiling or external grooving. Those types of turning processes can produce different shapes of materials such as straight, conical, curved or grooved work piece etc. In general, turning utilizes simple single-point cutting tools. Each group of work piece materials has an optimum set of tools angles which have been developed through the years. The bits of waste metal from turning operations are called ‘chips’ (in North America) or ‘swarf’ (in Britain). In some areas they may be called just ‘turnings’.

1.2.1 Turning Operations

This operation is one of the most basic machining operations. That is, the part is rotated while a single point cutting tool is moved parallel to the axis of rotation (Todd, 1994). Turning (refer figure 1) can be done on the external surface of the part as well as internally (boring). The starting material is generally a work piece generated by other processes such as casting, forging, extrusion, or drawing (Google, 2013). Straight turning may he performed upon a work piece supported in a chuck, but the majority of work pieces turned on an engine lathe are turned between centers. Turning is the removal of metal from the external surface of cylindrical work pieces using various types of cutter tool bits.

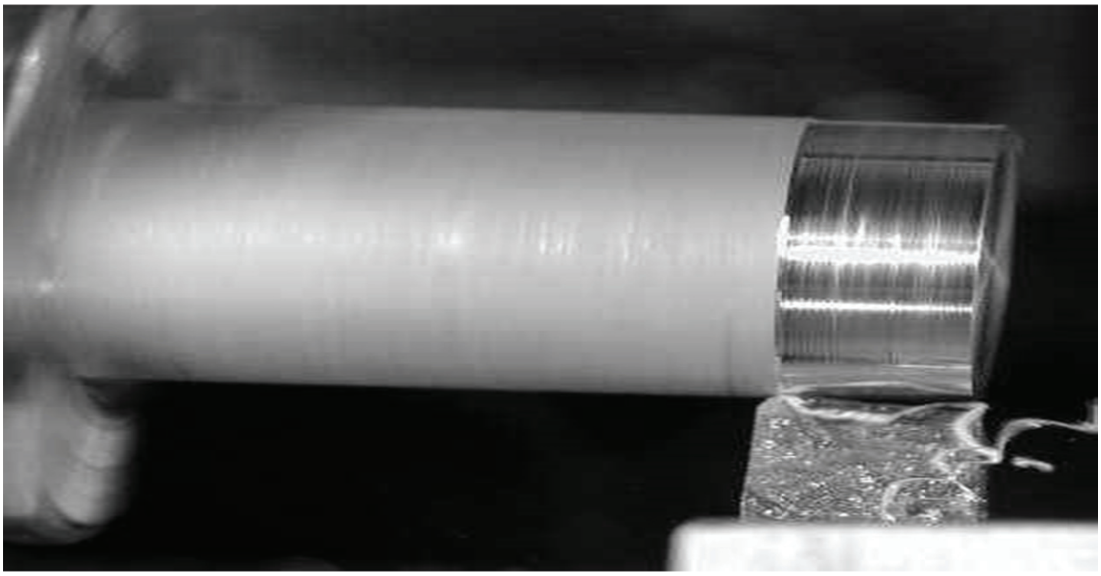


Figure 1 Turning

(Source: Google Images)

1.2.2 Tapered Turning

In straight turning, the cutting tool moves along a line parallel to the axis of the work, causing the finished job to be the same diameter throughout. However during taper cutting the tool moves at an angle to the axis of the work, producing a taper (Yahoo, 2013). Therefore, to turn a taper, the work must either be mounted on a lathe so that the axis upon which it turns is at an angle to the axis of the machine, or cause the cutting tool to move at an angle to the axis of the machine (see figure 2).

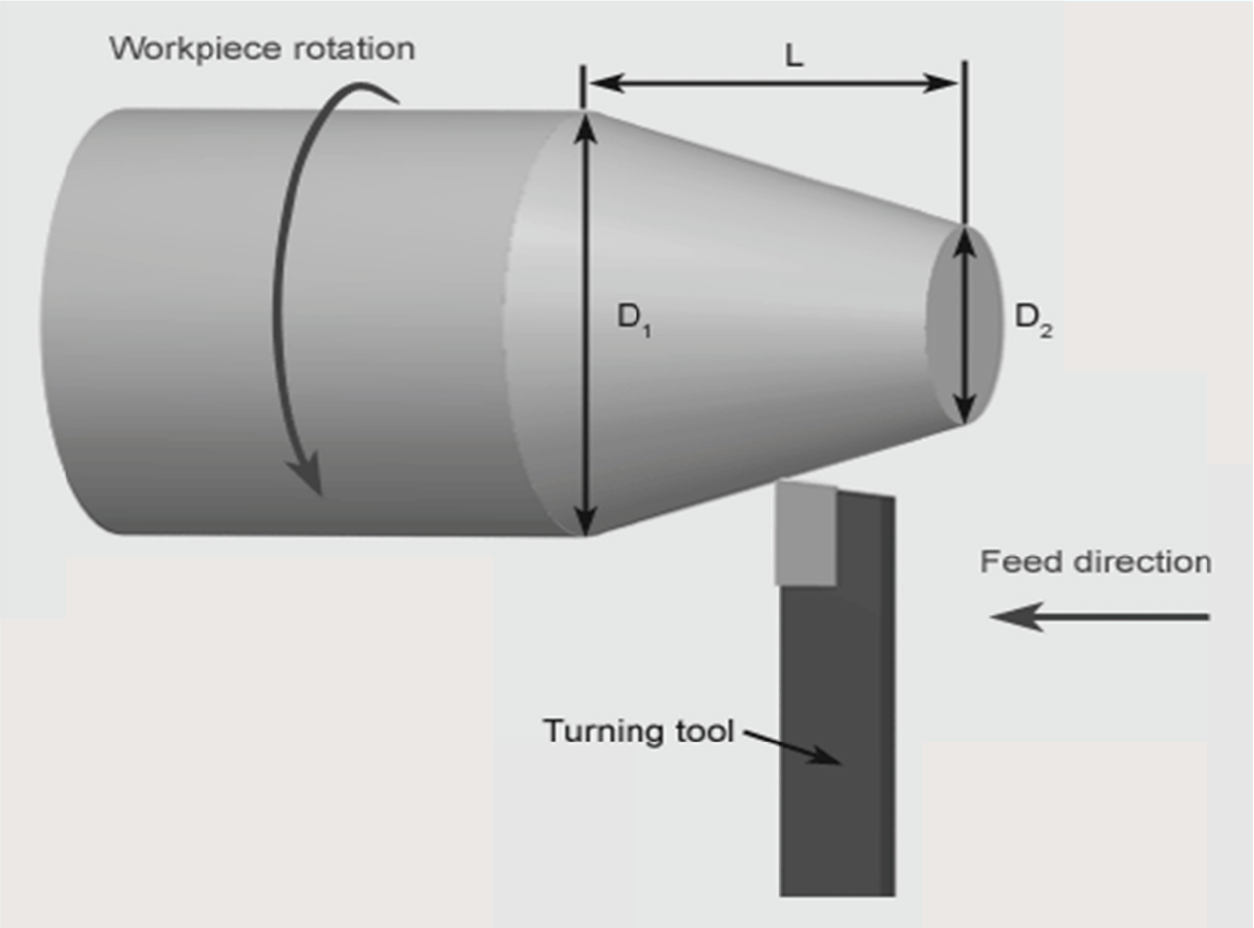


Figure 2 Taper Turning

(Source: Yahoo Images)

Taper turning can be performed from following ways:

- By the compound slide
- By taper turning attachment
- By Using a hydraulic copy attachment
- Using a C.N.C. lathe
- Using a form tool
- By the offsetting of the tailstock - this method is more suitable for shallow tapers.

1.2.3 Hard Turning

Hard turning is a turning operation done on materials with a Rockwell Hardness greater than 45. It is typically performed after the work piece is heat treated. The process is intended to replace or limit traditional grinding operations. It is applied for purely stock removal purposes and competes favorably with rough grinding. However, when it is used for finishing where form and dimension are critical then grinding is superior. Grinding produces more dimensional accuracy of roundness and cylindricity. In addition, polished surface finishes of Rz 0.3-0.8z cannot be achieved with hard turning alone. Hard turning is appropriate for parts requiring roundness accuracy of 0.5-12 micrometers, and/or surface roughness of Rz 0.8–7.0 micrometers. It is used for gears, injection pump components, hydraulic components and among other applications.

1.2.4 Facing

Facing is a type of turning work, which involves moving the cutting tool at right angles to the axis of rotation of the rotating work piece (Koepfer, 2010).

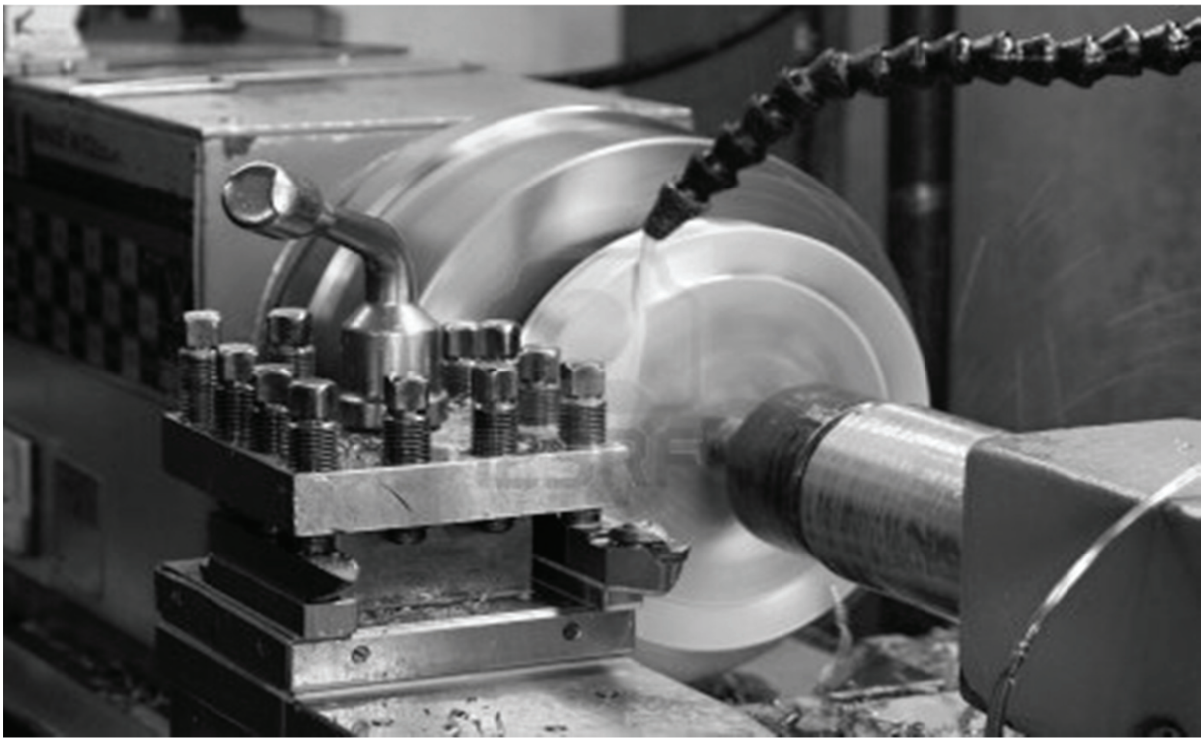


Figure 3 Facing

(Source: Wikipedia)

This can be performed by the operation of the cross-slide, if one is fitted, as distinct from the longitudinal feed (Wikipedia, 2013). It is frequently the first operation performed in the production of the work piece and often the last one also (look at figure 3 for details).

1.2.5 Grooving

According to Wikipedia Grooving is like parting, except that grooves are cut to a specific depth instead of severing a completed/part-complete component from the stock (Wikipedia, 2013). Grooving can be done on internal and external surfaces, as well as on the face of the work piece. (Also known as face grooving or trepanning, refer figure 4 and 5).

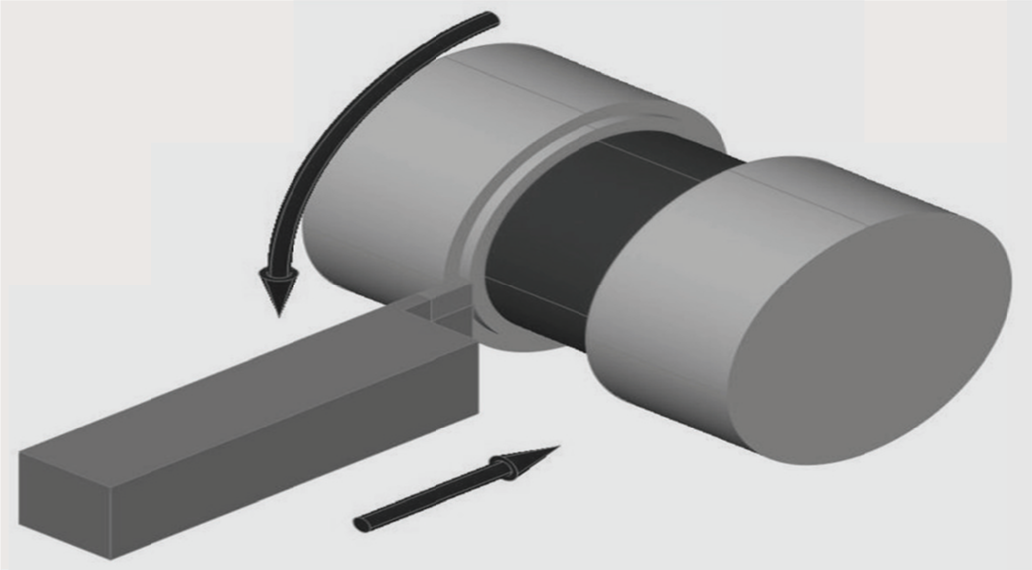


Figure 4 External Grooving

(Source: Wikipedia)

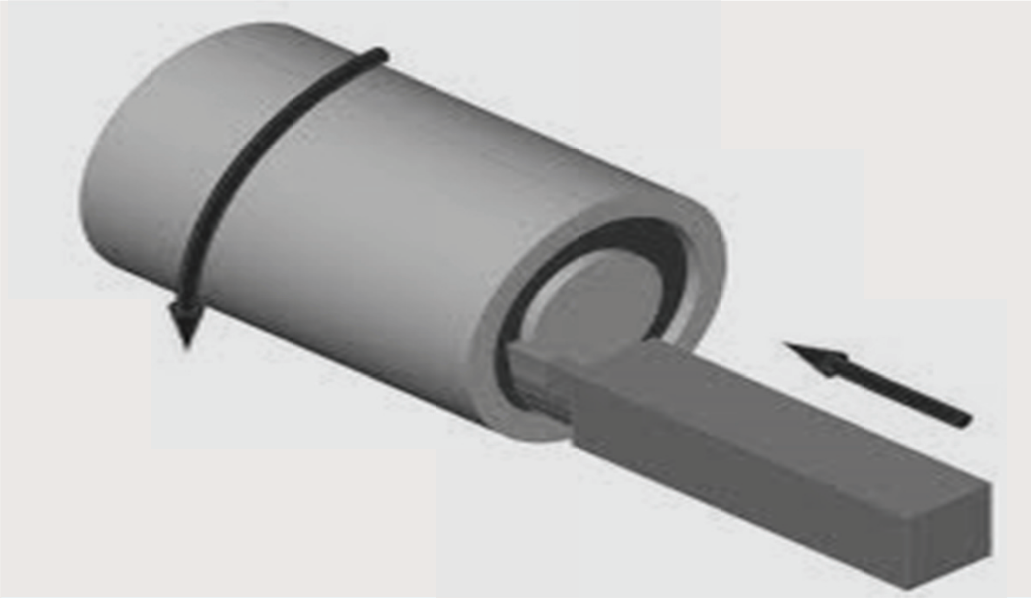


Figure 5 Face Grooving

(Source: Wikipedia)

Grooving is like parting, except that grooves are cut to a specific depth instead of severing a completed/part-complete component from the stock. Grooving can not only be executed on internal and external surfaces but it can also be on the face of the part (face grooving or trepanning). Other Miscellaneous machining operations are described briefly as under:

1.2.6 Boring

Enlarging or smoothing a hole created by drilling or moulding etc. The machining of internal cylindrical forms (generating) can be possible either by mounting work piece to the spindle via a chuck and faceplate or by mounting work piece onto the cross slide and placing cutting tool into the chuck (see figure 8 for more description).

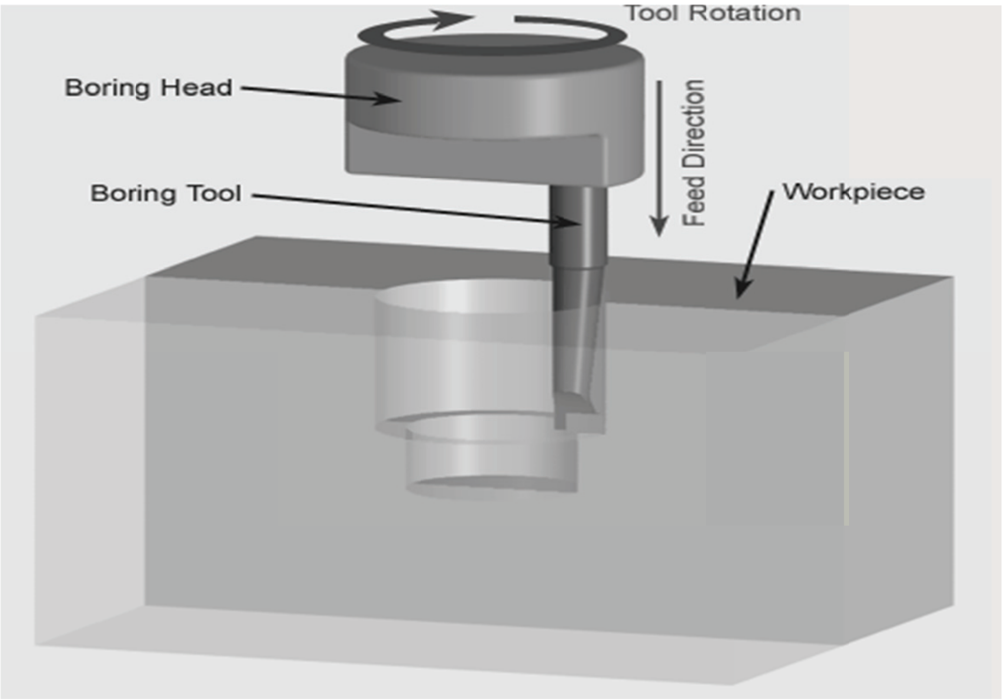


Figure 6 Boring

(Source: Ask.com Images)

On long bed lathes large work pieces can be bolted to a jig or fixture (on the bed) and a shaft is made to pass between two lugs of the work piece. Further these lugs can be bored out to size (Wikipedia, 2013).

1.2.7 Drilling

Drilling is a process of making a hole of required diameter in the work piece. Drilling process is of great significance from manufacturing point of view (Bralla, 1999). Drilling process is highlighted in the figure 6 as below.

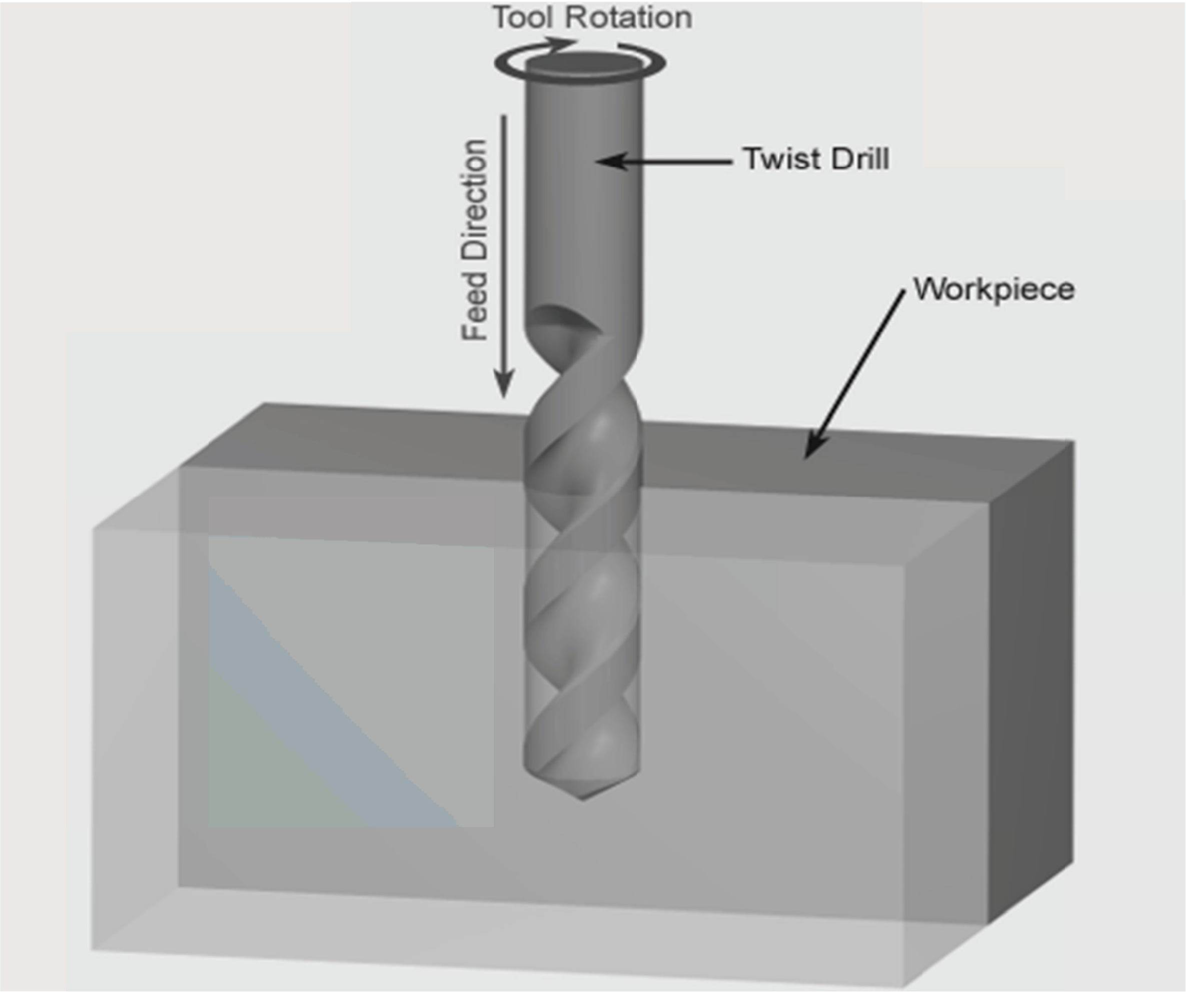


Figure 7 Drilling

(Source: Google Images)

Drilling is used to remove material from the inside of a work piece. This process uses standard drill bits held stationary in the tail stock or tool turret of the lathe (Google, 2013). The process can be executed by separately available drilling machines.

1.2.8 Knurling

Knurling is a process of creating diamond like cuts on the surface of the part which assists in its proper gripping. Knurling process is done with a specific knurling tool as described in figure 7 ahead.

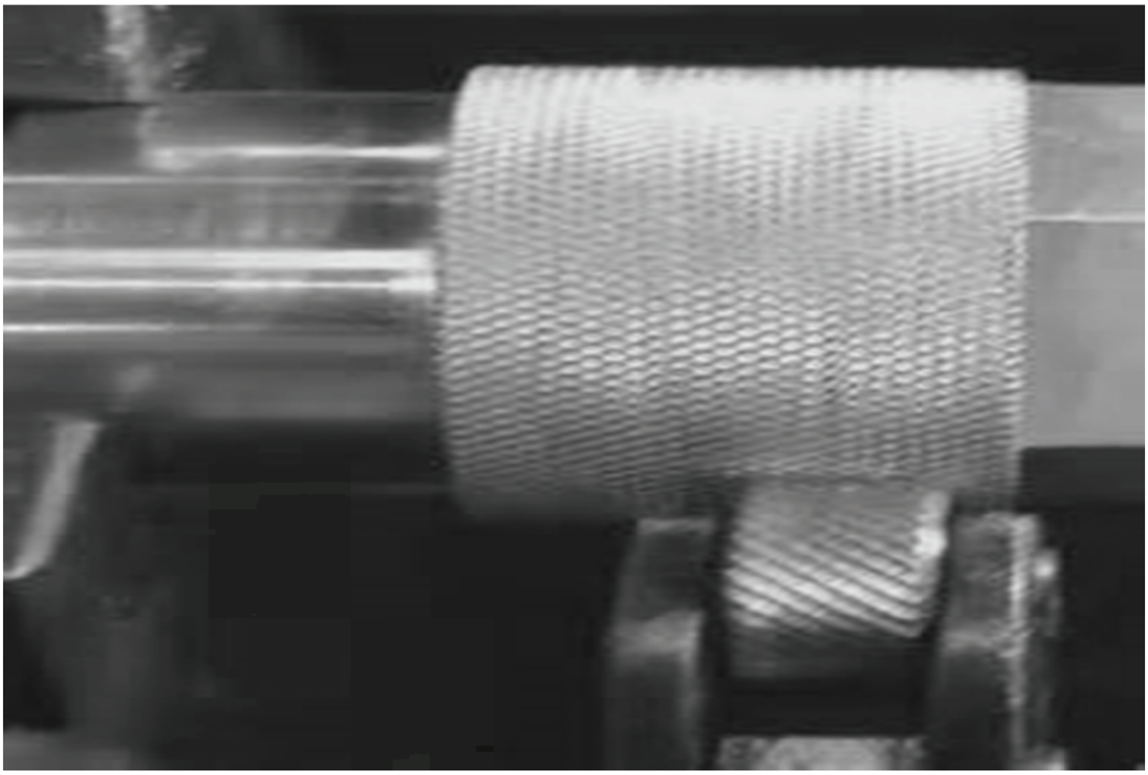


Figure 8 Knurling

(Source: Yahoo Images)

The cutting of a serrated pattern onto the surface of a part (for a better hand grip) through application of a special purpose 'knurling tool' is known as Knurling Operation (Yahoo Search, 2013).

1.2.9 Reaming

The sizing operation that eliminates a small amount of metal or material from an existing hole is called Reaming. It is done for making internal holes of very accurate diameters. For example, a 6mm hole is made by drilling with 5.98 mm drill bit and then reamed to achieve accurate dimensions (Ask.com, 2013).

1.2.10 Threading

Both standard and non-standard screw threads can be turned on a lathe by using an appropriate cutting tool. (Usually having a 60° or 55° nose angle) Either externally or within a bore generally referred to as single-point threading (look at figure 9).

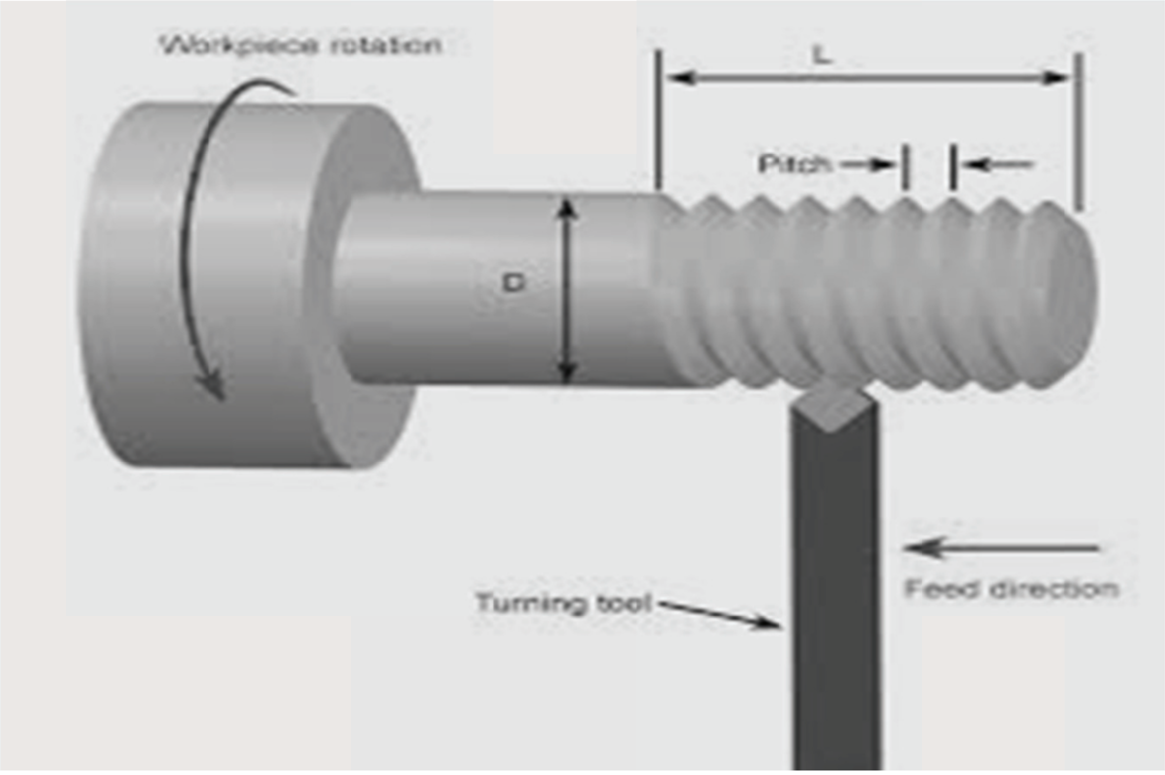


Figure 9 Threading

(Source: Bing Images)

Tapping of threaded nuts and holes can be done through hand taps or by using a tapping device with a slipping clutch to reduce risk of breakage of the tap (Bing, 2013). Threading operations include all types of external and internal thread forms using a single point tool also taper threads, double start threads, multi start threads, and worms as used in worm wheel reduction boxes, lead screw with single or multi-start threads. By the use of threading boxes fitted with 4 form tools, up to 2" diameter threads but it is possible to find larger boxes than this.

1.3 An Overview of Machining Technology

Machining is any process in which a cutting tool is used to remove material in the form of small chips from the work piece (the work piece is often called the "part"). To perform the operation, relative motion is required between the tool and the part. This relative motion is achieved in most machining operation by means of a primary motion, called "cutting speed" and a secondary motion called "feed". The shape of the tool and its penetration into the work surface, combined with these motions, produce the desired shape of the resulting work piece.

1.4 CNC Lathe / CNC Turning Center

Numerical control (NC) machine is an automated machine-tool that is operated by precisely programmed commands encoded on a storage medium (in contrast with manually controlled via; hand wheels, levers or cams alone). Most of NC machines are today computer numerical controlled (CNC), in which computers play an integral part of the control (Smid, 2008). The first NC machines were built in 1940s and 1950s, based on existing tools that were modified with motors that moved the controls to follow points fed into the system on punched tape. These early servomechanisms were rapidly augmented with analog and digital computers, creating the modern CNC machine tools that have revolutionized the machining processes, afterwards.

CNC Machine Variants

Computer numerical controlled (CNC) lathes are rapidly replacing the older production lathes (multi-spindle, etc.) due to their ease of setting, operation, repeatability and accuracy. These are designed to use modern carbide tooling and are more compatible with modern technology. The part may be designed and the tool paths are programmed by the CAD/CAM process (or manually by the programmer) and the resulting file is uploaded to the machine. After setting and taking trials, the machine will continue to turn out parts under the occasional supervision of an operator. Following are some of the few areas where CNC is working successfully:

- **Drills**
- **EDMs**
- **Embroidery machines**
- Lathes
- Milling machines
- Wood routers
- Sheet metal works (Turret punch)
- Wire bending machines
- Hot-wire foam cutters
- Plasma cutters
- Water jet cutters
- Laser cutting
- Oxy-fuel
- Surface grinders
- Cylindrical grinders
- 3D Printing
- Induction hardening machines
- submerged welding
- knife cutting
- glass cutting

The machine is controlled electronically via a computer menu style interface. The program may be modified and displayed at the machine, along with a simulated view of the process. The setter/operator needs a high level of skill to perform the process, however the knowledge base is broader compared to the older production machines where intimate knowledge of each machine was considered essential. These machines are often set and operated by the same person, where the operator will supervise a number of machines (or cells).

The design of a CNC lathe varies with different manufacturers, but they all have some common elements (Herrin, 1998). The turret holds the tool holders and can be indexed as per need, the spindle holds the work piece and there are slides that let the turret move in multiple axis simultaneously. The machines are often totally enclosed, due in large part to occupational health and safety (OH&S) issues. With rapid growth in this industry, different CNC lathe manufacturers use different user interfaces which sometimes make it difficult for operators as they have to be acquainted with them (Zhou et al., 1995). With the advent of cheap computers, free operating systems such as: Linux and open source CNC software, the entire price of CNC machines has been slashed. In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a post processor and then loaded into the CNC machines for production (Wannas, 2008). Since any particular component might require the use of a number of different tools – drills, saws, etc., modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine (Taj and Morosan, 2011). In either case, the series of steps needed to produce any part is highly automated and produces a part that closely matches the original CAD design.

Nowadays, more and more Computer Numerical Controlled (CNC) machines are being used in every kind of manufacturing processes (Suresh et al., 2002). In a CNC machine, functions like: program storage, tool offset and tool compensation, program-editing capability, various degrees of computation and ability to send and receive data from a variety of sources, including remote locations can be easily realized through on board computer (Boubekri et al., 2010). The computer can store multiple-part programs, recalling them as needed for different parts (Sahoo et al., 2008).

1.5 Present Work

In present case, the machine in focus is ‘Lokesh TL 250’ a CNC lathe having Siemen’s control system with the spindle speed ranges from 500 rpm to 4000 rpm, feed rate up to 20 mm/rev and 16 KVA power rating (refer figure 10). For generating the turning surfaces, CNC part programming for tool paths are created with specific commands (Mahdavinejad and Sharifi, 2009).

Figure 10 Lokesh TL 250 Used in Present Work

(Source: Ashoka Gears Patiala)

Tool Used: Commercially available carbide tool Taegutech TNMG 160408 –GM – TT.3500 with nose radius 0.8 mm is used in the present investigation. Compressed Sam Soil coolant is used as cutting environment.

***Material Used*:** The present study is carried out with Al 7020 aluminium alloy. The chemical composition of aluminium alloy is enlisted in the table below. Al-Zn alloys 7020 have the following composition by weight percentage (see table 1).

Alloy	7020
Mg	1.0-1.4
Mn	0.05-0.50
Fe	<0.40
Si	<0.35
Cu	<0.20
Zn	4.0-5.0
CR	0.10-0.35
Zr	0.08-0.20
Zr+Ti	0.08-0.25
Other element	<0.05
Total other	<0.15
Al	Rem

Table 1 Composition of Aluminium Alloy-7020

1.6 Machining Parameters

The effects of following turning parameters have been taken into account to optimize the machining responses like: Material Removal Rate (MRR) and Surface Finish (Ra).

1.6.1 Cutting Speed

Cutting speed may be defined as the rate (or speed) that the material moves past the cutting edge of the tool, irrespective of the machining operation used. In other words, it is the speed at which the metal is removed by the tool from the work piece (Google, 2013). In a lathe it is the peripheral speed of the part past the cutting tool expressed in meters per minute For a given material, there will be an optimum cutting speed for a certain set of machining conditions and from this speed the machine's spindle speed (RPM) can be calculated. Factors affecting the calculation of cutting speed are:

- The material being machined (steel, brass, tool steel, plastic, wood) (see table below).
- The material of the cutter (Carbon steel, high speed steel (HSS), carbide and ceramics).
- The economical life of the cutter (the cost to regrind or purchase new as compared to the quantity of parts produced)

Cutting speeds are calculated on the assumption that optimum cutting conditions exist, these include (Wikipedia, 2013):

- Metal removal rate (finishing cuts that remove a small amount of material may be run at increased speeds).
- Full and constant flow of cutting fluid (adequate cooling and chip flushing).
- Rigidity of the machine and tooling setup (reduction in vibration or chatter).
- Continuity of cut (as compared to an interrupted cut, such as machining square section material in a lathe).
- Condition of material (mill-scale, hard-spots due to white cast iron forming in castings etc.)

The cutting speed is given as a set of constants that are available from the material manufacturer (or supplier). The most common materials are available in reference books or charts but will always be subject to adjustment depending on the cutting conditions. The table 2 gives the cutting speeds for a selection of common materials under one set of conditions. The conditions are a tool life of 1 hour, dry cutting (no coolant) and at medium feeds so these may be appeared to be incorrect depending on circumstances.

Material Type	Meters per min (MPM)	Surface feet per min (SFM)
Steel (tough)	15–18	50–60
Mild steel	30–38	100–125
Cast iron (medium)	18–24	60–80
Alloy steels (1320–9262)	20-37	65–120
Carbon steels (C1008-C1095)	21-40	70–130
Free cutting steels (B1111-B1113 & C1108-C1213)	35-69	115–225
Stainless steels (300 & 400 series)	23-40	75–130
Bronzes	24–45	80–150
Leaded steel (Leadloy 12L14)	91	300
Aluminium	75–105	250–350
Brass	90-210	300-700 (Max. spindle speed)

Table 2 Cutting Speeds for Various Materials Using HSS Cutter ***(Source: Wikipedia)***

These cutting speeds may change if, for instance, adequate coolant is available or an improved grade of HSS is used (such as one that includes cobalt). The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (rpm). The preferred speed is determined by working backward from the desired surface speed (sfm or m/min) and incorporating the diameter (of work piece or cutter). The spindle may hold the:

- Material (as in a screw machine)
- Drill bit in a drill
- Milling cutter in a milling machine
- Router bit in a wood router
- Shaper cutter or knife in a wood shaper or spindle moulder
- Grinding wheel on a grinding machine.
- Or it may hold the chuck, which then holds the work piece in a lathe. In these cases the tool is often a stationary tool bit, although there are plenty of exceptions, such as in thread milling.

1.6.2 Feed Rate

Feed rate is the velocity at which the cutter is fed, or it is an advancement of cutter against the work piece. It is expressed in units of distance per revolution for turning and boring (typically in inches per revolution [ipr] or in millimeters per revolution). Feed rate is dependent on the (Wikipedia, 2013):

- Type of tool (a small drill or a large drill, high speed or carbide, a box tool or recess, a thin form tool or wide form tool, a slide knurl or a turret straddle knurl).
- Surface finish desired.
- Power available at the spindle (to prevent stalling of the cutter or work piece).
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the work piece (high feed rates will collapse thin wall tubing)
- Characteristics of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool and work.
- Threads per inch (TPI) for taps, die heads and threading tools.

When deciding what feed rate to use for a certain cutting operation, the calculation is fairly straightforward for single-point cutting tools, because all of the cutting work is done at one point. With a milling machine or jointer, where multi-tipped/multi-fluted cutting tools are involved, then the desirable feed rate becomes dependent on the number of teeth on the cutter, as well as the desired amount of material per tooth to cut (expressed as chip load). Greater the number of cutting edges, higher will be the feed rate permissible for a cutting edge to work efficiently (Ask.com, 2013). It must remove sufficient material to cut rather than rub and it also must do its fair share of work. The ratio of the spindle speed and the feed rate controls decides the aggressiveness of the cut and the nature of the swarf formed.

Formula to determine feed rate

This formula can be used to figure out the feed rate which the cutter travels into or around the work. This would apply to cutters on a milling machine, drill press and a number of other machine tools. This is not to be used on the lathe for turning operations, as the feed rate on a lathe is given as feed per revolution.

$$\mathbf{FR = RPM \times T \times CL}$$

Where:

- *FR* is the calculated feed rate in inches per minute or mm per minute.
- *RPM* is the calculated speed for the cutter.
- *T* is the Number of teeth on the cutter.
- *CL* is the chip load or feed per tooth. This is the size of chip that each tooth of the cutter takes.

1.6.3 Depth of Cut

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 (Google, 2013).

1.7 Summary

Machining is a manufacturing process in which unwanted material is removed from the work piece to get the desired shape and dimensions. During turning process we expect highest material removal rate and at the same time minimum surface roughness. Therefore it becomes important to optimize turning parameters to achieve the highest material removal rate and at the same time minimum surface roughness. The parameters during CNC turning which affects these responses are cutting speed, feed, depth of cut, tool material, environmental conditions, coolant used, operator skill etc. Surface roughness and material removal rate have great impact on the mechanical properties such as corrosion resistance, fatigue and creep. It also impacts on the functionality of the machine such as friction, wear, heat transmission etc.

In the present work the optimization of CNC turning parameters like cutting speed, feed and depth of cut for aluminum - zinc alloy 7020 is done by performing experiments using Response Surface Method (RSM) to maximize the material removal rate and at the same time minimizing the surface roughness. After optimization results are appraised through ANOVA.

CHAPTER 2

CUTTING TOOLS

2.1 Tools

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 figure 11 briefly. For single point tools, the most important angles are the rake angles and the end and side relief angles (E. Paul DeGarmo).

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.

Face: The flat surface of a single point tool through which, the work piece rotates during turning operation (Khandey, 2008). On a typical turning setup, the face of the tool is positioned upwards.

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.

Side rake angle: It is the angle formed by the face of the tool and the centerline of the work piece (Antony, 2000). A positive side rake angle tilts the tool face down toward the floor, and a negative angle tilts the face up and toward work piece.

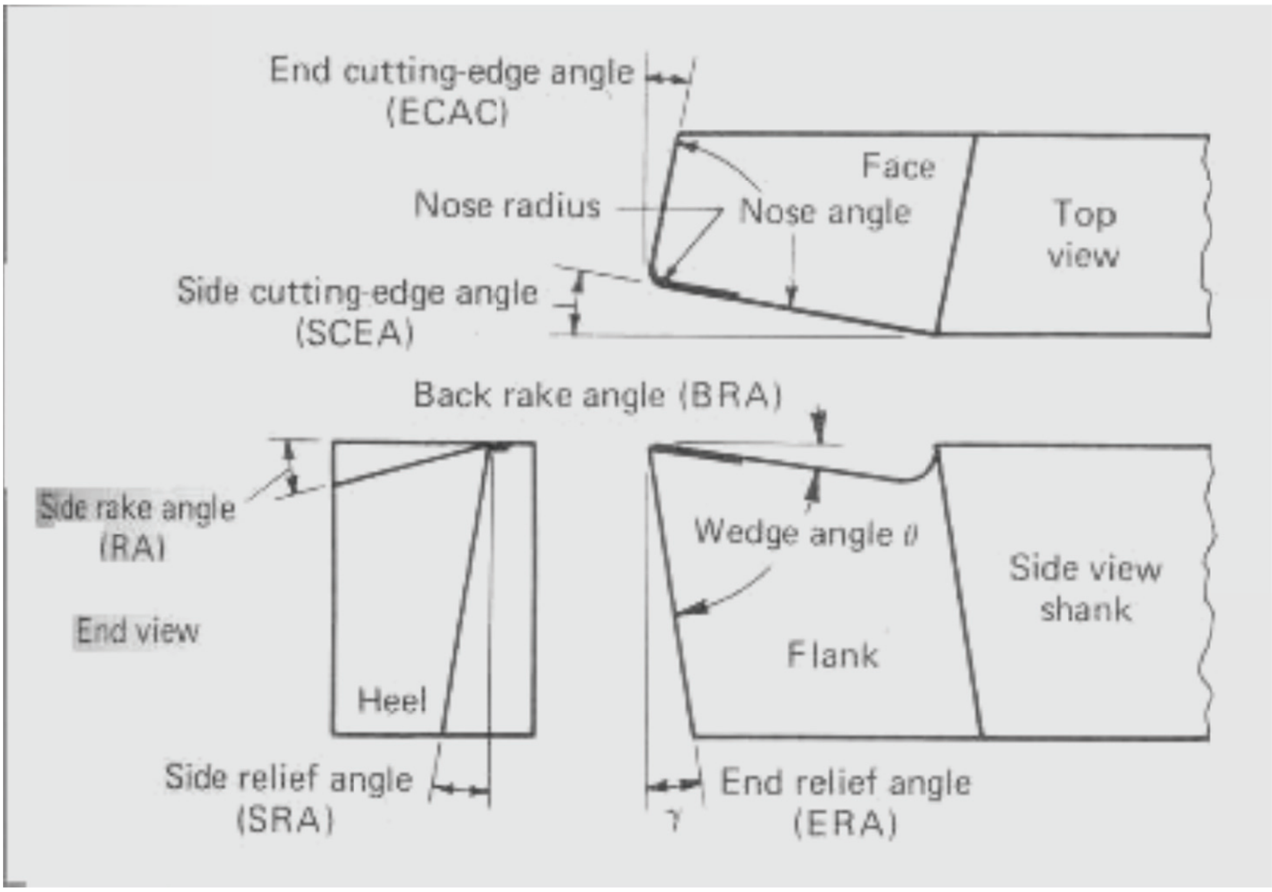


Figure 11 Geometry of a Single Point Turning Tool [66]

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 centerline. 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.

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 centerline (Bhattacharyya, 2006). Increasing the end cutting edge angle tilts the far end of the cutting edge away from the work piece.

Side relief angle: If viewed behind the tool 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.

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 (Ahmed, 2006). Increasing the end relief angle tilts the end flank away from the work piece.

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.

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 (Abburi, 2006). 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. 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.

2.2 Multiple Cutting-Edge Tools

These have more than one cutting edge and usually achieve their motion relative to the work part by rotating. Drilling and milling uses rotating multiple-cutting-edge tools. Although the shapes of these tools are different from a single-point tool, many elements of tool geometry are similar.

2.3 Stages in Metal Cutting

Machining operations usually divide into two categories, distinguished by purpose and cutting conditions:

- Roughing cuts and
- Finishing cuts

Roughing cuts are used to remove large amount of material from the starting work part as rapidly as possible, i.e. with a large Material Removal Rate (MRR), in order to produce a shape close to the desired form, but leaving some material on the piece for a subsequent finishing operation (Albert, 2011). Finishing cuts are used to complete the part and achieve the final dimensions, tolerances and surface finish. In production machining jobs, one or more roughing cuts are usually performed on the work, followed by one or two finishing cuts. Roughing operations are done at high feeds and depths. Feeds of 0.4-1.25 mm/rev (0.015-0.050 in/rev) and depths of 2.5-20 mm (0.100-0.750 in) are typical but actual values depend on the work piece materials. Finishing operations are carried out at low feeds and depths. Feeds of 0.0125-0.04 mm/rev (0.0005-0.0015 in/rev) and depths of 0.75-2.0 mm (0.030-0.075 in) are typical. Cutting speeds are lower in roughing than in finishing. A cutting fluid is often applied to the machining operation to cool and lubricate the cutting tool. Today other forms of metal cutting are becoming increasingly popular. An example of this is water jet cutting. Water jet cutting involves pressurized water in excess of 620 MPa and is able to cut metal and have a finished product. This process is called cold cutting and it increases efficiency as opposed to laser and plasma cutting.

2.4 Tool Material

The classes of cutting tool materials currently in use for machining operation are high speed tool steel, cobalt-base alloys, cemented carbides, ceramic, 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:

Carbon steels: Carbon steels have been used since the 1880s for cutting tools (Khandey, 2008). However carbon steels start to soften at a temperature of about 180oC. 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 wood working and they can be used in a router to machine aluminium sheet up to about 3mm thick.

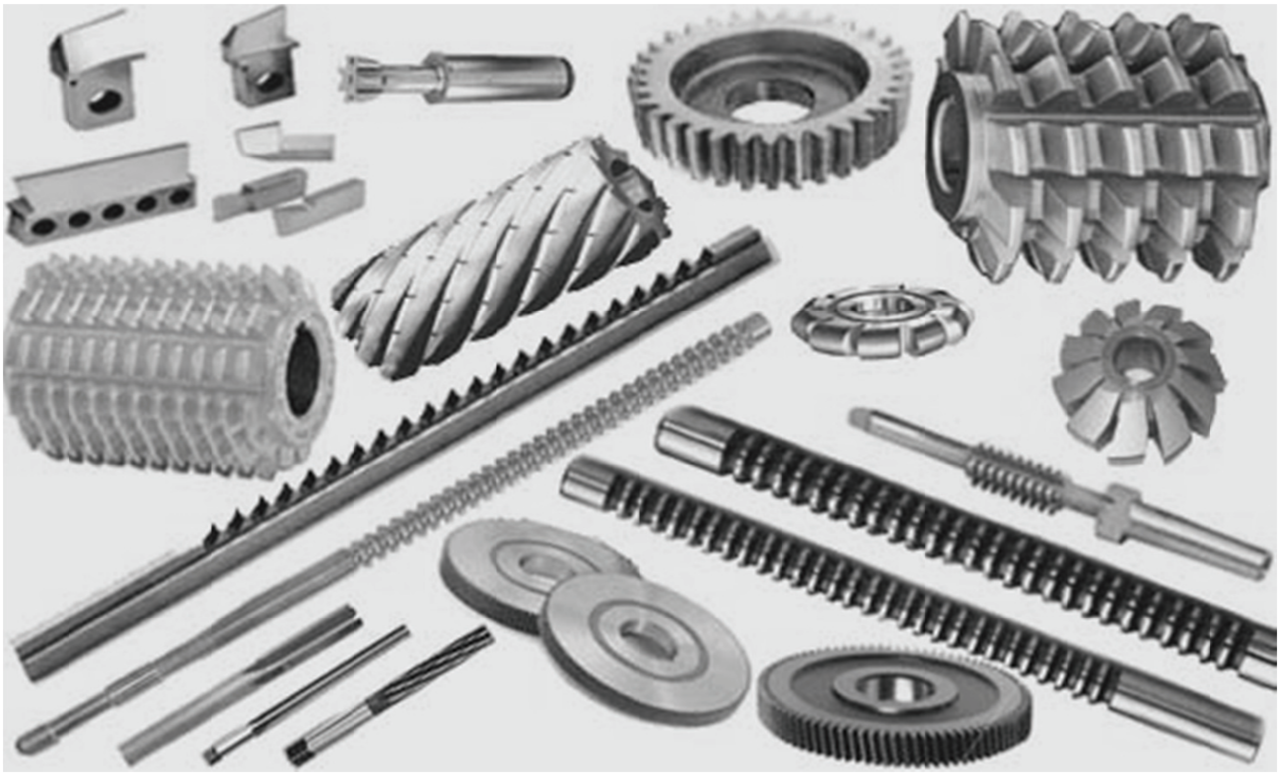


Figure 12 Multi Point Cutting Tool

(Source: Yahoo Images)

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" (Al-Ahmari A, 2007). M. A. 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.

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.

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 (Doniavi, 2007). Tungsten carbide particles (1 to 5 micrometer) 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.

Coatings: Coatings are frequently applied to carbide tool tips to improve tool life or to enable higher cutting speeds. Coated tips typically have lives 10 times greater than uncoated tips. Common coating materials include titanium nitride, titanium carbide and aluminum oxide, usually 2 - 15 micro-m thick. Often several different layers may be applied, one on top of another, depending upon the intended application of the tip. The techniques used for applying coatings include chemical vapour deposition (CVD) plasma assisted CVD and physical vapour deposition (PVD). Diamond coatings are also in use and being further developed (Feng C., 2002)

Cermets: Developed in the 1960s, these typically contain 70% aluminum oxide and 30% titanium carbide. Some formulation contains molybdenum carbide, niobium carbide and tantalum carbide. Their performance is between those of carbides and ceramics and coatings seem to offer few benefits. Typical cutting speeds: 150 - 350 m/min.

Ceramics (Alumina): Introduced in the early 1950s, two classes are used for cutting tools: fine grained high purity aluminium oxide (Al2O3) and silicon nitride (Si3N4) are pressed into insert tip shapes and sintered at high temperatures. Additions of titanium carbide and zirconium oxide (ZrO2) may be made to improve properties. But while ZrO2 improves the fracture toughness, it reduces the hardness and thermal conductivity. Silicon carbide (SiC) whiskers may be added to give better toughness and improved thermal shock resistance. The tips have high abrasion resistance and hot hardness and their superior chemical stability compared to HSS and carbides means they are less likely to adhere to the metals during cutting and consequently have a lower tendency to form a built up edge (Fnides, 2008). Their main weakness is low toughness and negative rake angles are often used to avoid chipping due to their low tensile strengths. Stiff machine tools and work set ups should be used when machining with ceramic tips as otherwise vibration is likely to lead to premature failure of the tip. Typical cutting speeds: 150-650 m/min.

Silicon Nitride: In the 1970s a tool material based on silicon nitride was developed, these may also contain aluminium oxide, yttrium oxide and titanium carbide. SiN has an affinity for iron and is not suitable for machining steels. A specific type is 'Sialon', containing the elements: silicon, aluminium, oxygen and nitrogen. This has higher thermal shock resistance than silicon nitride and is recommended for machining cast irons and nickel based super alloys at intermediate cutting speeds.

Cubic Boron Nitride (CBN): Introduced in the early 1960s, this is the second hardest material available after diamond. CBN tools may be used either in the form of small solid tips or or as a 0.5 to 1 mm thick layer of of polycrystalline boron nitride sintered onto a carbide substrate under pressure. In the latter case the carbide provides shock resistance and the CBN layer provides very high wear resistance and cutting edge strength. Cubic boron nitride is the standard choice for machining alloy and tool steels with a hardness of 50 Rc or higher. Typical cutting speeds: 30 - 310 m/min.

Diamond: The hardest known substance is diamond. Although single crystal diamond has been used as a tool, they are brittle and need to be mounted at the correct crystal orientation to obtain optimal tool life. Single crystal diamond tools have been mainly replaced by polycrystalline diamond (PCD). This consists of very small synthetic crystals fused by a high temperature high pressure process to a thickness of between 0.5 and 1mm and bonded to a carbide substrate. The result is similar to CBN tools. The random orientation of the diamond crystals prevents the propagation of cracks, improving toughness.

Because of its reactivity, PCD is not suitable for machining plain carbon steels or nickel, titanium and cobalt based alloys. PCD is most suited to light uninterrupted finishing cuts at almost any speed and is mainly used for very high speed machining of aluminium - silicon alloys, composites and other non - metallic materials (Hope A. D 2008). Typical cutting speeds: 200 - 2000 m/min. To improve the toughness of tools, developments are being carried out with whisker

Reinforcement, such as silicon nitride reinforced with silicon carbide whiskers. As rates of metal removal have increased, so has the need for heat resistant cutting tools. The result has been a progression from high-speed steels to carbide, and on to ceramics and other super hard materials. High-speed steels cut four times faster than the carbon steels they replaced. There are over 30 grades of high-speed steel, in three main categories: tungsten, molybdenum, and molybdenum-cobalt based grades. In industry today, carbide tools have replaced high-speed steels in most applications. These carbide and coated carbide tools cut about 3 to 5 times faster than high-speed steels. Cemented carbide is a powder metal product consisting of fine carbide particles cemented together with a binder of cobalt. The major categories of hard carbide include tungsten carbide, titanium carbide, tantalum carbide, and niobium carbide. Ceramic cutting tools are harder and more heat-resistant than carbides, but more brittle. They are well suited for machining cast iron, hard steels, and the super alloys. Two types of ceramic cutting tools are available: the alumina-based and the silicon nitride-based ceramics. The alumina-based ceramics are used for high speed semi- and final-finishing of ferrous and some non-ferrous materials. The silicon nitride-based ceramics are generally used for rougher and heavier machining of cast iron and the super alloys.

2.5 Tool Wear

Tool wear has following types:

- Hard particle wear (abrasive wear)
- Adhesive wear
- Diffusion wear
- Chemical wear
- Fracture wear

Hard particle wear (abrasive wear): Abrasive wear is mainly caused by the impurities within the work piece material, such as carbon, nitride and oxide compounds, as well as the built-up fragments. This is a mechanical wear, and it is the main cause of the tool wear at low cutting speeds (Khandey, 2010).

Adhesive wear: The simple mechanism of friction and wear proposed by Bowden and Tabor is based on the concept of the formation of welded junctions and subsequent destruction of these. Due to the high pressure and temperature, welding occurs between the fresh surface of the chip and rake face (chip rubbing on the rake face results in a chemically clean surface). [Process is used to advantage when Friction welding to produce twist drill and broaches and in tool manufacturing]. Severe wear is characterized by considerable welding and tearing of the softer rubbing surface at high wear rate, and the formation of relatively large wear particles. Under mild wear conditions, the surface finish of the sliding surfaces improves.

Diffusion wear: Holm thought of wear as a process of atomic transfer at contacting asperities (Armarego and Brown 2005). A number of workers have considered that the mechanism of tool wear must involve chemical action and diffusion. They have demonstrated welding and preferred chemical attack of tungsten carbide in tungsten-titanium carbides. They have shown the photo-micrograph evidence of the diffusion of tool constituents into the work piece and chip. This diffusion results in changes of the tool and work piece chemical composition. There are several ways in which the wear may be dependent on the diffusion mechanism.

- Gross softening of the tool
- Diffusion of major tool constituents into the work (chemical element loss)
- Diffusion of a work-material component into the tool

Chemical wear: Corrosive wear (due to chemical attack of a surface)

Facture wear: Fracture can be the catastrophic end of the cutting edge. The bulk breakage is the most harmful type of wear and should be avoided as far as possible. Chipping of brittle surfaces

Other forms of tool wear: Thermo-electric wear can be observed in high temperature region, and it reduces the tool wear (Kirby, 2004). The high temperature results in the formation of thermal couple between the work piece and the tool. Due to the heat related voltage established between the work piece and tool, it may cause an electric current between the two. However, the mechanism of thermo-electric wear has not been clearly developed. Major improvement (decrease) of tool wear has been seen through experimental tests with an isolated tool and component.

Thermal Cracking and Tool Fracture: In milling, tools are subjected to cyclic thermal and mechanical loads. Teeth may fail by a mechanism not observed in continuous cutting. Two common failure mechanisms unique to milling are thermal cracking and entry failure. The cyclic variations in temperature in milling induce cyclic thermal stress as the surface layer of the tool expands and contracts. This can lead to the formation of thermal fatigue cracks near the cutting edge. In most cases such cracks are perpendicular to the cutting edge and begin forming at the outer corner of the tool, spreading inward as cutting progresses. The growth of these cracks eventually leads to edge chipping or tool breakage. Thermal cracking can be reduced by reducing the cutting speed or by using a tool material grade with a higher thermal shock resistance. In applications when coolant is supplied, adjusting the coolant volume can also reduce crack formation. An intermittent coolant supply or insufficient coolant can promote crack formation; if a steady, copious Volume of coolant cannot be supplied, tool-life can often be increased by switching to dry cutting. Edge chipping is common in milling. Chipping may occur when the tool first contacts the part (entry failure) or, more commonly, when it exits the part (exit failure). WC tool materials are especially prone to this. Entry failure most commonly occurs when the outer corner of the insert strikes the part first. This is more likely to occur when the cutter rake angles are positive. Entry failure is therefore most easily prevented by switching from positive to negative rake cutters.

CHAPTER 3

ALUMINIUM AND ITS ALLOYS

3.1 Aluminium

Aluminium (or aluminum) is a chemical element in the boron group with symbol Al and atomic number 13. It is a silvery white, soft and ductile metal. Aluminum is the third most abundant element (after oxygen and silicon) and the most abundant metal**,** in the earth**-**crust. It makes up about 8% by weight of the Earth's solid surface (Askeland, 2005). Aluminum metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals. The chief ore of aluminum is bauxite.

Aluminum is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminum and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminum, at least on a weight basis, are the oxides and sulfates. Despite its prevalence in the environment, aluminum salts are not known to be used by any form of life. In keeping with its pervasiveness, aluminum is well tolerated by plants and animals (Yumoto, 2009). Owing to their prevalence, potential beneficial (or otherwise) biological roles of aluminum compounds are of continuing interest.

3.2 Fundamentals of Aluminum Alloys

In the ANSI (NADCA) numbering system, major Aluminium alloying elements and certain combinations of elements are indicated by specific number series, as follows:

Number Series	Alloy Type
1XX.X	99.0% minimum aluminum content
2XX.X	Al + Cu
3XX.X	Al + Si & Mg, or Al + Si& Cu, or Al + Si & Mg & Cu
4XX.X	Al + Si
5XX.X	Al + Mg
7XX.X	Al + Zn
8XX.X	Al + Sn

Table 3 Al Alloys

3.2.1 1XX.X Series Alloys

(Non-heat treatable – with ultimate tensile strength of 10 to 27 ksi)

This series is often referred to as the pure aluminum series because it is required to have 99.0% minimum aluminum. They are weld able. However, because of their narrow melting range, they require certain considerations in order to produce acceptable welding procedures. When considered for fabrication, these alloys are selected primarily for their superior corrosion resistance such as in specialized chemical tanks and piping, or for their excellent electrical conductivity as in bus bar applications (Andersson, 1998). These alloys have relatively poor mechanical properties and would seldom be considered for general structural applications. These base alloys are often welded with matching filler material or with 4xx.x filler alloys dependent on application and performance requirements.

3.2.2 2XX.X Series Alloys

(Heat treatable– with ultimate tensile strength of 27 to 62 ksi)

These are aluminum/copper alloys (copper additions ranging from 0.7 to 6.8%) and are high strength, high performance alloys that are often used for aerospace and aircraft applications. They have excellent strength over a wide range of temperature. Some of these alloys are considered non-weld able by the arc welding processes because of their susceptibility to hot cracking and stress corrosion cracking however, others are arc welded very successfully with the correct welding procedures (Maud, 1988). These base materials are often welded with high strength 2xxx series filler alloys designed to match their performance, but can sometimes be welded with the 4xxx series fillers containing silicon or silicon and copper, dependent on the application and service requirements.

3.3.3 3XX.X Series Alloys

(Non-heat treatable – with ultimate tensile strength of 16 to 41 ksi)

These are the aluminum/manganese alloys (manganese additions ranging from 0.05 to 1.8%) and are of moderate strength, have good corrosion resistance, good formability and are suited for use at elevated temperatures (Sackett, 1917). One of their first uses was pots and pans, and they are the major component today for heat exchangers in vehicles and power plants. Their moderate strength however, often precludes their consideration for structural applications. These base alloys are welded with 1xxx, 4xxx and 5xxx series filler alloys, dependent on their specific chemistry and particular application and service requirements.

3.2.4 4XX.X Series Alloys

(Heat treatable and non-heat treatable – with ultimate tensile strength of 25 to 55 ksi)

These are the aluminum/silicon alloys (silicon additions ranging from 0.6 to 21.5%) and is the only series which contain both heat treatable and non-heat treatable alloys. Silicon, when added to aluminum reduces its melting point and improves its fluidity when molten. These characteristics are desirable for filler materials used for both fusion welding and brazing. Consequently, this series of alloys is predominantly found as filler material (Millberg, 2007). Silicon (independently in aluminum) is non-heat treatable however, a number of these silicon alloys have been designed to have additions of magnesium or copper, which provides them with the ability to respond favorably to solution heat treatment. Typically, these heat treatable filler alloys are used only when a welded component is to be subjected to post weld thermal treatments.

3.2.5 5XX.X Series Alloys

(Non-heat treatable – with ultimate tensile strength of 18 to 51 ksi) These are the aluminum/magnesium alloys (magnesium additions ranging from 0.2 to 6.2%) and has the highest strength of the non-heat treatable alloys. In addition, this alloy series is readily weld able and for these reasons they are used for a wide variety of applications such as shipbuilding, transportation, pressure vessels, bridges and buildings (Hetherington, 2007). The magnesium base alloys are often welded with filler alloys, which are selected after consideration of the magnesium content of the base material and the application and service conditions of the welded component. Alloys in this series with more than 3.0% magnesium are not recommended for elevated temperature service above 150 deg F because of their potential for sensitization and subsequent susceptibility to stress corrosion cracking. Base alloys with less than approximately 2.5% magnesium are often welded successfully with the 5xxx or 4xxx series filler alloys. The base alloy 5052 is generally recognized as the maximum magnesium content base alloy that can be welded with a 4xxx series filler alloy. Because of problems associated with eutectic melting and associated poor as-welded mechanical properties, it is not recommended to weld material in this alloy series, which contain higher amounts of magnesium with the 4xxx series fillers. The higher magnesium base materials are only welded with 5xxx filler alloys, which generally match the base alloy composition.

3.2.6 6XX.X Series Alloys

(Heat treatable – with ultimate tensile strength of 18 to 58 ksi)

These are the aluminum/magnesium – silicon alloys (magnesium and silicon additions of around 1.0%) and are found widely throughout the welding fabrication industry, used predominantly in the form of extrusions, and incorporated in many structural components. The addition of magnesium and silicon to aluminum produces a compound of magnesium-silicide, which provides this material its ability to become solution heat treated for improved strength. These alloys are naturally solidification crack sensitive, and for this reason, they should not be arc welded autogenously (without filler material). The addition of adequate amounts of filler material during the arc welding process is essential in order to provide dilution of the base material, thereby preventing the hot cracking problem. They are welded with both 4xxx and 5xxx filler materials, dependent on the application and service requirements.

3.2.8 7XX.X Series Alloys

(Heat treatable – with ultimate tensile strength of 32 to 88 ksi)

These are the aluminum/zinc alloys (zinc additions ranging from 0.8 to 12.0%) and comprise some of the highest strength aluminum alloys (Dunster, 2007). These alloys are often used in high performance applications such as aircraft, aerospace, and competitive sporting equipment. Like the 2xxx series of alloys, this series incorporates alloys which are considered unsuitable candidates for arc welding, and others, which are often arc welded successfully. The commonly welded alloys in this series, such as 7005, are predominantly welded with the 5xxx series filler alloys.

Aluminium Alloy 7020 is a heat treatable alloy that age hardens naturally and therefore will recover properties in a heat affected zone after welding. Alloy 7020 is used in armored vehicles, military bridges, motor cycle and bicycle frames, Structural truck components, containers, building construction, railway coach bodies, floor assembly etc.

CHAPTER 4

RESPONSE SUFRFACE METHODOLOGY

4.1 RSM

A set of advanced design of experiments (DOE) techniques that help you better understand and optimize responses. Response Surface design methodology is often used to refine models after important factors have been determined using factorial designs; especially if suspect curvature in the response surface. The difference between a response surface equation and the equation for a factorial design is the addition of the squared (or quadratic) terms that allow you to model curvature in the response, making them useful for Understanding or mapping a region of a response surface (Barker, 2001). Response Surface equations model defines that how changes in input variables influence a response of interest. It’s quite helpful also to find the levels of input variables that optimize a response and further to select the operating conditions to meet specifications. For example, we would like to determine the best conditions for injection-molding of a plastic part. Firstly, used a factorial experiment to determine the significant factors (temperature, pressure, cooling rate) then one can use a response surface designed experiment to find the optimal settings for each factor. There are two main types of response surface designs as described briefly below:

- ***Central Composite designs:*** It can fit a full quadratic model. These are often used when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment (Ramon, 1996).
- ***Box-Behnken designs:*** Typically it has fewer design points thus, these are less expensive to run than central composite designs with the same number of factors. These allow efficient estimation of the first and second-order coefficients however, these can't incorporate runs from a factorial experiment.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building (Adesta and Riza, 2009). The objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). Response-surface methodology comprises a body of methods for exploring for optimum operating conditions through experimental methods. Typically, this involves doing several experiments, using results of one experiment to provide direction for what to do next (Fang and Wu, 2005). This next action could be to focus the experiment around a different set of conditions, or to collect more data in the current experimental region in order to fit a higher order model or confirm what seems to have found. The application of RSM is also aimed to reduce the expenses of other difficult analytical methods (like; Finite Element Method or CFD analysis etc.) and their associated numerical noises (Srikanth and Kamala, 2008). The problem can be approximated with smooth functions of Central Composite Design of RSM that improve the convergence of the optimization process because these reduces the effect of noises and inherent errors, substantially (Thamizhmanii et al., 2007). The responses can be represented graphically, either in the three-dimensional space or as contour plots that further help to visualize relation of response surfaces with input variables, more clearly.

4.1.1 Designs for First and Second-Degree Models

Designs for fitting first-degree models are called first-order designs and those for fitting second-degree models are referred to as second-order designs.

4.1.2 The 2k Factorial Design

In a 2k factorial design, each control variable is measured at two levels, which can be coded to take the values: −1 and 1, that correspond to the so-called low and high levels, respectively of each variable (Montgomery, 1997).

4.1.3 The Plackett–Burman Design

The Plackett–Burman design allows two levels for each of the k control variables, just like a 2k design, but requires a much smaller number of experimental runs, especially if k is large. It is therefore more economical than the 2k design

4.4.4 The Simplex Design

The simplex design is also a saturated design with $n = k + 1$ points. Its design points are located at the vertices of a k-dimensional regular-sided figure (or a simplex) characterized by the fact that that the angle θ, (which any two points make with the design center and located at the origin of the coordinates system) is such that; $\cos \theta = -1k$.

4.2 Outline of ANOVA

Analysis of variances is the method of testing the presence of one or more effects in experiments, it manipulates one or more independent variables, control other independent variables and measures one or more dependent variables (Schneider & Kasperski, 1993). Each independent variable (or factor) has two or more levels. Each datum comes from some condition or combination of the levels of the factors. ANOVA is a powerful tool that allows us to perform analysis of variance, test for equality of variances and generate various plots. Some common types of ANOVA are as follows:

One Way ANOVA- performs a one-way analysis of variance, with the response in one column, subscripts in another and performs multiple comparisons of means

One-Way (Un-stacked)- performs a one-way analysis of variance, with each group in a separate column.

Two-way- performs a two-way analysis of variance for balanced data.

Analysis of Means- displays an Analysis of Means chart for normal, binomial or Poisson data.

Balanced ANOVA- analyzes balanced ANOVA models with crossed or nested and fixed or random factors.

General Linear Model- analyzes balanced or unbalanced ANOVA models with crossed or nested and fixed or random factors. You can include covariates and perform multiple comparisons of means.

Fully Nested ANOVA- analyzes fully nested ANOVA models and estimates variance components.

Balanced MANOVA- analyzes balanced MANOVA models with crossed or nested and fixed or random factors.

General MANOVA- analyzes balanced or unbalanced MANOVA models with crossed or nested and fixed or random factors. You can also include covariates.

Analysis of an experiment with one factor is called “1-way”and of an experiment with two factors known as “2-way” etc. Since the test for an effect of a factor by forming an f-ratio, there is a separate f-ratio for each factor in of experiment; these checks are for main effects (Hamada, 2008). This doesn’t depend on how many levels each factor has. f-ratios can also be formed for the various subsets of the data these are called interactions.

4.3 Considered Responses

In this study, while performing the experiments two responses are kept under consideration these are Material Removal Rate (MRR) and Surface Roughness (Ra), which are discussed in detail ahead.

4.3.1 Material Removal Rate (MRR)

The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm³/min. For each revolution of the work piece, a ring shaped layer of material is removed. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the work piece. Material removal processes are shaping operations, the common feature of which is removal of material from work piece so the remaining part has the desired shape.

. Material Removal Rate (MRR or Q): $\frac{\text{Volume Removed}}{\text{Cutting Time}}$

$$MRR = \frac{\pi * L\ (D_1^2 - D_2^2)}{\frac{4\ L}{f_r\ N}}$$

$$MRR = k\ f_r\ V \left[\frac{D_1 - D_2}{2}\right] * \left[\frac{D_1 + D_2}{2D_1}\right]$$

$$\left[\frac{D_1 - D_2}{2}\right] \approx t$$

$$\left[\frac{D_1 + D_2}{2D_1}\right] \approx 1$$

Where D_2 is finished diameter and t is depth of cut.

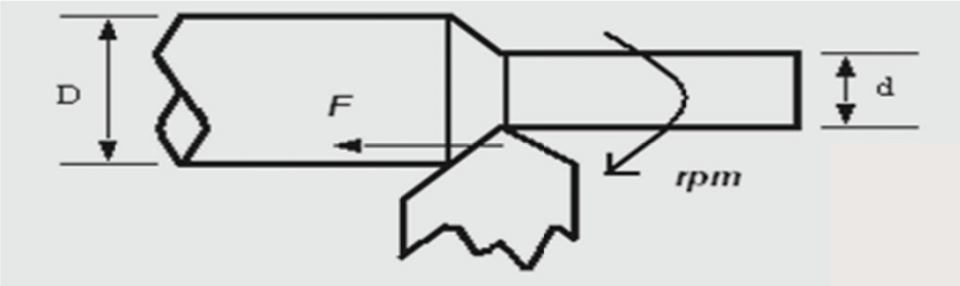


Figure 13 Material Removal Rate

4.3.2 Surface Roughness (Ra)

The concept of roughness is often described with terms such as ‘uneven’, ‘irregular’, ‘coarse in texture’, ‘broken by prominences’ etc. The value of surface roughness depends on the scale of measurement. The characterization of surface roughness can be done in two principal planes. Using a sinusoidal curve as a simplified model of the surface profile, roughness can be measured at right angles to the surface in terms of the wave amplitude and parallel to the surface in terms of the surface wavelength (Poon, 1995). The latter one is also recognized as texture. The technique used to measure roughness in any of these two planes will inevitably have certain limitations. The smallest amplitude and wavelength that the instrument can detect correspond to its vertical and horizontal resolution, respectively. Similarly, the largest amplitude and wavelength that can be measured by the instrument are the vertical and horizontal range. The first amplitude parameter used for roughness measurements was the vertical distance between the highest peak and the lowest valley of the unfiltered profile point. The designation of this parameter was subsequently changed to right when electrical filters were incorporated (Thomas, 1998). Surface characteristics are shown in fig no. 4.1. Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface (see surface metrology).

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces (see tribology book). Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Although roughness is often undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application. A roughness value can either be calculated on a profile (line) or on a surface (area). The profile roughness parameter (Ra, Rq.) are more common. The area roughness parameters (Sa, Sq.) give more significant values.

Profile roughness parameters

Each of the roughness parameters is calculated using a formula for describing the surface. There are many different roughness parameters in use, but R_a is by far the most common. Other common parameters includeR_z, R_q, and R_{sk}. Some parameters are used only in certain industries or within certain countries. For example, the R_k family of parameters is used mainly for cylinder bore linings, and the Motif parameters are used primarily within France. Since these parameters reduce all of the information in a profile to a single number, great care must be taken in applying and interpreting them. Small changes in how the raw profile data is filtered, how the mean line is calculated, and the physics of the measurement can greatly affect the calculated parameter. By convention every 2D roughness parameter is a capital R followed by additional characters in the subscript. The subscript identifies the formula that was used, and the R means that the formula was applied to a 2D roughness profile. Different capital letters imply that the formula was applied to a different profile. For example, Ra is the arithmetic average of the roughness profile, Pa is the arithmetic average of the unfiltered raw profile, and Sa is the arithmetic average of the 3D roughness. Each of the formulas listed in the tables assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n ordered, equally spaced points along the trace, and y_i is the vertical distance from the mean line to the i^{th} data point. Height is assumed to be positive in the up direction, away from the bulk material.

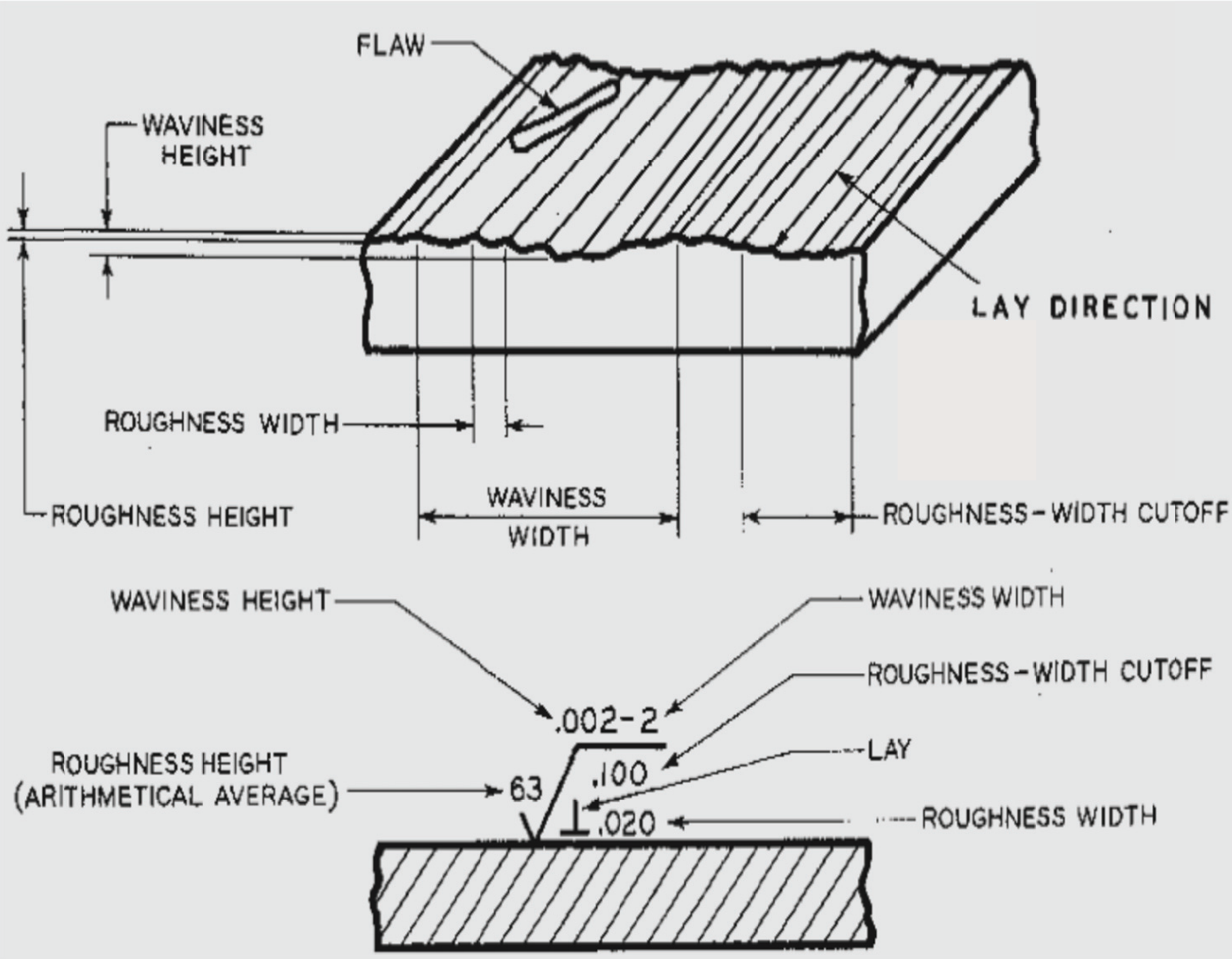


Figure 14 Surface Characteristics[39]

In the present work Morttoyostylus Profilometer surface roughness measurement device is used with stylus having diamond tip. It measures Ra in µm, having range of 800 µm and maximum stylus travel of 0.6 mm. figure 14 shows the Morttoyostylus Profilometer surface roughness measurement device used in the present work.

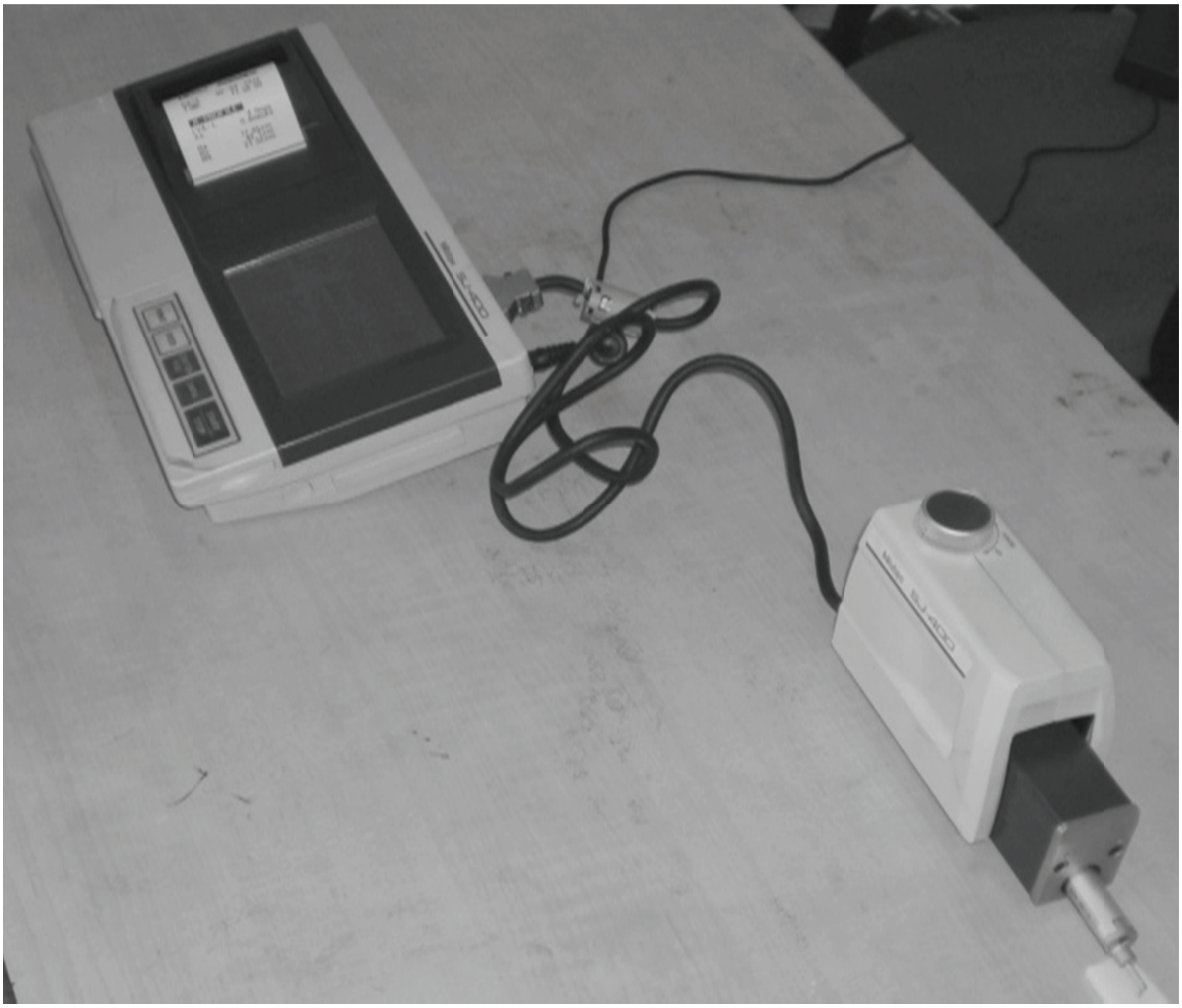


Figure 15 Surface Roughness Measuring Instrument

(Source: SVIET, Banur)

4.4 Motivation of Study

In physical experiments, there are chances that error or inaccuracy may occur due to measurement errors, lack of operator skill, improper calibration of measuring device etc. While, in computer experiments, numerical noise occurs due to incomplete convergence of processes, round-off errors or the discrete representation of continuous physical phenomena. In RSM, the errors are assumed to be random. The application of RSM to design optimization is aimed at reducing the cost of expensive analysis methods (e.g. finite element method etc.) and their associated numerical complications. Therefore RSM shows good compatibility for the optimization of machining parameters and hence shortlisted during present work.

CHAPTER 5

BACKGROUND OF MACHINING OPTIMIZATION

Thorough literature survey has been carried out to capture the voice of concerned people and their relevant work as far as machining of non- ferrous alloys are concerned. Brief description of these has been represented in chronological order below.

Zhou et al. [1](1995) investigated on tool life criteria in raw turning. A new tool-life criterion depending on a pattern-recognition technique was proposed and neural network and wavelet techniques were used to realize the new criterion. The experimental results showed that this criterion was applicable to tool condition monitoring in a wide range of cutting conditions.

Lin et al. [2] (2001)adopted an abdicative network to construct a prediction model for surface roughness and cutting force. Once the process parameters: cutting speed, feed rate and depth of cut were given; the surface roughness and cutting force could be predicted by this network. Regression analysis was also adopted as second prediction model for surface roughness and cutting force. Comparison was made on the results of both models indicating that adductive network was found more accurate than that by regression analysis.

Suresh et al.[3] (2002)focused on machining mild steel by TiN-coated tungsten carbide (CNMG) cutting tools for developing a surface roughness prediction model by using Response Surface Methodology (RSM). Genetic Algorithms (GA) used to optimize the objective function and compared with RSM results. It was observed that GA program provided minimum and maximum values of surface roughness and their respective optimal machining conditions.

Feng et.al[4] (2002)investigated for the prediction of surface roughness in finish turning operation by developing an empirical model through considering working parameters: work piece hardness (material), feed, cutting tool point angle, depth of cut, spindle speed, and cutting time. Data mining techniques, nonlinear regression analysis with logarithmic data transformation were employed for developing the empirical model to predict the surface roughness.

Fang et.al[5] (2004)discussed the effects of tool edge geometry in machining have received much attention in recent years due to a variety of emerging machining techniques, such as finish hard turning and micro-machining. In these techniques, the uncut chip thickness is often on the same order of magnitude as tool edge dimension. This paper presents and analyses the results of our recent experimental and theoretical study on the effects of tool edge geometry in machining. Both chamfered and honed tools are investigated covering a wide range of cutting speed and feed rate conditions. The three aluminum alloys 7075-T6, 6061-T6, and 2024-T351 are selected as work materials for particular research purposes. The cutting force, the thrust force, the ratio of the cutting force to the thrust force, and the chip thickness are measured. The similarities and differences in machining with a chamfered tool and with a honed tool are compared. A new slip-line model of chip formation for machining with a chamfered tool is proposed. Good agreement has been reached between the predicted and experimental results. The effects of different aluminum alloys and cutting speeds on the cutting forces, especially on the thrust force, are also studied.

Ozelet.al[6] (2005) studied for prediction of surface roughness and tool flank wear by utilizing the neural network model in comparison with regression model. The data set from measured surface roughness and tool flank wear were employed to train the neural network models. Predictive neural network models were found to be capable of better predictions for surface roughness and tool flank wear within the range in between they were trained.

Kohliet.al[7] (2005) proposed a neural-network-based methodology with the acceleration of the radial vibration of the tool holder as feedback. For the surface roughness prediction in turning process the back-propagation algorithm was used for training the network model. The methodology was validated for dry and wet turning of steel using high speed steel and carbide tool and observed that the proposed methodology was able to make accurate prediction of surface roughness by utilizing small sized training and testing datasets.

Additions of Mg to 319 alloys and different heat treatments for 356 and 319 alloys were employed to obtain similar levels of hardness in both alloys. Conditions of Sr-modified (200–250 ppm) 356 and 319 alloys containing mainly _-Fe-intermetallics and related to different levels of hardness (90, 100 and 110 HB) were selected for the drilling study. The effects of Mg and _-Fe-intermetallic volume fractions on the machinability of heat-treated 319 alloys were studied at two levels of Mg (0.1 and 0.28%) and at two levels of _-Fe-intermetallic volume fractions (2 and 5%), respectively. The range of the hardness and Fe-intermetallic volume fractions used in this study conform to the most common levels observed in the commercial applications of these alloys. It was found that a higher Mg content results in a higher cutting force at the same level of hardness. This can be explained by the fact that a high volume fraction of Mg-intermetallics or precipitates can be formed within the alloy matrix in the high Mg-content 319 alloys compared to the low Mg-content ones. The low Cu content in 356 alloy resulted in a higher cutting force compared to 319 alloys exhibiting the same level of hardness. This may be explained by the improvement in the homogeneity of the alloy matrix hardness in 319 alloys on the basis of the combined effect of Cu-and Mg-intermetallics, where hardening occurs by cooperative precipitation of Al2Cu and Mg2Si phase particles, compared to only Mg2Si precipitation in the case of 356 alloys. The morphology of iron intermetallics was found to affect the cutting force results when the aging was carried out for 2 h at 180 ◦C and not at 220 ◦C. It seems that cutting force and moment are only slightly influenced by cooling and quenching rates. Heat treatments that increase the hardness will reduce the built-up-edge (BUE) on the cutting tool. Hardness affects the machinability of 319 alloys in that machinability improves as the hardness increases. It is observed that both cutting force and moment increase with the hardness while the build-up on the cutting edge decreases. The low Mg-content 319 alloys (0.1% Mg) yielded the longest tool life, more than twice that of 356 alloys (0.3% Mg) and one-and-a-half times that of the high Mg-content 319 alloys (0.28% Mg). It is customary to rate the machinability of the 319 alloy as higher than that of 356 alloy, and the machinability of the low Mg-content 319 alloy as higher than that of the high Mg-content one. Deceptive chip formation (welding) was observed on 356 and 319 alloys (M1 and M3). Full, half turn and helical chips are generated for both 356 and 319 alloys at the start of a cutting operation when the drill is new (shearing process). As the drill begins to wear, the chips gradually become deformed, as both shearing and deformation occur.

Pal et.al[8] (2005)studied on development of a back propagation neural network model for prediction of surface roughness in turning operation and used mild steel work-pieces with high speed steel as the cutting tool for performing a large number of experiments. The authors used speed, feed, depth of cut and the cutting forces as inputs to the neural network model for prediction of the surface roughness. The work resulted that predicted surface roughness was very close to the experimental value.

Singhet.al[9](2006)studied on optimization of feed force through setting of optimalvalue of process parameters namely speed, feed and depth of cut in turning of EN24 steelwith TiC coated tungsten carbide inserts. The authors used Taguchi's parameter designapproach and concluded that the effect of depth of cut and feed in variation of feed forcewere affected more as compare to speed.

Ahmed[10] **(2006)**developed the methodology required for obtaining optimal processparameters for prediction of surface roughness in Al turning. For development of empirical model nonlinear regression analysis with logarithmic data transformation wasapplied. The developed model showed small errors and satisfactory results. The studyconcluded that low feed rate was good to produce reduced surface roughness and also thehigh speed could produce high surface quality within the experimental domain.

Abburiet.al[11]**(2006)** developed a knowledge-based system for the prediction ofsurface roughness in turning process. Fuzzy set theory and neural networks were utilizedfor this purpose. The authors developed rule for predicting the surface roughness forgiven process variables as well as for the prediction of process variables for a givensurface roughness.

Zhong et al.[12] **(2006)**predicted the surface roughness of turned surfaces using networkswith seven inputs namely tool insert grade, work piece material, tool nose radius, rakeangle, depth of cut, spindle rate, and feed rate.

Ozel et al.[13] **(2007)** investigated surface finishing and tool flank wear in finish turning of AISI D2 steels (60 HRC) using ceramic wiper (multi-radii) design inserts. Multiple linear regression models and neural network models were developed for predicting surface roughness and tool flank wear. In neural network modeling, measured forces, power and specific forces were utilized in training algorithm.

Fu and Hope [14] **(2008)** established an intelligent tool condition monitoring system by applying a unique fuzzy neural hybrid pattern recognition system. The study concluded that armed with the advanced pattern recognition methodology, the established intelligent tool condition monitoring system had the advantages of being suitable for different machining conditions, robust to noise and tolerant to faults.

Shetty et al.[15] **(2008)** discussed the use of Taguchi and response surface methodologies for minimizing the surface roughness in turning of discontinuously reinforced aluminum composites (DRACs) having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles of mean diameter 25µm under pressured steam jet approach. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. The experiments were conducted using Taguchi's experimental design technique. The matrix of test conditions included cutting speeds of 45, 73 and 101 m/min, feed rates of 0.11, 0.18 and 0.25 mm/rev and steam pressure 4, 7, 10 bar while the depth of cut was kept constant at 0.5 mm. The effect of cutting parameters on surface roughness was evaluated and the optimum cutting condition for minimizing the surface roughness was also determined finally. A secondorder model was established between the cutting parameters and surface roughness using response surface methodology. The experimental results revealed that the most significant machining parameter for surface roughness was steam pressure followed by feed. The predicted values and measured values were fairly close, which indicated that the developed model could be effectively used to predict the surface roughness in the machining of DRACs.

Srikanth et al.[16] **(2008)** proposed a real coded genetic algorithm (RCGA) to find optimum cutting parameters (speed, feed and depth of cut). This paper explained various issues of RCGA and its advantages over the approach of binary coded genetic algorithm. The results obtained, conclude that RCGA was reliable and accurate for solving the cutting parameter optimization.

Thamma[17] **(2008)** constructed the regression model to find out the optimal combination of process parameters in turning operation for Aluminium 6061 work pieces. The study highlighted that cutting speed, feed rate, and nose radius had a major impact on surface roughness. Smoother surfaces could be produced when machined with a higher cutting speed, smaller feed rate, and smaller nose radius.

Dwivedi et.al[18] **(2008)** Studied about the influence of melt treatment (grain refinement and modification) and heat treatment (T6) of cast LM13 and LM28 aluminium alloys on machining behaviour has been reported. Alloys under investigation were prepared by controlled melting and casting followed by heat treatment (T6). As-cast, melt-treated and heat-treated alloys were investigated for machining characteristic at different cutting speeds. Melt treatment of both the alloys (LM13 and LM28) reduced the cutting force and cutting temperature whereas heat treatment increased both cutting force and cutting temperature. Cutting temperature was found higher in machining of LM28 alloy than the LM13 alloy. Maximum cutting temperature was found for both the alloys in heat-treated conditions. Heat treatment of LM28 alloy reduced the surface roughness whereas heat treatment of LM13 alloy increased it. Melt treatment and heat treatment of LM13 alloy increased the average number of chips per gm. LM28 alloy produced higher number of chips per gm than the LM13 alloy.

Xiao et.al[19] **(2009)**presented an analysis of a polycrystalline diamond (PCD)-tipped tool after drilling 40,000 holes in aluminum (Al) 319 alloy under fully lubricated conditions is reported. It is found that aluminum adheres to the PCD tip surface during the machining process under lubricated condition. The aluminum transferring leads to poor surface finishing. Surface morphology analysis and element mapping suggests that the cobalt (Co) binder in the PCD tips is responsible for the adhesion of aluminum to the PCD surface, due to the chemical affinity between aluminum and cobalt. Approaches to prevent the adhesion of aluminum to the tool are discussed.

Gopalsamy et al.[20] **(2009)**applied Taguchi method to find optimum process parameters for end milling while hard machining of hardened steel. A L16 array, signal-to-noise ratio and analysis of variance (ANOVA) were applied to study performance characteristics of machining parameters (cutting speed, feed, depth of cut and width of cut) with consideration of surface finish and tool life. Results obtained by Taguchi method match closely with ANOVA and cutting speed is most influencing parameter.

Mahdavinejad et al.[21] **(2009)**showed the precision of machine tools on one hand and the input setup parameters on the other hand, were strongly influenced in main output machining parameters such as stock removal, toll wear ratio and surface roughness. There were a lot of input parameters which were effective in the variations of these output parameters. In CNC machines, the optimization of machining process in order to predict surface roughness is very important. From this point of view, the combination of adaptive neural fuzzy intelligent system was used to predict the roughness of dried surface machined in turning process.

Adesta et al.[22] **(2009)** investigated tool wear and surface roughness under different rake angles and different cutting speed. Experiments were carried out by using cermet (CT5015). For every single pass of cutting, surface roughness of work pieces were measured by surface roughness tester. The experimental results showed that by increasing negative rake angles the higher wear occurred shorter duration of tool life and poor surface finish.

Suhail et al.[23] **(2010)**presented experimental study to optimize the cutting parameters using two performance measures, work piece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The experimental results showed that the work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment.

Mustafal and Tanju[24] **(2011)**investigated that Aluminum and aluminum alloys were vital to the aerospace industry. They are of great significance to other areas of transportation and building in which durability, strength and light weight are required. In this study, surface roughness, cutting temperature and cutting forces in turning of aluminum 7075 alloy using diamond like carbon (DLC) coated cutting tools was presented. The effects of the feed rate, cutting speed and depth of cut on surface roughness, cutting temperature and cutting force were examined. In order to optimize the experimental results, Taguchi optimization method was employed. The effect of each parameter on the obtained results was determined by the use of analysis of variance (ANOVA). The relationship between dependent and independent parameters was modelled with regression analysis. The optimal machinability of Al 7075 alloy with DLC coated insert was successfully determined in this study.

Yadav et.al (2012) analyzed that A common method to manufacture parts to a specific dimension involves the removal of excess material by machining operation with the help of cutting tool. Turning process is the one of the methods to remove material from cylindrical and non-cylindrical parts. In this work the relation between change in hardness caused on the material surface due the turning operation with respect to different machining parameters like spindle speed, feed and depth of cut have been investigated. Taguchi method has been used to plan the experiments and EN 8 metal selected as a work piece and coated carbide tool as a tool material in this work and hardness after turning has been measured on Rockwell scale. The obtained experimental data has been analyzed using signal to noise and. The main effects have been calculated and percentage contribution of various process parameters affecting hardness also determined.

Ananthakumar.P et.al (2013) worked on Optimization of machining process parameters to achieve a set of quality attributes is important in bridging up the quality and productivity requirements especially in a turning operation. The quality attributes considered are surface finish, material removal rate and tool flank wear. The Present work applies to optimize the process parameter for turning medium carbon steel bar using HSS tool bit via conventional machining. Optimizing one quality attribute may lead to loss of other quality attribute. Hence in order to simultaneously satisfy all the three quality requirements a multi objective optimization is required. To achieve this exploration of grey relational theory, utility concepts are attempted. To meet the basic assumption of taguchimethod that quality attributes should be uncorrelated the study applies PCA based multivariate statistical method and eliminates correlation that exists in between the responses. Experiments have been conducted based on taguchi'sL9 Orthogonal array design with different combinations of process control parameters: (Cutting speed, Feed, Depth of cut). Surface roughness, Material removal rate, Tool Flank wear are the response parameters that will be optimized. The obtained result will be verified through confirmatory test. This work highlights the effectiveness of proposed method for solving multi objective optimization of turning process. The above said methodology has been found fruitful in the cases where simultaneous optimization of huge responses is required.

D. Lazarević et.alinvestigated thatIn any machining process, it is most important to determine the optimal settings of machining parameters aiming at reduction of production costs and achieving the desired product quality. This paper discusses the use of Taguchi method for minimizing the surface roughness in turning polyethylene. The influence of four cutting parameters, cutting speed, feed rate, depth of cut, and tool nose radius on average surface roughness (Ra) was analyzed on the basis of the standard L27 Taguchi orthogonal array. The experimental results were then collected and analyzed with the help of the commercial software package MINITAB. Based on the analysis of means (ANOM) and analysis of variance (ANOVA), the optimal cutting parameter settings are determined, as well as level of importance of the cutting parameters.

R.A. Collacott discussed the purpose of monitoring the condition of machine components there is evidence to suggest that the logging of sound spectra and comparison with a reference spectrum can aid in the formation of decisions regarding individual components of a machine. Since most machines operate in enclosures among other machinery, it is important to assess the problems involved in isolating individual sound sources under such conditions. This investigation explored the response of six machine tools in a workshop when operating individually (solo) and together (simultaneously). Studies are made of the respective time-domain wave forms, decibel-frequency spectra (sound signatures) and power spectral density-frequency spectra. A comparison has been made between the resulting power spectral density spectra when all machines are working together and the computer-summated spectra of the machines when running individually. There is reason to believe that the discrete frequencies of separate components within a machine can be separated from the sound in a multiple-source sound environment. Results suggest that the greatest sensitivity is likely to be achieved within the frequency range 100 to 600 Hz and that higher frequency effects may be influenced by field reverberation effects of the enclosure.

E.J. Richards, M.E. Westcott and R.K. Jeyapalan studied the introduction of legislation regarding the limits of noise in factories has led to the need for prediction of likely noise levels produced by a machine at its design stage. This paper, the first of a series, is concerned with the noise generated by impacting bodies due to the high surface accelerations during the contact period. An account is presented of the theoretical development and experimental validation of curves for the prediction of peak sound pressure and radiated energy for collisions of compact bodies which are incapable of flexural motions. It is shown that acceleration noise energy is of the same order of magnitude as that due to ringing, that it cannot be greater than 1·5 × 10−4 times the kinetic energy input at impact, and that it falls off rapidly as the normalized contact time increases above a critical value.

Erkki Jantunen [3] presented a summary of the monitoring methods, signal analysis and diagnostic techniques for tool wear and failure monitoring in drilling that have been tested and reported in the literature. The paper covers only indirect monitoring methods such as force, vibration and current measurements, i.e. direct monitoring methods based on dimensional measurement etc. are not included. Signal analysis techniques cover all the methods that have been used with indirect measurements including e.g. statistical parameters and Fast Fourier and Wavelet Transform. Only a limited number of automatic mdiagnostic tools have been developed for diagnosis of the condition of the tool in drilling.

All of these rather diverse approaches that have been available are covered in this study. In the reported material there are both success stories and also those that have not been so successful. Only in a few of the papers have attempts been made to compare the chosen approach with other methods. Many of the papers only present one approach and unfortunately quite often the test material of the study is limited especially in what comes to the cutting process parameter variation, i.e. variation of cutting speed, feed rate, drill diameter and material and also work piece material.

WimDesmet, Paul Sas, ReeneBoonon and Greg Pinte studied about the noise pollution, caused by industrial activities, is an increasing environmental problem. Especially in machine halls with working machines such as punching machines, presses and, generating impact noise, the radiated noise level is too high to meet the regulations

for noise emission. The objective of this project is to develop silent machine tools and taking measures over the machine structure, tools and components of punching machines and metal working presses. To attain this objective, innovative concepts in acoustic structural control (ASAC) and active noise control (ANC) will be used to develop new

devices combining passive elements with active components. The program started with the identification of the noise sources and transfer paths on the machines. This was carried out by means of measurements and FEM simulations. Once the main noise sources were identified, the development of noise attenuation devices started. New algorithms, specific for transient noise, were developed to control the devices. The optimal spatial configuration of the chosen sensors and actuators, which has great influence on the efficiency of the control system, is determined. This work is carried out on a small scale representative demonstrator. Based on the obtained results, the devices will be redimensioned for the large scale machines and evaluated.

Kurasawahideo, Hanedayoshiaki and Miyaoyoshikazu studied about recentlyenvironmental problem becomes important more and more in domestic and overseas. Theregion of this problem has the very wide field like global warming, deforestation, acidrain. Here, the noise in the environment was noticed, and also authors had the interest forthe noise in the working environment. In this paper, the noise of machine tool intechnology education center in our school was measured by the sound level meter. The results show that the noise level of the most machine tool does not exceed the working environment criteria for the noise.

CHAPTER 6

MACHINING OF ALUMINIUM AND ITS ALLOYS

Aluminum and its alloys are of great significance for areas related with transportation and building, in which durability and strength is required (Mustafa and Karagol, 2011). The effects of the feed rate, cutting speed and depth of cut on surface roughness, cutting temperature and MRR can be accessed after reviewing the literature. In order to optimize the experimental results, application of Design of Experiments (full factorial or partial), Taguchi's Method, RSM, Finite Element Method etc. are sufficiently found in literature. The effects of each parameter on obtained results were determined for different materials, tools and machining operations. Some people have even explained the relationship between dependent and independent machining parameters through regression models. After motivating from above survey, an effort has been made to bring optimization in turning of Al-7020 alloy while machining with Lokesh TL-250CNC turner.

6.1 CNC Machining

CNC machines are extensively used in machining industry to maximize production with higher degree of precision and accuracy (Singh and Khanduja, 2011a). In order to achieve this effectively, parametric optimization has been required to be done. The detailed methodology adopted for the machining and response measurements is discussed as under. The study has been performed with machining of Al-zinc alloy-7020 bars having dimensions of 32 mm diameter and 60 mm length on CNC turning center by using carbide tool of 0.8 mm nose radius.

6.2 Methodology Proposed

The work has been channelized through following adopted procedure:

- Check and prepare the CNC Turning Centre ready for performing the machining operation.
- Cut the Al-Zn Alloy-7020 bars by power saw and perform initial turning operation on simple lathe to get desired dimensions of work pieces.
- Calculate weight of each specimen by high precision Digital Balance Meter (DBM) before machining.

- Perform straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut etc. These experiments are pre designed with RSM and executed as per orthogonal matrix provided by RSM technique.
- Calculate the weight of each machined bar again by DBM and assessed the material removal rate suitably.
- Measure surface roughness and surface profile with the help of a portable Stylus-Type Profilometer ‘Talysurf’.
- Analyse the RSM statics through statistical software ‘Minitab16’ and tried to optimize the considered factors for favorable values of selected responses.
- At the end, One Way Un-stacked Analysis of Variance (ANOVA) will be used as a tool to verify and validate the results achieved during optimization by RSM.

CHAPTER 7

MACHINING OPTIMIZATION: A CASE STUDY

Rather using one factor at a time (OFAT) approach to inculcate optimization of selected input factors (i.e. Cutting Speed, Feed and Depth of Cut) for maximizing MRR and surface finish, it is decided to adopt methodology of designed experiments through RSM. Central Composite Design of RSM has been chosen as it will not only save effort and cost of experimentation, but also analyze the output more concisely to predict or forecast results (Singh and Khanduja, 2010a). Designs of this type are usually chosen when curvature in the response surface is suspected (Singh and Khanduja, 2010b). Each factor is defined at its two levels respectively, which are discussed ahead.

7.1 Machining Parameters along with their Levels

Experimentation has been done by considering the following levels of process variables (Singh and Sodhi, 2014). These parameters (refer table 4) has been decided by referring Kadirgama [38] and Sahoo [21].

Process variables	Lower limit	Upper limit
Cutting Speed (m/min)	100	150
Feed (mm/rev)	0.09	0.17
Depth of cut (mm)	0.5	2

Table 4 Process Variables with Their Levels

7.2. RSM Matrix

Experiments have been carried out using response surface method. Experimental design consist 20 combinations of cutting speed, longitudinal feed rate and depth of cut as an experimental runs (Singh and Sodhi, 2014). Experiments are executed as per the orthogonal matrix generated by RSM with 3 factors at 2 levels while 0 blocking and with replicate value of 1 (see table 5 for designed experiments).

Std	Run	Cutting Speed (m/min)	Feed (mm/rev)	Depth (mm)
14	1	125	0.13	-0.01
16	2	100	0.17	0.50
7	3	100	0.17	2.00
8	4	100	0.09	0.50
20	5	150	0.17	2.00
17	6	125	0.20	1.25
15	7	150	0.17	0.50
4	8	167	0.13	1.25
6	9	125	0.13	1.25
3	10	150	0.09	0.50
1	11	125	0.13	2.51
10	12	100	0.09	2.00
12	13	125	0.13	1.25
13	14	125	0.06	1.25
11	15	125	0.13	1.25
9	16	125	0.13	1.25
19	17	125	0.13	1.25
2	18	150	0.09	2.00
5	19	83	0.13	1.25
18	20	125	0.13	1.25

Table 5 Orthogonal Matrix of RSM

7.3. Execution of Designed Experiments

Experiments are performed on above suggested combinations of variables. Effects of these combinations on material removal rate and surface roughness are shown in table 6 (Singh and Sodhi, 2014).

Std	Run	Cutting Speed (m/min)	Feed (mm/rev)	Depth (mm)	MRR (mm^3/min)	Ra (µm)
14	1	125	0.13	-0.01	0.00	3.02
16	2	100	0.17	0.50	4428.04	2.5
7	3	100	0.17	2.00	12076.48	4.5
8	4	100	0.09	0.50	1265.16	0.98
20	5	150	0.17	2.00	15628.39	1.63
17	6	125	0.20	1.25	8610.09	2.78
15	7	150	0.17	0.50	3907.10	0.98
4	8	167	0.13	1.25	11070.11	0.77
6	9	125	0.13	1.25	7852.21	1.35
3	10	150	0.09	0.50	3542.44	0.68
1	11	125	0.13	2.51	13082.86	3.85
10	12	100	0.09	2.00	6958.36	2.52
12	13	125	0.13	1.25	7047.10	1.37
13	14	125	0.06	1.25	4744.33	0.86
11	15	125	0.13	1.25	7244.00	1.31
9	16	125	0.13	1.25	7152.00	1.32
19	17	125	0.13	1.25	7044.62	1.34
2	18	150	0.09	2.00	12231.00	1.12
5	19	83	0.13	1.25	5904.06	2.38
18	20	125	0.13	1.25	7044.62	1.29

Table 6 Execution of Experiments

7.4. RSM Statistics for MRR

Histogram: It is a graph used to assess the shape and spread of continuous sample data. You might create a histogram prior to or in conjunction with an analysis to help confirm assumptions and guide further analysis (Singh and Khanduja, 2011a). To draw a histogram, statistical software like ‘Minitab’ divides sample values into many intervals called bins. By default, bars represent the number of observations falling within each bin (its frequency). Minitab automatically determines an optimal number of bins, but you can edit the number of bins as well as the intervals covered by each.

Probability Plot: It is used to evaluate the fit of a distribution to your data, estimate percentiles and compare different sample distributions (Singh and Khanduja, 2012c). The scales are transformed as necessary so that the fitted distribution should be alongside the straight line. It may display the approximate 95% confidence intervals for the percentiles or it may display a table with distribution parameter estimates along with the Anderson-Darling statistic and p-value to help you evaluate the distribution fit to your data (Singh and Khanduja, 2012a).

Firstly data has been checked for its normality by probability plot (see first plot of figure 16). As data points are distributed all along the normal line and having negligible outliers, so data can be concluded as normally distributed. The second plot doesn't show any trend while plotting residual versus fitted values of data which implies RSM model chosen is well fitted with given data set (Singh and Khanduja, 2012b). Third plot is frequency histogram showing data distribution and at last residue versus order plot highlights the random data points which signifies non-significance of experimental order as far as first response (MRR) is concerned.

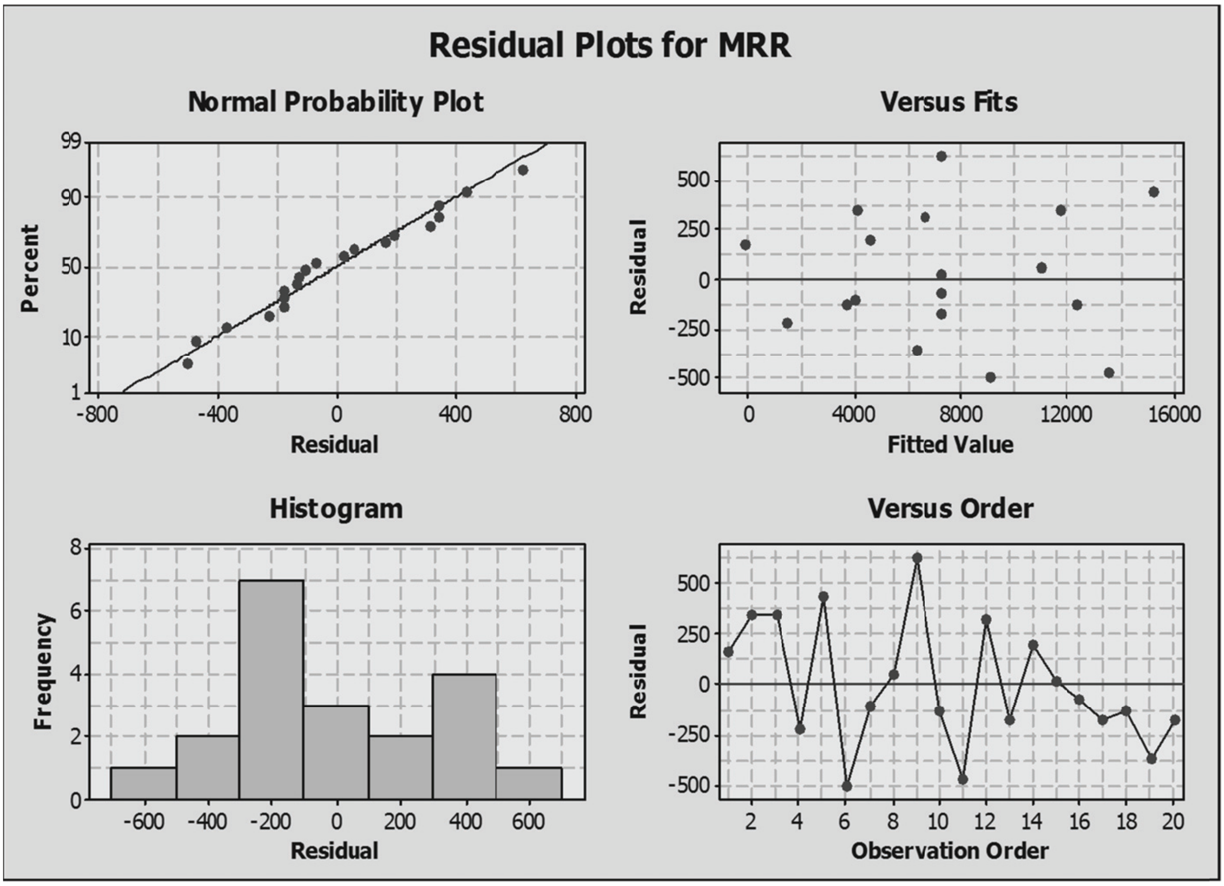


Figure 16 Data Normality Testing for MRR

RSM for MRR has been applied at 95% confidence, so all factors and their interactions having p (probability) value less than 0.05 will be statistically significant for MRR and must be further taken care of. Refer table 7 for more details of statistical analysis of RSM for MRR. As p values are more than 0.05 for (feed*feed) and (depth*depth) and hence can be ignored during optimization of MRR because of their negligible analytical affect. Coefficients represent the relative impact of each factor and its interactions on MRR that have been analyzed at 99% R-sq and R-sq (adjusted) value.

Term	Coef	SE Coef	T	P	Significant / Not Significant
Constant	7225.7	173.0	41.765	0.000	Significant
Cutting Speed (m/min)	2374.3	193.1	12.298	0.000	Significant
Feed (mm/rev)	2284.6	193.1	11.834	0.000	Significant
Depth (mm)	6863.5	193.0	35.563	0.000	Significant
Cutting Speed (m/min)* Cutting Speed (m/min)	1417.8	316.1	4.486	0.001	Significant
Feed (mm/rev)*Feed (mm/rev)	-392.1	316.1	-1.240	0.243*	**Not Significant***
Depth (mm)*Depth (mm)	-531.7	316.0	-1.683	0.123*	**Not Significant***
Cutting Speed (m/min)*Feed (mm/rev)	-1597.7	424.2	-3.766	0.004	Significant
Cutting Speed (m/min)*Depth (mm)	2497.7	424.0	5.891	0.000	Significant
Feed (mm/rev)*Depth (mm)	1762.6	424.0	4.157	0.002	Significant
S = 424.208 PRESS = 10838148					
R-Sq = 99.40% R-Sq (pred.) = 96.37% R-Sq(adj.) = 98.85%					

Table 7 Statics for MRR

Next analysis of variance (ANOVA) has been performed over RSM of MRR just to verify the authenticity of used RSM model and found p- values significant (less than 0.05) for linear, squared and interaction of factors (look at table 8).

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	296738697	296738697	32970966	183.22	0.000
Linear	3	279978545	280017089	93339030	518.69	0.000
Square	3	4852579	4852579	1617526	8.99	0.003
Interaction	3	11907573	11907573	3969191	22.06	0.000
Residue Error	10	1799527	1799527	179953	---------	---------
Lack-of-Fit	5	1303918	1303918	260784	2.63	0.156
Pure Error	5	495609	495609	99122	---------	---------
Total	19	298538224	---------	---------	---------	---------

Table 8 ANOVA to Check RSM Statics

7.5 Graphical Inferences for MRR

Main Effects Plot: Main effects plot is used to plot data means when you have multiple factors. The points in the plot are the means of the response variable at the various levels of each factor, with a reference line drawn at the grand mean of the response data (Singh et al., 2011b). Use the main effects plot for comparing magnitudes of main effects. The software has deduced the results in graphical form also. Figure 18 highlights the one factor at a time effect on response (MRR).

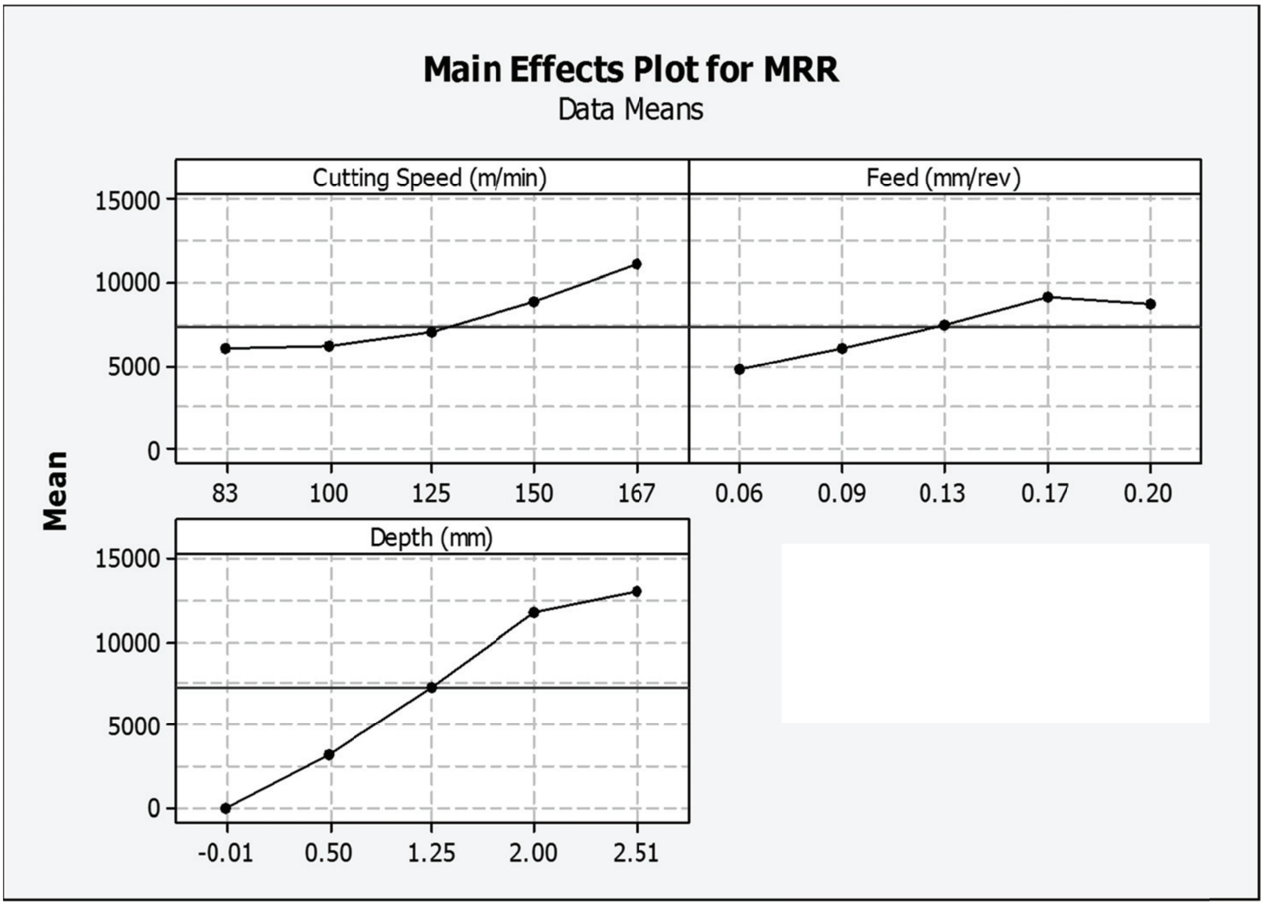


Figure 17 Main Effect Plots for MRR

First graph of Fig. 7.2 represents that there is an increase in the material removal rate with the rise of cutting speed. Where as in second graph of figure 17, it is clear that the material removal rate increases up to feed 0.17 (mm/rev), but at the next level i.e. at feed rate 0.20 (mm/rev) there has been a slight decrease in the material removal rate. Similarly in third graph of figure 17, rise in material removal rate is recorded with the increase of Depth of cut. Similarly effect of two factors simultaneously on MRR has been captured by figure 18 (Singh and Sodhi, 2014).

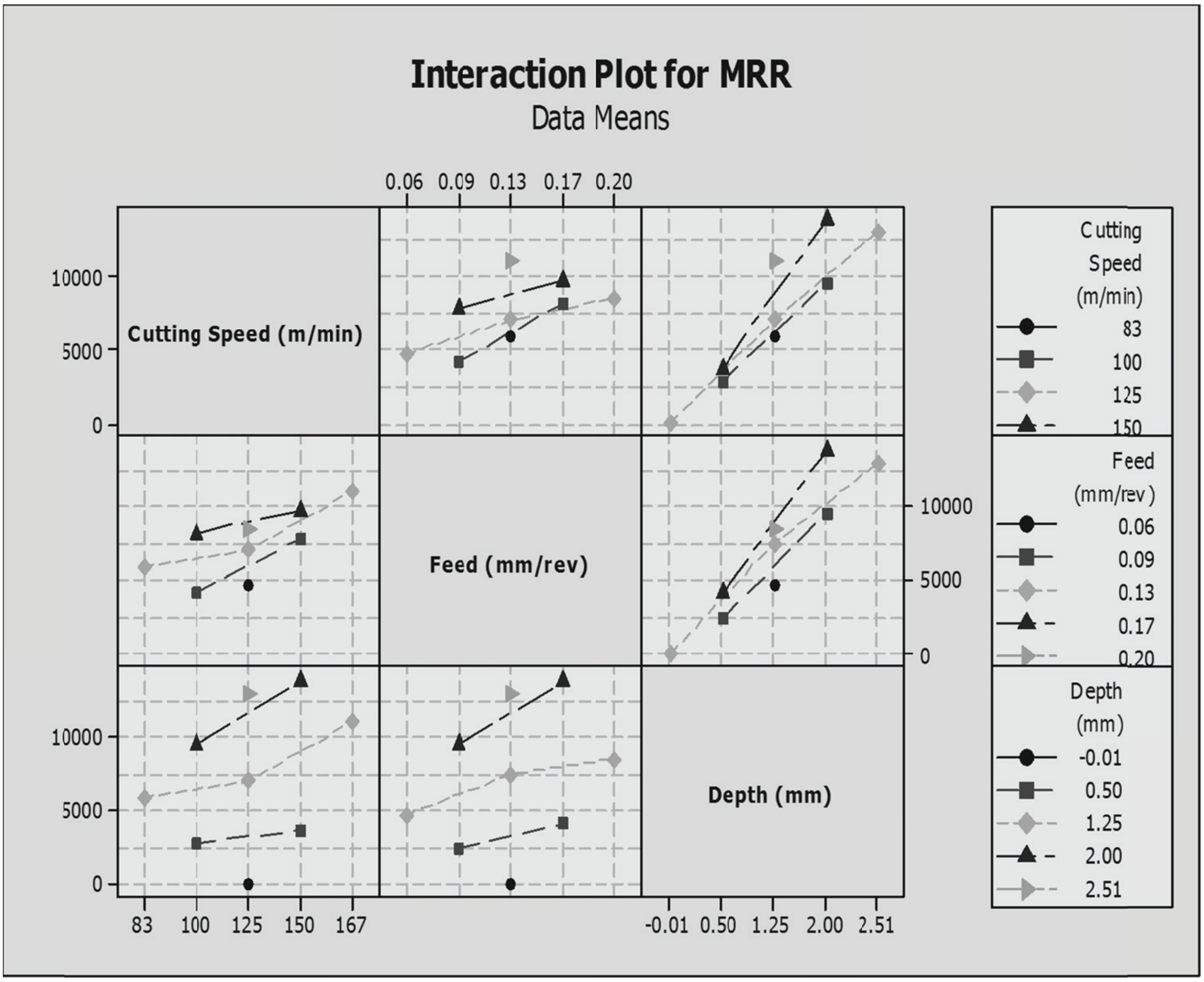


Figure 18 Two-Way Interaction Plot for MRR

The 3-D surface plots as a function of two factors at a time, maintaining all other factors at fixed levels not only provides understanding of both the main and the interaction effects of these two factors, but also helps to identify the optimum level of each variable for maximum response (Singh and Khanduja, 2012d). See figure 19 containing surface plot and its corresponding 2-D contour plot of MRR versus Speed & Depth of Cut at a holding value of feed on 0.13 (Singh and Sodhi, 2014).

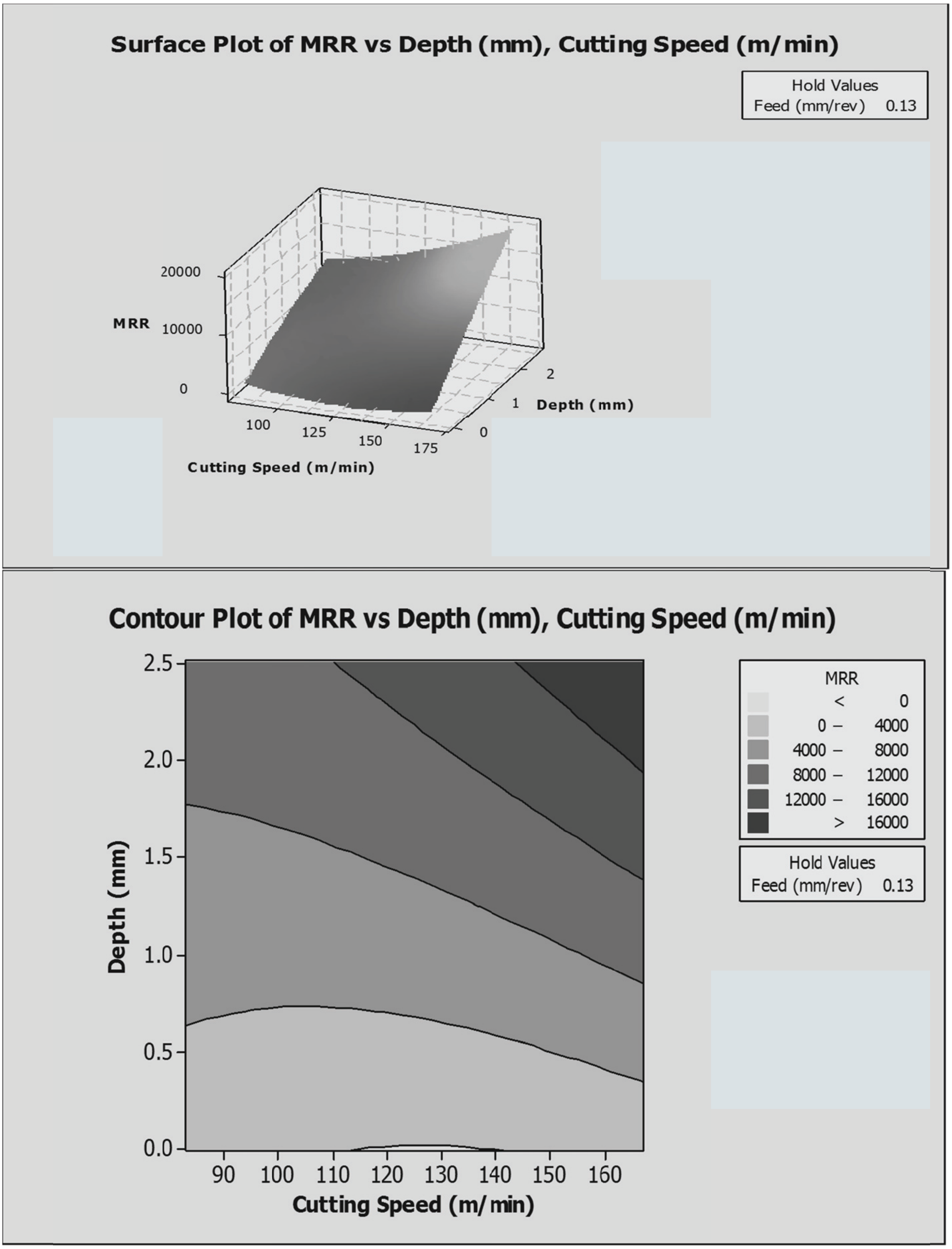


Figure 19 Surface Plots of MRR Vs Depth of Cut & Cutting Speed

Contour plots are basically orthographic views of 3-D plot and consists of colored regions of input variables bearing different value of output response. Like dark green region of above plot reflects the area having values of Feed and Depth of Cut where MRR may be reached up to 16000 or more.

On the same pretext figure 20 demonstrates the surface plot and contour plot of MRR Vs Cutting Speed & Feed at holding value of Depth of Cut on 1.25mm. Here dark green region is the area having values of Cutting Speed and Feed where MRR will be in the range of 10,000 or more and it is the maximum possible MRR that can be achieved at these input settings.

Figure 21 has been generated as surface and contour plot for MRR Vs Feed and Dept of Cut at holding value of Cutting Speed on 125m/min. Different colour combinations signifies the effect of feed rate and cutting Speed on value of first response (MRR).

The dark green region in present plot reflects the area having Speed and Feed values bearing 15000 or higher MRR and is the maximum possible value of MRR at given settings. In contrast, blue region is the lower MRR region ranging up to 2500 approximately at holding value of Cutting Speed on 125m/minute.

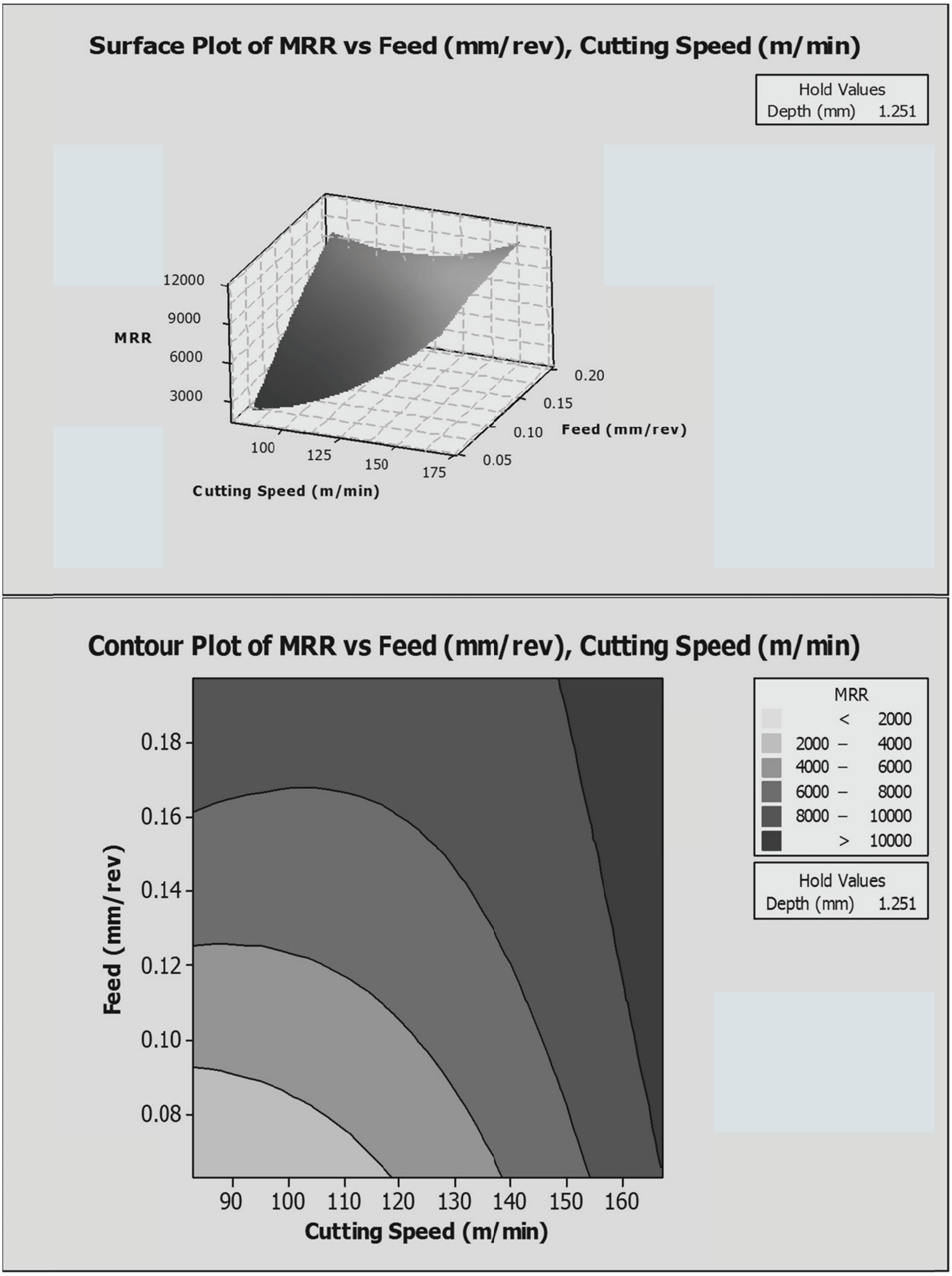


Figure 18 Surface Plot of MRR Vs Cutting Speed & Feed

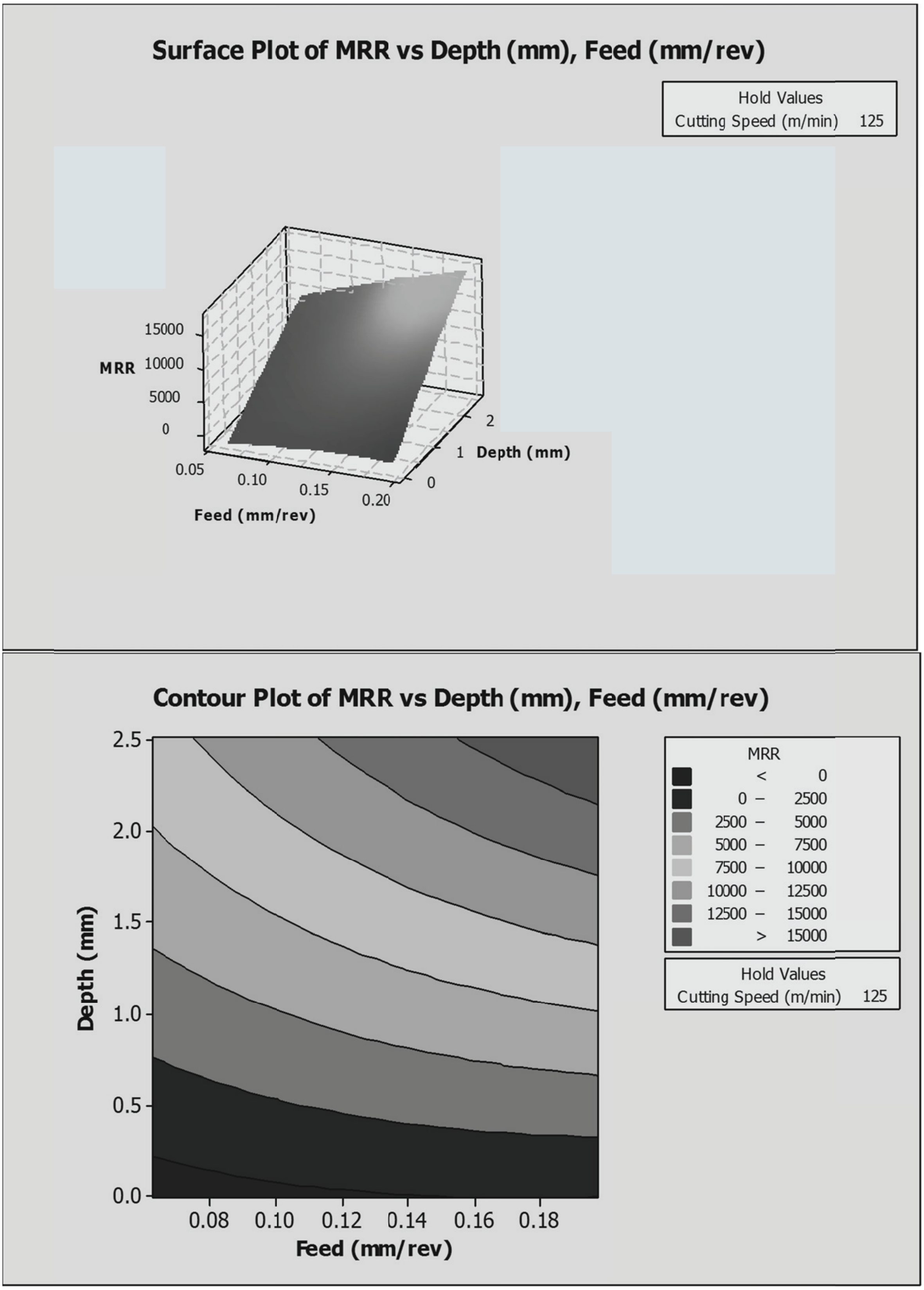


Figure 19 Surface Plot of MRR Vs Depth & Feed

At end, Minitab has created an Estimated Regression Coefficients for MRR in terms of its significant factors and their interactions, as detailed below in table 9

Term	**Coef**
Constant	1054.20
Cutting Speed (m/min)	-129.541
Feed rate (mm/rev)	101101
Depth of cut (mm)	-2310.90
Cutting Speed (m/min)* Cutting Speed (m/min)	0.802041
Feed rate (mm/rev)* Feed rate (mm/rev)	-86632.5
Depth of cut (mm)* Depth of cut (mm)	-334.536
Cutting Speed (m/min)*Feed rate (mm/rev)	-564.870
Feed (mm/rev)*Depth (mm)	20783.2

Table 9 Estimated Regression Coefficients for MRR

Optimization Equation of MRR

MRR = 1054.2-129.5 (Cutting Speed) + 101101 (Feed) - 2310.9 (Depth) + 0.8 (Cutting Speed)^2 - 564.8 (Cutting Speed x Feed) + 47.1(Cutting Speed x Depth) + 20783.2 (Feed x Depth)

The coefficient of each factor reflects its weightage with MRR and its positive or negative sign signifies the respective proportionality. Feed rate and Depth of Cut seems to be highly impacting factors along with its interaction, as far as high MRR is in question.

7.6 RSM Statistics for Ra

Similarly to minimize surface roughness (Ra), Minitab has performed RSM on selected input turning variables (Singh and Sodhi, 2014). Roughness factors have been measured with Profilometer for each experimental run. Firstly, Ra data has been checked for its normality and found ok (look at fig 7.7).

As data points are distributed all along the normal line and having negligible outliers, so data can be concluded as normally distributed (Singh and Khanduja, 2011c). The second plot doesn't show any trend while plotting residual versus fitted values of data which implies RSM model chosen is well fitted with given data set.

Third plot is frequency histogram showing data distribution and at last residue versus order plot highlights the random data points which signifies non-significance of experimental order as far as second response (Ra) is concerned.

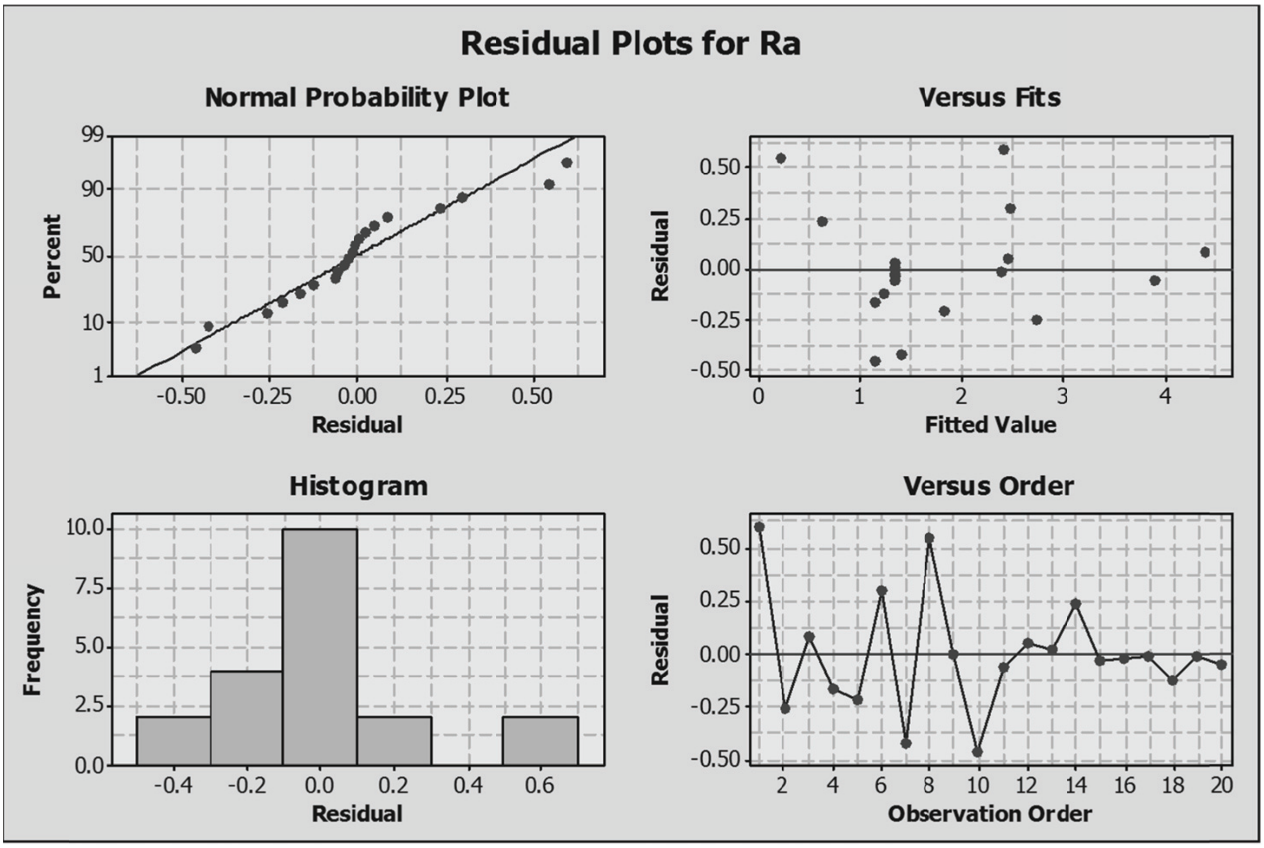


Figure 20 Data Normality Testing for Ra

p-values have been generated for each factor and its interaction and demonstrated as below through table 10. Square of Feed rate and Dept of Cut along with its interaction

(Feed x Depth of Cut) have been realized as non-significant, as far as optimization of Ra is concerned.

Term	Coef	SE Coef	T	P	Significant / Not Significant
Constant	1.34580	0.1502	8.963	0.000	Significant
Cutting Speed (m/min)	-1.08387	0.1675	-6.469	0.000	Significant
Feed (mm/rev)	0.92853	0.1675	5.542	0.000	Significant
Depth (mm)	0.74311	0.1675	4.437	0.001	Significant
Cutting Speed (m/min)* Cutting Speed (m/min)	-0.03613	0.2743	-0.132	**0.898***	**Not Significant***
Feed (mm/rev)*Feed (mm/rev)	0.20887	0.2743	0.761	**0.464***	**Not Significant***
Depth (mm)*Depth (mm)	1.82284	0.2742	6.647	0.000	Significant
Cutting Speed (m/min)*Feed (mm/rev)	-0.95106	0.3682	-2.583	0.027	Significant
Cutting Speed (m/min)*Depth (mm)	-0.86574	0.3680	-2.353	0.040	Significant
Feed (mm/rev)*Depth (mm)	0.23675	0.3680	0.643	**0.534***	**Not Significant**
S = 0.368168 PRESS = 10.2409					
R-Sq = 93.73% R-Sq (pred) = 52.67% **R-Sq(adj) = 88.10%**					

Table 10 Estimated Regression Coefficients for Ra

ANOVA has been applied (see table 11) to check the lack-of-fit or residue in Ra model and indicates substantial significance of above findings made during linear, square and factors in interactions (Singh and Sodhi, 2014).

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	20.2801	20.2801	2.25334	16.62	0.000
Linear	3	12.4911	12.5031	4.16771	30.75	0.000
Square	3	6.0780	6.0780	2.02601	14.95	0.001
Interaction	3	1.7109	1.7109	0.57031	4.21	0.036
Residual Error	10	1.3555	1.3555	0.13555	-------	-------
Lack-of-Fit	5	1.3513	1.3513	0.27026	321.73	0.000
Pure Error	5	1.3513	0.0042	0.00084	-------	-------
Total	19	0.0042	21.6356	-------	-------	-------

Table 11 ANOVA to Check RSM Statics (Ra)

7.7 Inferences for Ra

Graphical implications of RSM for second response (Ra) have also been chalked out. Variation of Surface Finish with considered input factors, have been drawn in figure 23.

Remember, as Surface Roughness (Ra) increases than its corresponding Surface Finish decreases and vice versa.

First graph of figure 23 represents that there is an increase in the Ra when the cutting speed rises from 83 m/min to 100 m/min but with the further rise of cutting speed, the value of surface roughness decreases.

Where as in second graph of figure 23, it is obvious that the value of surface roughness is lesser at lower feed rate.

Similarly in third graph of figure 23 shown that the value of surface roughness is less at depth of cut 0.5 mm.

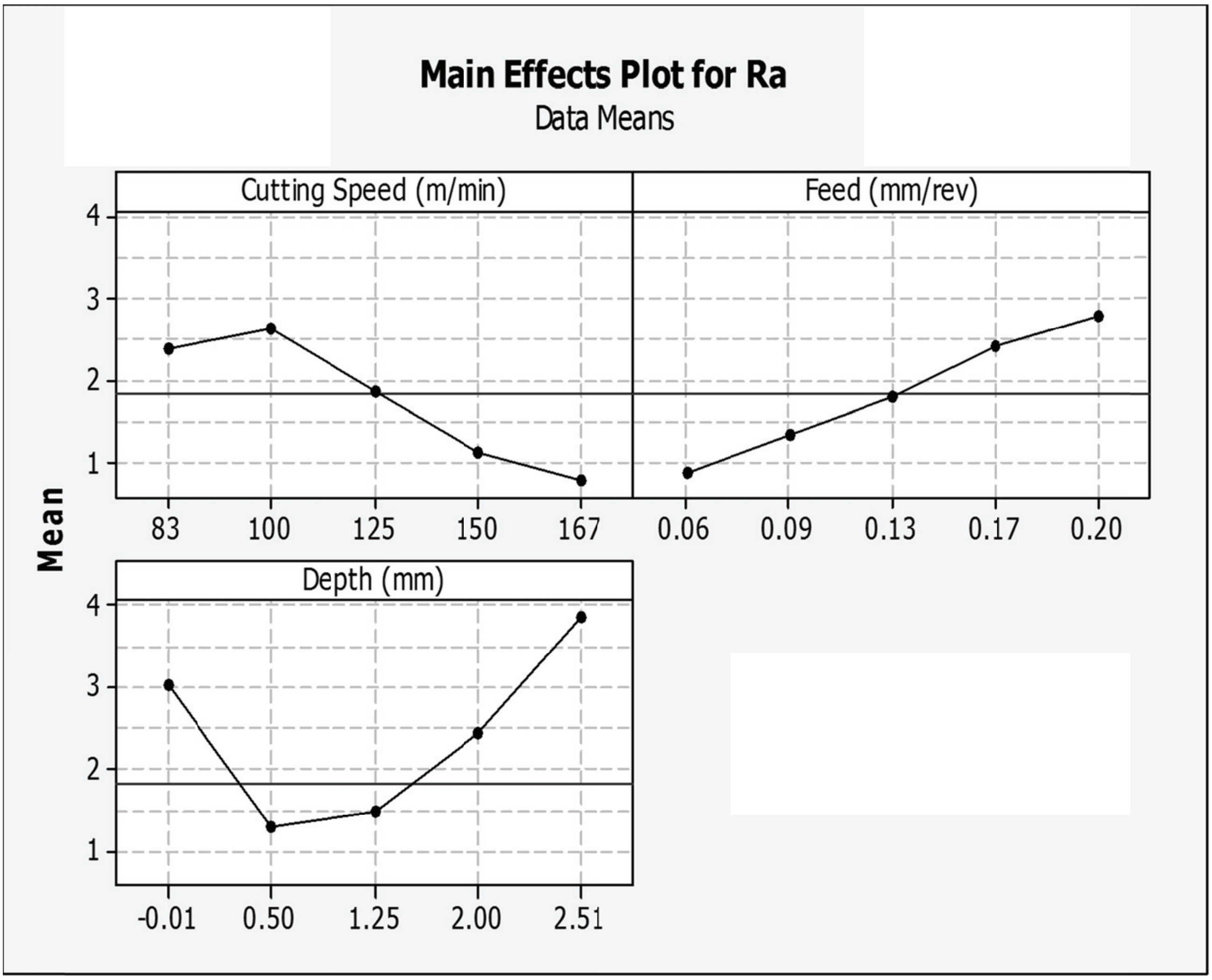


Figure 21 Main Effect Plots for Ra

Impact of two factors at a time (TFAT) on Ra has been freezed by figure 7.9 (Singh and Sodhi, 2014). The corresponding graphs of parameters, highlighting lines that are crossing each other or about to cross, seems to be possessing significant interactions. From figure 7.9, the plight of cutting speed*feed and cutting speed*dept of cut are appearing to be critical as signified earlier through RSM statistics of Ra.

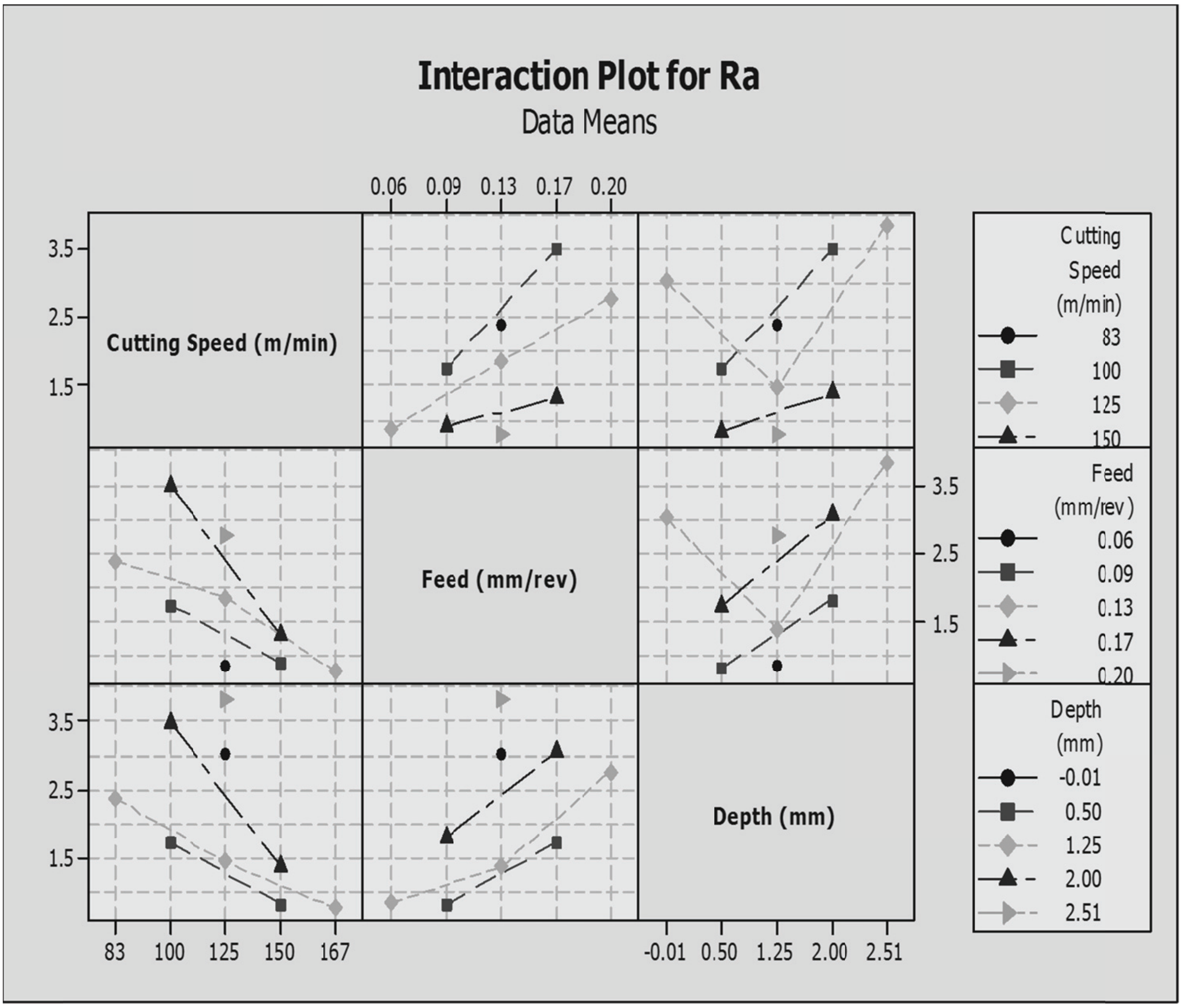


Figure 22 Two-Way Interaction Plot for Ra

The 3-D surface plots as a function of two factors at a time, maintaining all other factors at fixed levels not only provides understanding of both the main and the interaction effects of these two factors, but also helps to identify the optimum level of each variable for maximum response. See figure 25 containing surface plot and its corresponding 2-D contour plot of Ra versus feed and cutting speed at a holding value of depth on 1.251 (Singh and Sodhi, 2014).

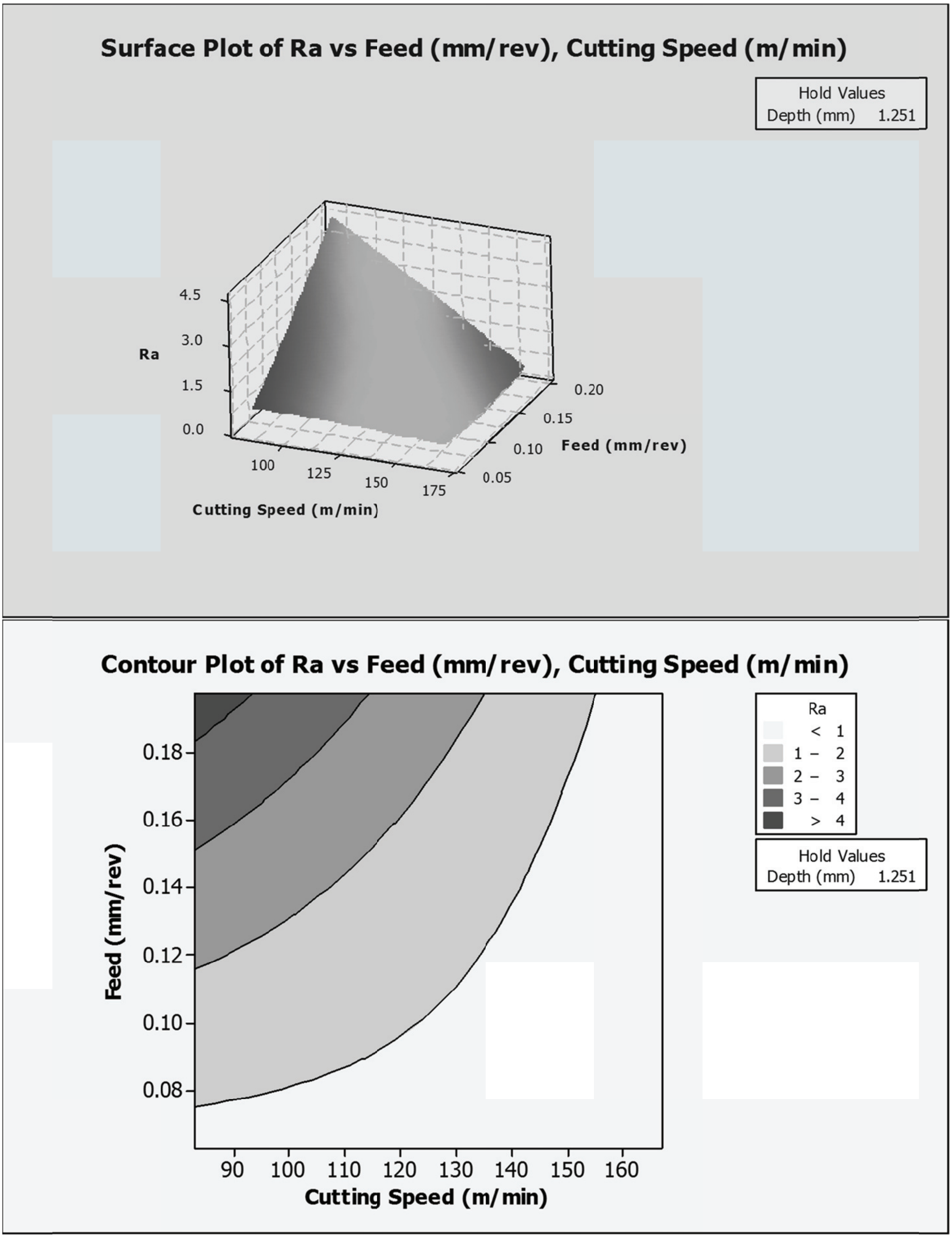


Figure 23 Surface Plot of Ra Vs Feed & Cutting Speed

Contour plot in figure 7.12 highlights Ra versus feed and cutting speed. Different color combinations show the effect of feed and cutting speeds on the value of surface roughness (Ra).

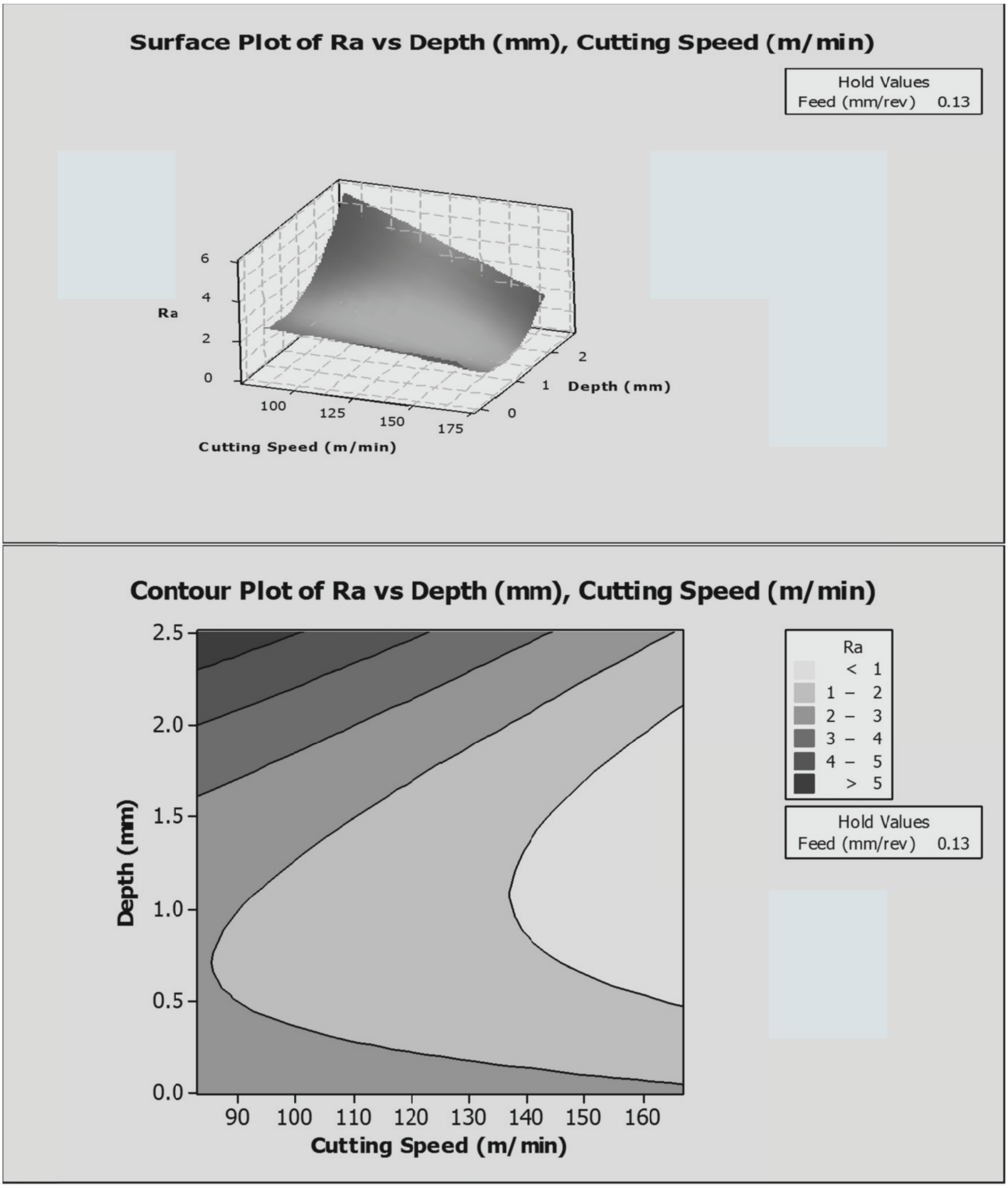


Figure 24 Surface Plot of Ra Vs Depth of Cut & Cutting Speed

Figure 26 shows the surface plot of Ra vs depth of cut and Cutting Speed by holding the value of feed at 0.13 (mm/rev).

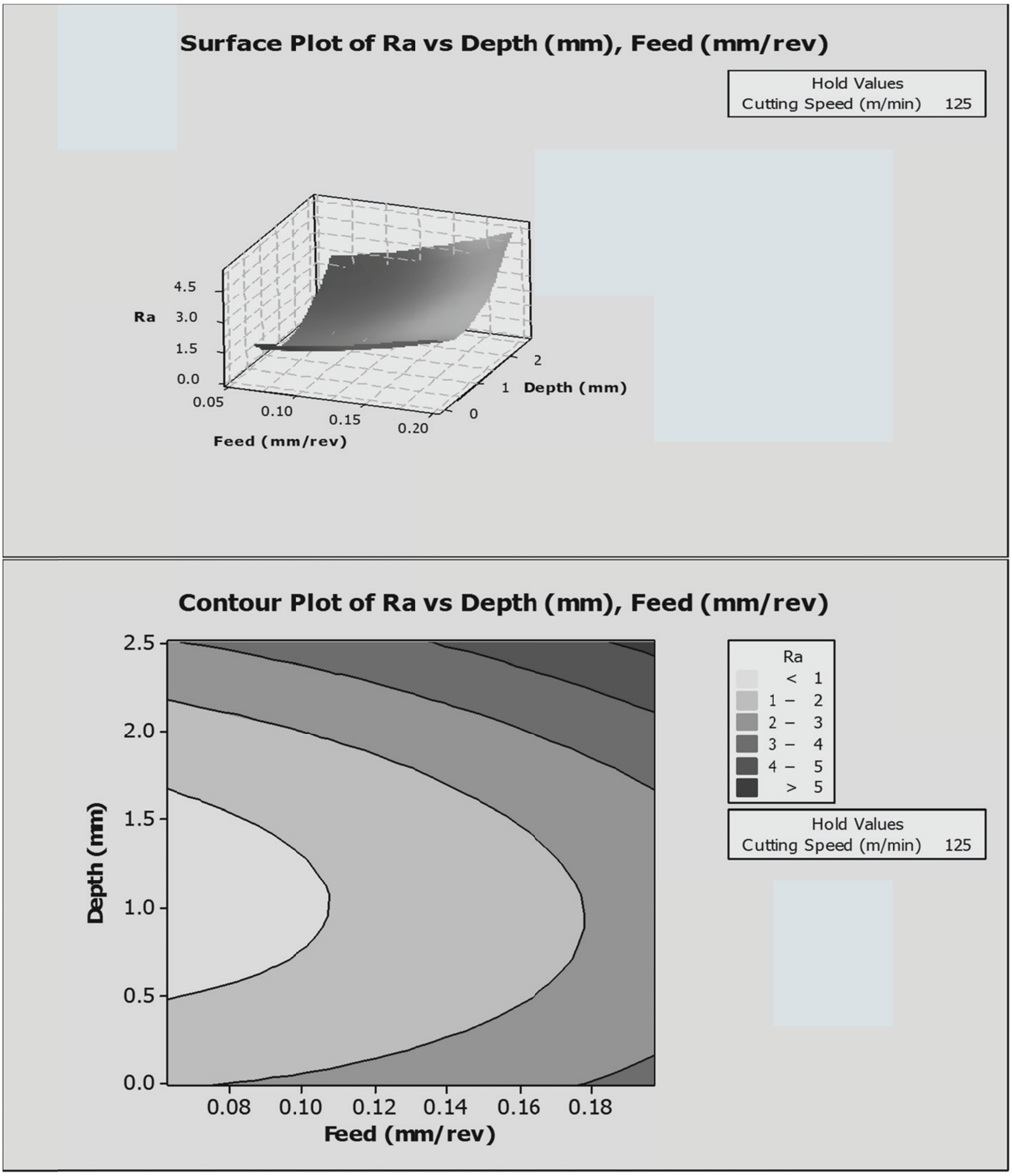


Figure 25 Surface Plot of Ra Vs Depth of Cut & Feed

Region under light green color in above contour plots (see figure 27) highlight the settings of turning parameters where second response, Surface Roughness (Ra) is minimum or even less than 1.

At end, Minitab has created an Estimated Regression Coefficients for Ra in terms of its significant factors and their interactions, as detailed under in table 12

Term	**Coef**
Constant	-3.27231
Cutting Speed (m/min)	0.0434706
Feed (mm/rev)	40.3423
Depth (mm)	-0.600718
Cutting Speed (m/min)* Cutting Speed (m/min)	-2.04369E-05
Feed (mm/rev)*Feed (mm/rev)	46.1547
Depth (mm)*Depth (mm)	1.14695
Cutting Speed (m/min)*Feed (mm/rev)	-0.336250
Depth (mm)*Depth (mm)	-0.0163333
Feed (mm/rev)*Depth (mm)	2.79167

Table 12 Estimated Regression Coefficients for Ra Using Data in Un-coded Units

Ra = -3.2 - 0.04 (Cutting Speed) + 40.3 (Feed) – 0.60 (Depth) + 1.14 (Depth) ^{2} - 0.03 (Cutting Speed x Feed) -0.01 (Cutting Speed x Depth).

From above relation it is obvious that coefficients factors like; Feed, Depth of Cut and (Dept of Cut) ^{2} seem to be more influential on surface roughness (Ra) or should be taken care of while machining non ferrous alloys.

7.8 RSM Solution

At last lower, upper and target values of both the responses has been fed into Response Optimizer tool of Minitab together by giving equal weightage, refer table 7.10 for details.

Goal	**Lower**	**Target**	**Upper**	**Weight**	**Import**
MRR	0.00	15600.0	15628.4	1	1
Ra	0.68	0.7	4.5	1	1

Table 13 Response Optimization

Table 13 demonstrates that by taking cutting Speed of 167 m/min, feed 0.1 mm/rev and Depth of cut 2.0 mm, we will achieve material removal rate of 15600 (mm³/min) and corresponding surface roughness of 0.69 µm at composite desirability of 98.6%.

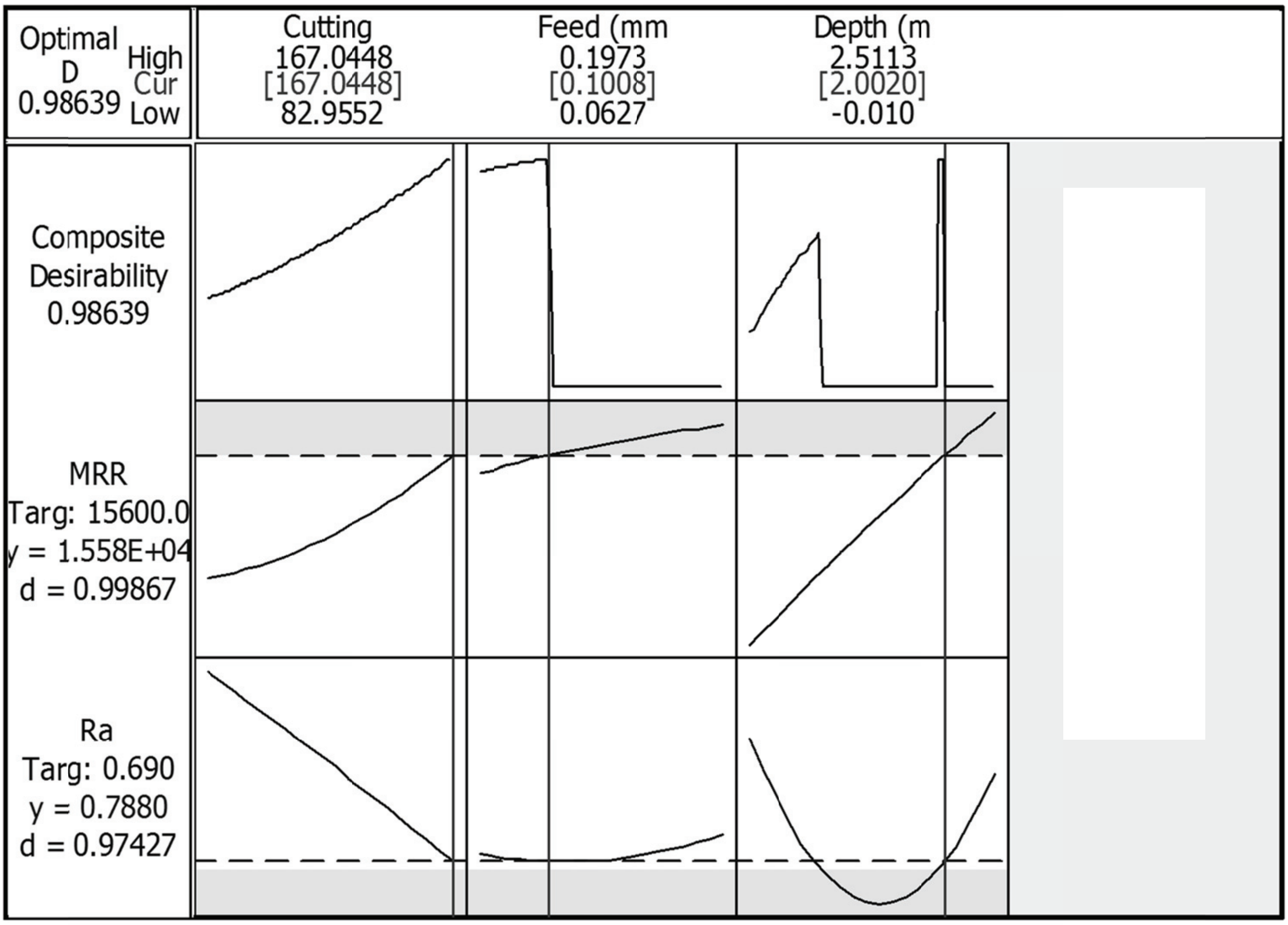


Figure 26 Predicted Responses

After analyzing the data of experiments, software has provided the solution at 98% composite desirability that at Cutting Speed of 1670.4 m/min, Feed of 0.1 mm/rev and Depth of Cut of 2.0 mm, maximum MRR of 15600 mm³/min along with minimum Ra of 0.69µm can be achieved.

Lower half of figure 28 reflects graphical representation of Variation of MRR and Ra with focused input variables beside pin-pointing desired optimal points by blue dotted line.

7.9. Validation of Solution through ANOVA

To verify real world achievements, around thirty experimental runs have been performed at three different machine settings coded as; Machine Setting 1, 2 and 3 respectively. At machine setting 1, lower value of parameters were selected, the machine was run at a cutting speed of 82.9 m/min, feed rate of 0.06 m/rev and depth of cut is maintained at 0.5 mm, respectively.

Whereas at machine settings 2, machine was made to run at the optimized parameters which we got after the RSM analysis. These parameters were; cutting speed 167.4 m/min, feed rate 0.1m/rev and depth of cut 2 mm. At last machine was run at higher values of parametric variables. These values of parameters were cutting speed 167.4 m/min, feed rate 0.19 m /rev and depth of cut 2.5 mm. Results achieved after performing all these sets of experiments were quite satisfactory, as we get the desired results at optimized machine settings.

The material removal rate achieved at machine setting 2 was on higher side and at the same time surface roughness was on lower side. After that One Way ANOVA (unstacked) is decided to use for validating results incurred due to optimization. Both responses MRR and Ra are suitably calculated as per laid methodology and quoted appropriately for each machine setting in data table.

M/c Settings - 1

Cutting Speed = 82.9 m/min
Feed = 0.06 mm/rev.
Dept of Cut = 0.5 mm

MRR (mm^3/min)	Ra (μm)
1192	1.21
1783	1.89
1527	2.11
1329	2.56
1128	1.67
1837	2.31
1623	1.46
1325	1.13
1989	1.58
1316	1.37
1867	1.88
1296	1.47
1692	2.16
1087	1.89
1752	1.82
1802	2.38
1451	1.26
1389	1.87
1458	2.48
1589	1.59
1056	2.37
1748	1.63
1364	1.97
1859	1.41
1653	2.19
1318	1.53
1712	1.88
1627	2.29
1389	1.84
1528	1.71

M/c Settings - 2

Cutting Speed = 167.04 m/min
Feed = 0.1 mm/rev.
Dept of Cut = 2 mm

MRR (mm^3/min)	Ra (μm)
15294	0.92
15326	1.12
15317	0.98
15411	0.86
14911	1.24
15362	1.17
14854	1.13
15219	0.98
15453	1.06
15022	0.96
15286	1.29
14911	1.21
15237	0.89
15212	1.16
15263	0.94
15398	1.03
14987	1.32
15258	1.14
15127	1.09
15316	0.98
15012	1.14
14917	1.22
15102	1.04
15235	0.92
14912	1.15
14984	1.11
15377	1.24
15119	0.86
15117	1.16
15358	1.08

M/c Settings - 3

Cutting Speed = 167.04 m/ min
Feed = 0.19 mm/rev.
Dept of Cut = 2.5 mm

MRR (mm^3/min)	Ra (μm)
15167	2.19
14726	1.89
14912	1.54
13256	2.42
10108	1.95
12919	1.67
14236	1.72
11119	1.61
9108	2.13
15723	2.38
11821	1.72
10256	2.14
14856	2.53
13485	1.63
12216	1.87
9781	2.13
9328	2.46
13285	1.84
11297	1.98
10256	2.09
12987	2.49
11356	1.85
13786	1.93
15421	1.87
8736	2.14
12897	1.67
8456	2.43
15119	1.96
12361	1.77
9216	2.38

Table 14 Responses on Machine Settings 1, 2 and 3

These data values are checked for normality and found ok as far as Ra is related (see figure 29). The scattered data dots are showing some lack of normality for MRR, but statistically, if group size of data becomes more than 15 than normality doesn't be an important issue and can even be ignored, while predicting.

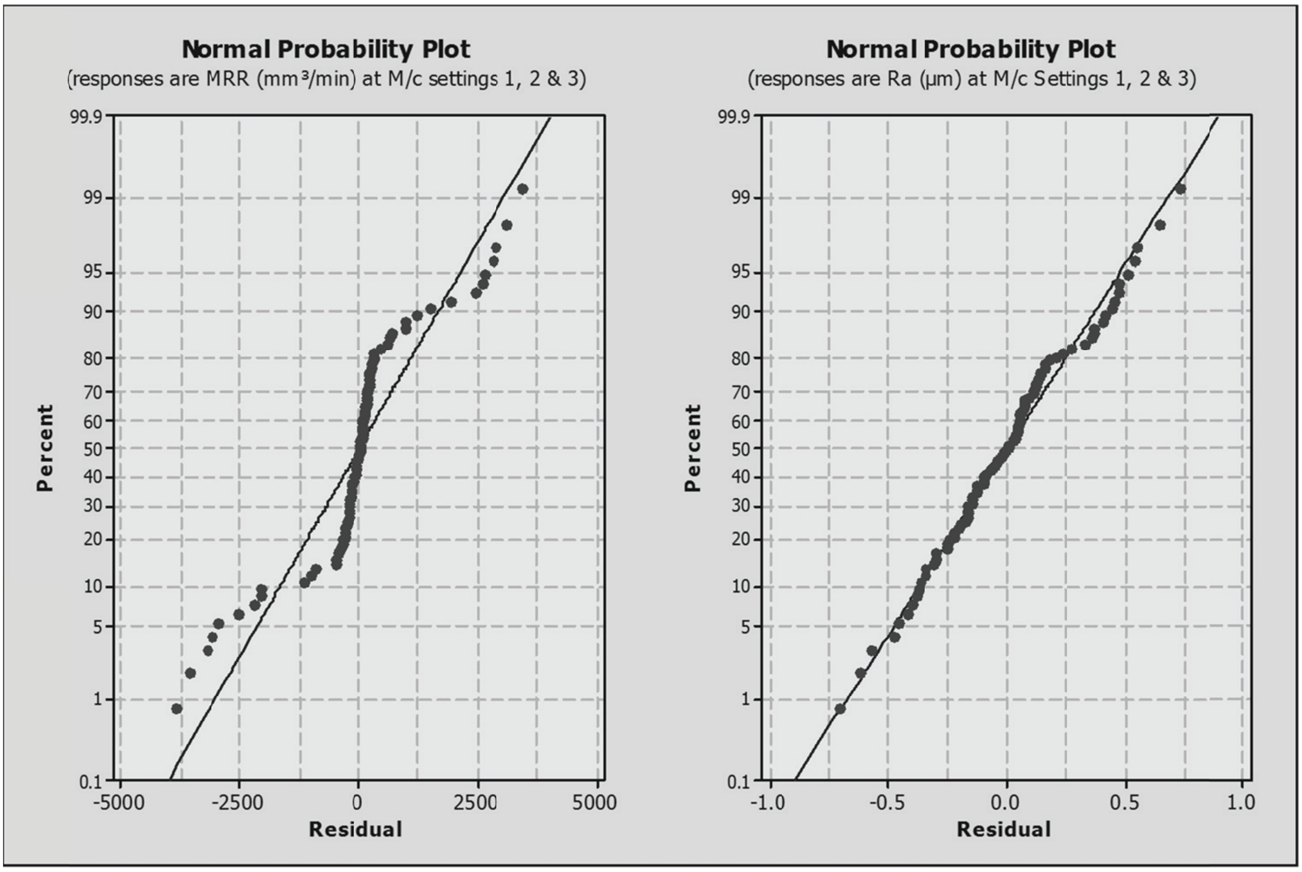


Figure 27Normal Probability Plot of MRR and Ra

After analyzing data at 95% confidence level, p-value is generated as less than 0.05 and hence M/c settings seems to be substantially significant and have impact on MRR. Mean (15177) is maximum at M/c Setting-2 and minimum (1523) at M/c Setting-1, correspondingly.

Source	**DF**	**SS**	**MS**	**F**	**P**
Factor	2	3104195898	1552097949	905.47	0.000
Error	87	149129091	1714127	------	------
Total	89	3253324988	------	------	------

S = 1309 R-Sq = 95.42% R-Sq(adj) = 95.31%

Individual 95% CIs For Mean Based on pooled standard deviation

M/c Settings	**Level**	**N**	**Mean**	**StDev**
1	MRR (mm^3/min)	30	1523	253
2	MRR (mm^3/min)	30	15177	178
3	MRR (mm^3/min)	30	12273	2246

Pooled St Dev = 1309

Table 15 One-way ANOVA for MRR (mm^3/min) at M/c settings 1, 2 & 3

Similarly, data has been processed with ANOVA for Ra and found statics as shown in table 15. The p-value (0.000) is again less than the barrier and hence it can be concluded that the variation of Surface Roughness (Ra) is related with M/c Settings1, 2, and 3 positively.

Source	**DF**	**SS**	**MS**	**F**	**P**
Factor	2	14.6723	7.3362	85.18	0.000
Error	87	7.4926	0.0861	------	------
Total	8	22.1649	------	------	------

S = 0.2935 **R-Sq = 66.20%** **R-Sq(adj) = 65.42%**

Individual 95% CIs For Mean Based on Pooled StDev

M/c Settings	**Level**	**N**	**Mean**	**StDev**
1	Ra (µm)	30	1.8303	0.3933
2	Ra (µm)	30	1.0797	0.1287
3	Ra (µm)	30	2.0127	0.2952

Pooled St Dev = 0.2935

Table 16 One-way ANOVA for Ra (µm) at M/c Settings 1, 2 & 3

Medium value of R-sq (adj) reflects dependency of Ra on some other factors also (beside taken input turning factors). Figure 31 shows the mean value of MRR and Ra as a 1523 mm^3/min and 1.83 µm, respectively at Machine Setting-1.While performing at Machine Setting-2, mean value of MRR and Ra comes out to be 15177 mm^3/min and 1.07 µm. At end, mean value of MRR and Ra for Machine Setting-3 has been found as 12273mm^3/min and 2.012 µm, respectively. So from the above results it becomes obvious that maximum mean value of MRR and minimum mean value of Ra can only be achieved at Machine Setting-2 only, which is a desired result.

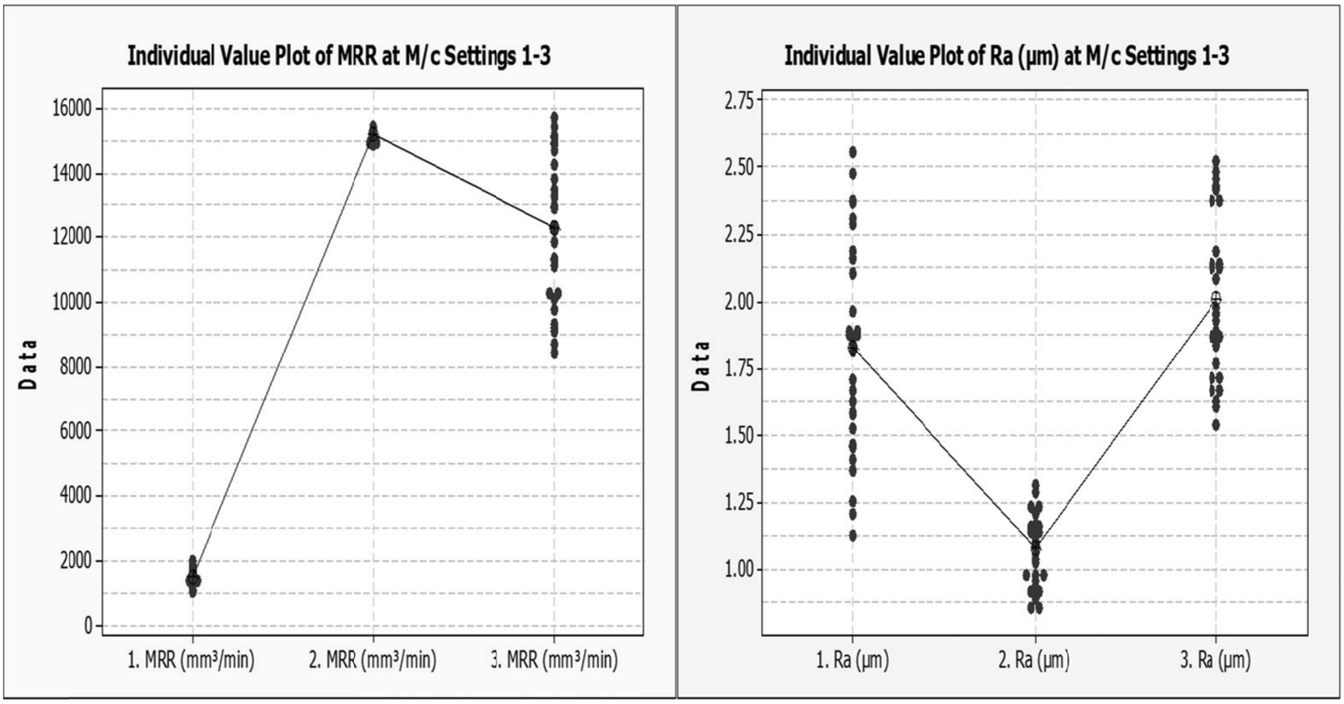


Figure 28 Individual Value Plot of MRR and Ra at Machine Settings 1, 2 and 3

Figure 30 describes that the mean value of MRR and surface roughness is 1523 mm³/min and 1.83 µm, respectively at machine settings 1. While performing the experiments on machine settings 2 we got the mean value of MRR and surface roughness 15177 mm³/min and 1.07 µm, respectively. Similarly, the mean value of MRR and surface roughness 12273 mm³/min and 2.012 µm has been generated at machine settings 3. So from the above results we can conclude that we are getting the maximum mean value of MRR and minimum mean value of surface Roughness on machine setting 2 which are the needed results.

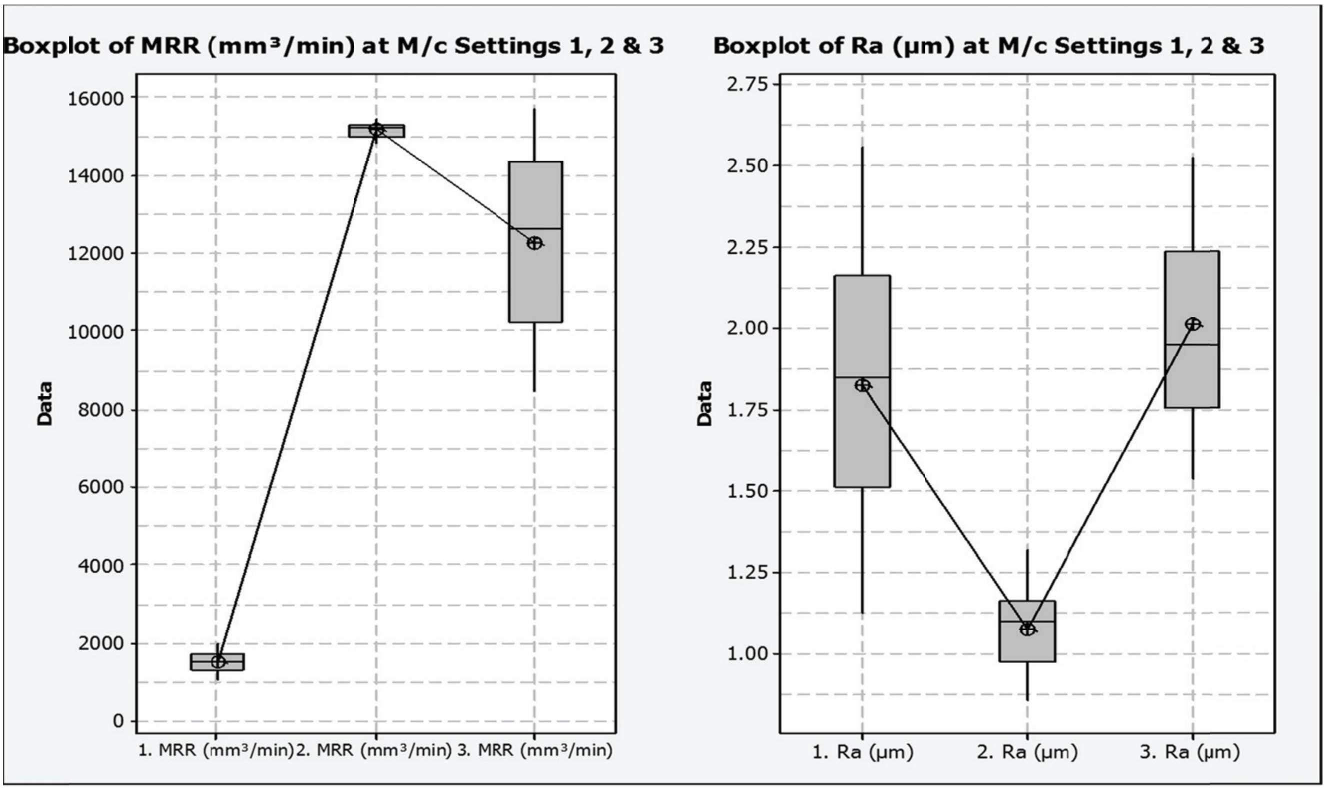
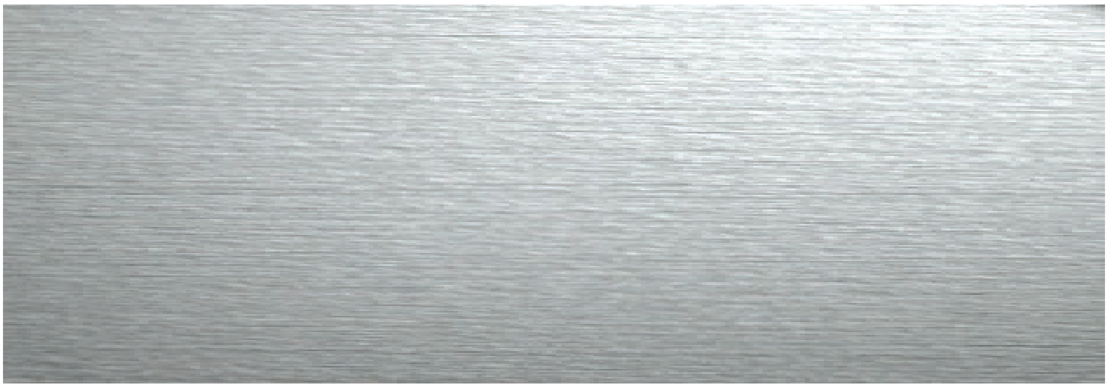


Figure 29 Box Plot of MRR and Ra at Machine Settings 1, 2 and 3

According to Minitab MRR would be 15580m^3/min at M/c Setting-2 (see figure 28) but in actual after running the M/c in present machining conditions, only 15177 m^3/min MRR has been incurred. Next, forecasted Ra was 0.78 µm but attained value of Ra is 1.07 µm. These deviations in responses may be due to some inherent machining constraints like turning skill of operator, error in measuring instruments or in calculations etc.

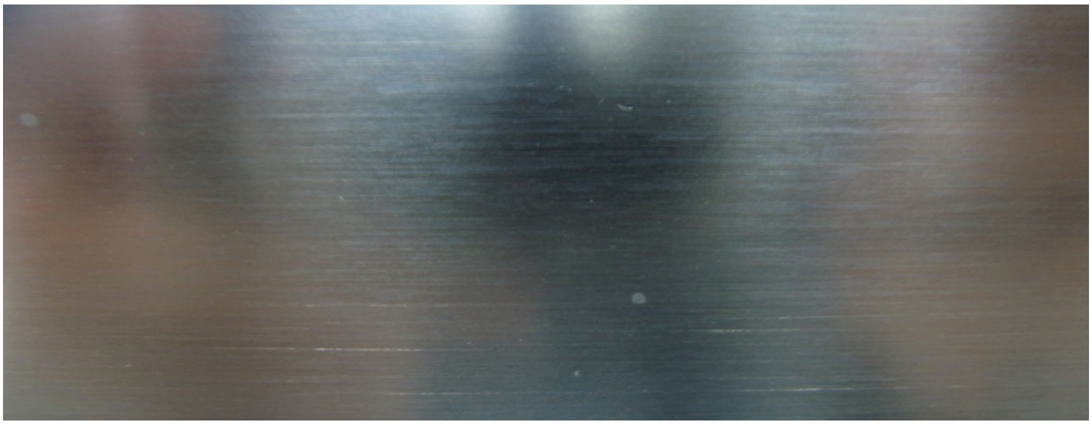
Figure 32 has snapped the physical appearance of machined surfaces at M/c Settings-1, 2 & 3 and aesthetically verified the excellent surface finish results at optimized turning parameters provided by RSM.

Poor Surface Finish at M/c settings 1



Ra mean value = 2.01

Excellent Surface Finish at M/c settings 2



Ra mean value = 1.07

Good Surface Finish at M/c settings 3

Ra mean value = 1.83

Figure 30 Pictures of Al-7020 (Samples) Turned at Different M/C Settings

Finally, a report prepared as an overall result of whole experimentation has been summarized through figure 33. Values of MRR and Ra corresponding to different M/c Settings have been plotted on separate graphs. Frequency histograms pin-points the response distribution and concerned control chart describe the variation with mean values of MRR and Ra suitably.

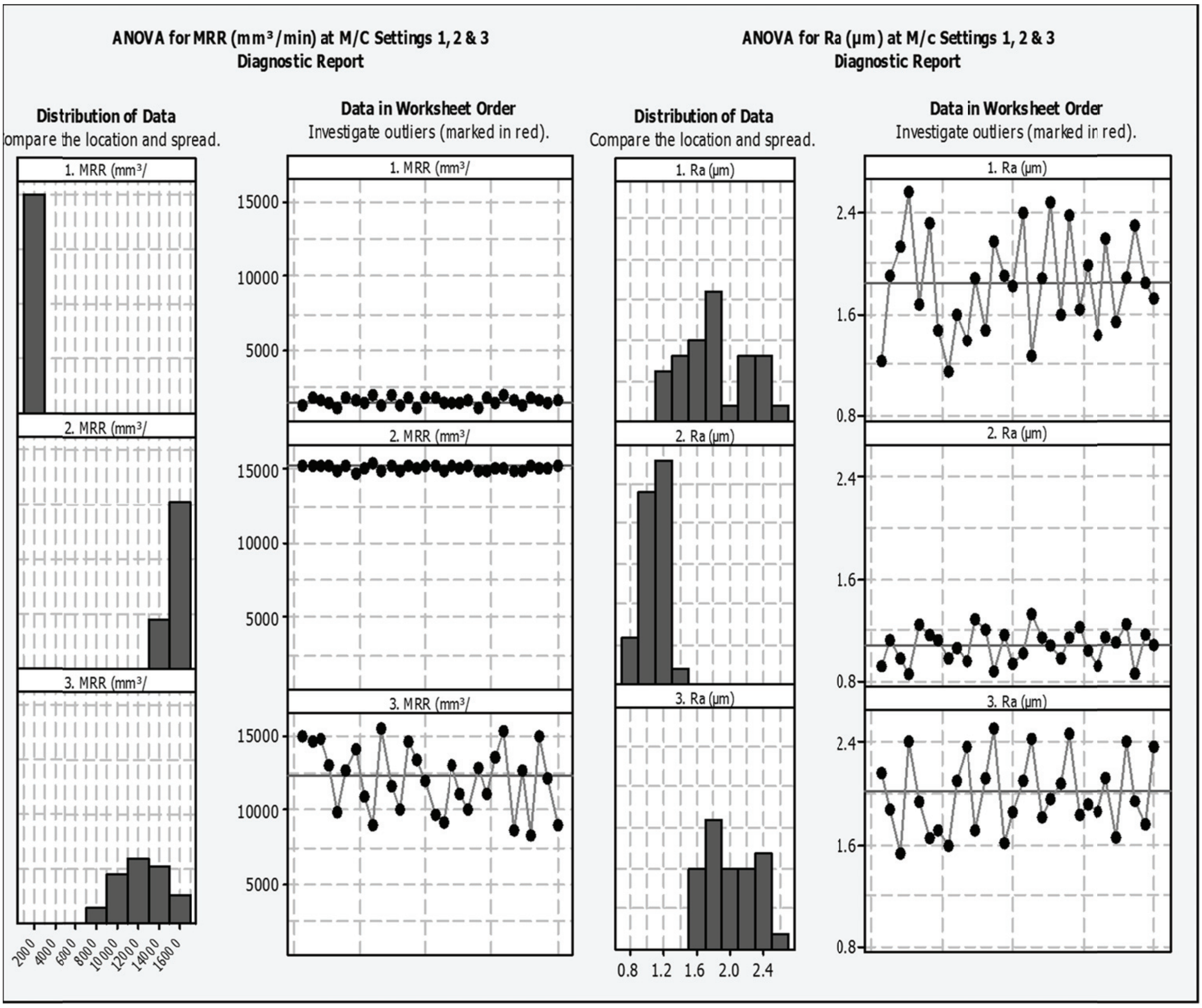
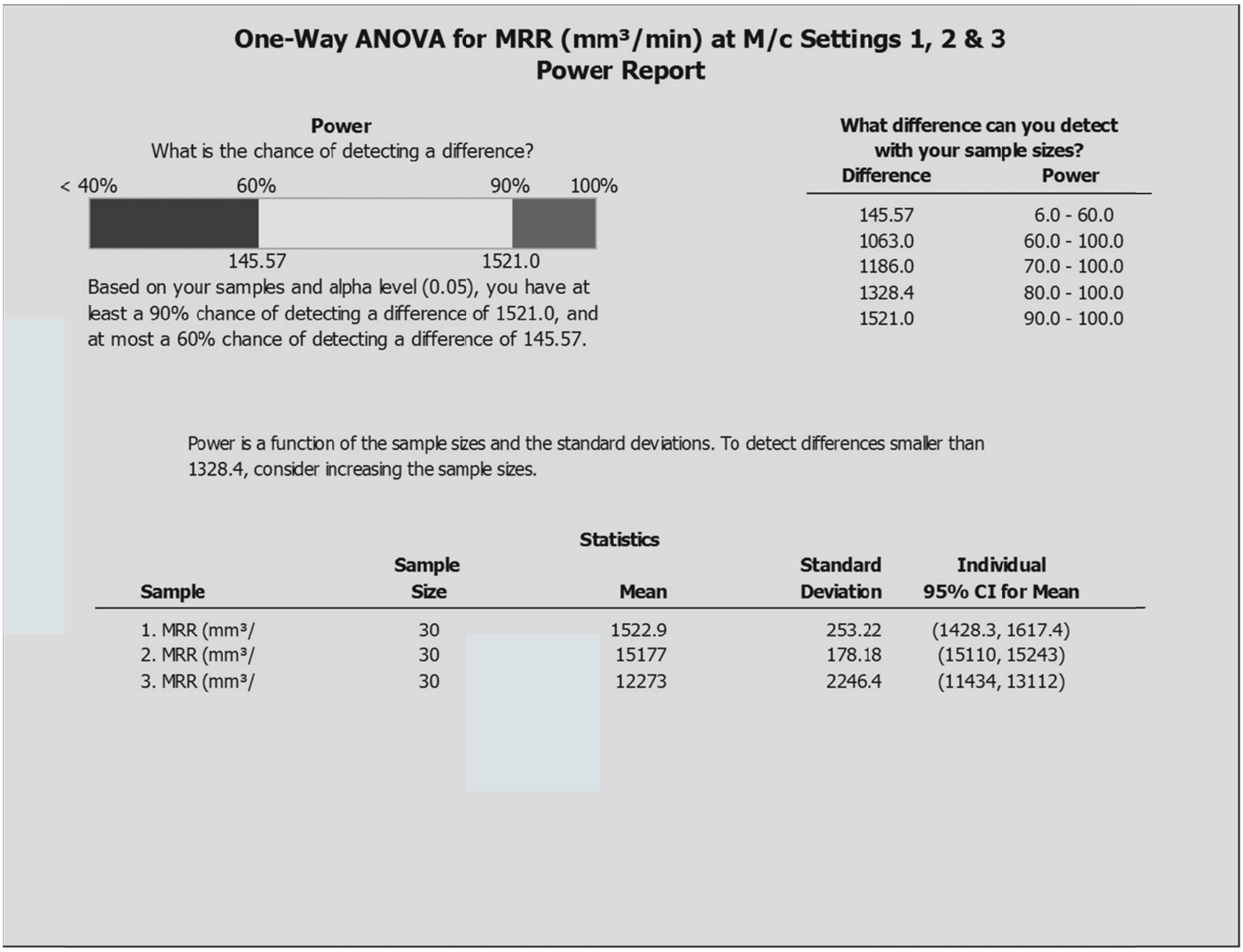


Figure 31 Diagnostic Report of ANOVA for MRR and Ra at M/c Settings 1, 2 and 3

It also demonstrates that at optimized turning conditions (M/c setting-2) not only the MRR increases and Ra decreases but also related standard deviations have also been reduced effectively (see the data patterns within control limits) which leads to turning of Al-7020 alloy toward more stability and precision.



One-Way ANOVA for MRR (mm³/min) at M/c Settings 1, 2 & 3
Power Report

Power
What is the chance of detecting a difference?

Based on your samples and alpha level (0.05), you have at least a 90% chance of detecting a difference of 1521.0, and at most a 60% chance of detecting a difference of 145.57.

What difference can you detect with your sample sizes?

Difference	Power
145.57	6.0 - 60.0
1063.0	60.0 - 100.0
1186.0	70.0 - 100.0
1328.4	80.0 - 100.0
1521.0	90.0 - 100.0

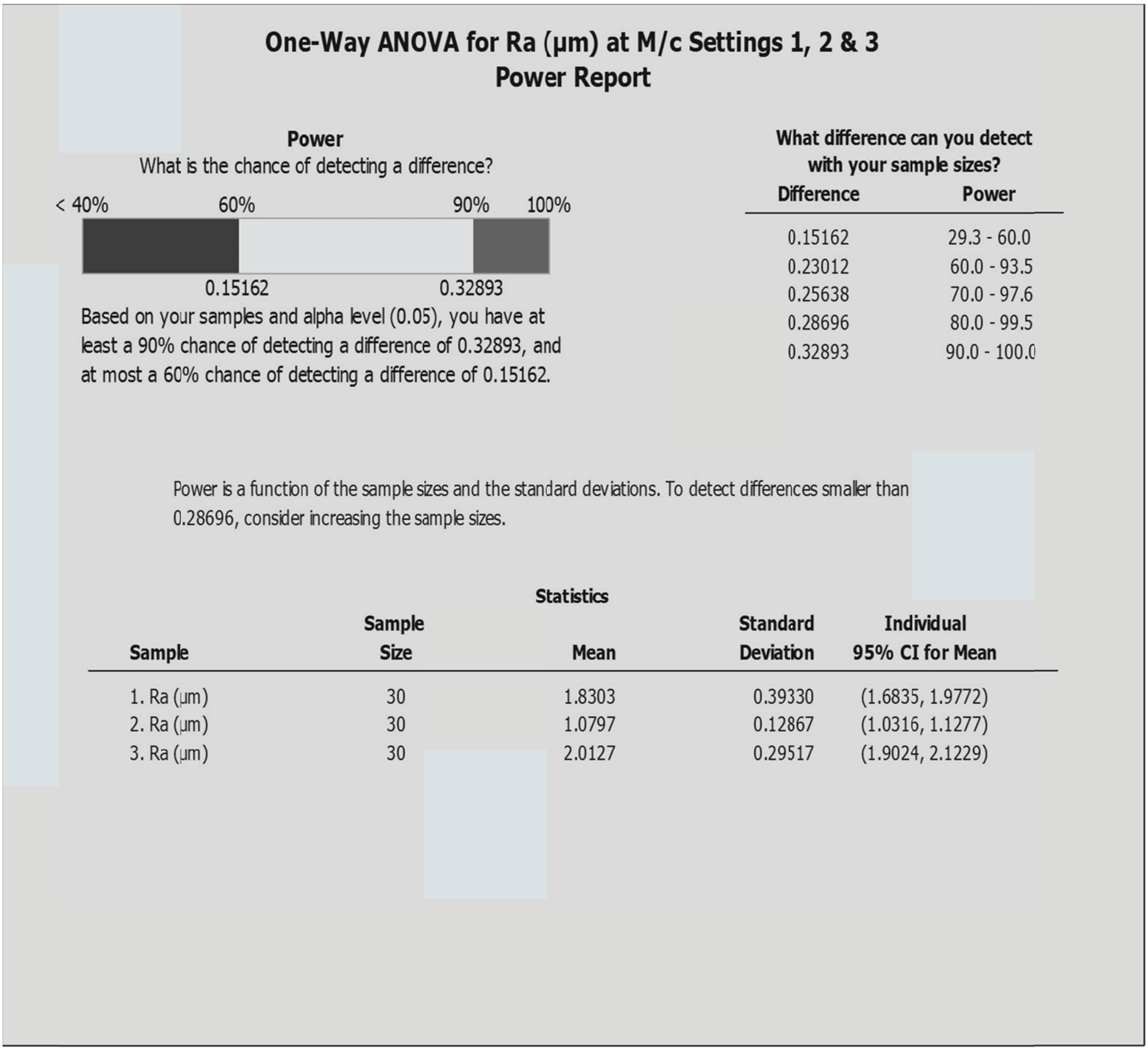
Power is a function of the sample sizes and the standard deviations. To detect differences smaller than 1328.4, consider increasing the sample sizes.

Statistics

Sample	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
1. MRR (mm³/	30	1522.9	253.22	(1428.3, 1617.4)
2. MRR (mm³/	30	15177	178.18	(15110, 15243)
3. MRR (mm³/	30	12273	2246.4	(11434, 13112)

Figure 32 One way ANOVA Power Report for MRR at M/c Settings 1, 2 and 3

Power is a function of detecting the difference between sample sizes and standard deviations. From the results it can be concluded that on the basis of samples and alpha level (0.05) we have at least a 90% chance of detecting a difference of 1521 mm³/min material removal rate, and at most a 60% chances of detecting a difference of 145.57 mm³/min material removal rate.



One-Way ANOVA for Ra (µm) at M/c Settings 1, 2 & 3
Power Report

Power
What is the chance of detecting a difference?

Based on your samples and alpha level (0.05), you have at least a 90% chance of detecting a difference of 0.32893, and at most a 60% chance of detecting a difference of 0.15162.

What difference can you detect with your sample sizes?

Difference	Power
0.15162	29.3 - 60.0
0.23012	60.0 - 93.5
0.25638	70.0 - 97.6
0.28696	80.0 - 99.5
0.32893	90.0 - 100.0

Power is a function of the sample sizes and the standard deviations. To detect differences smaller than 0.28696, consider increasing the sample sizes.

Statistics

Sample	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
1. Ra (µm)	30	1.8303	0.39330	(1.6835, 1.9772)
2. Ra (µm)	30	1.0797	0.12867	(1.0316, 1.1277)
3. Ra (µm)	30	2.0127	0.29517	(1.9024, 2.1229)

Figure 33 One way ANOVA Power Report for Ra at M/c Settings 1, 2 and 3

Power report is a function of detecting the difference between sample sizes and standard deviations. From the results it can be concluded that on the basis of samples and alpha level (0.05) we have at least a 90% chance of detecting a difference of 0.32893 µm of surface roughness, and at most 60% chances of detecting a difference of 0.15162 µm of surface roughness.

Red curve in the figure 36 signifies the standard deviation and spread of MRR within the samples. It is distributed along its optimized mean value while machine is running at setting 2.

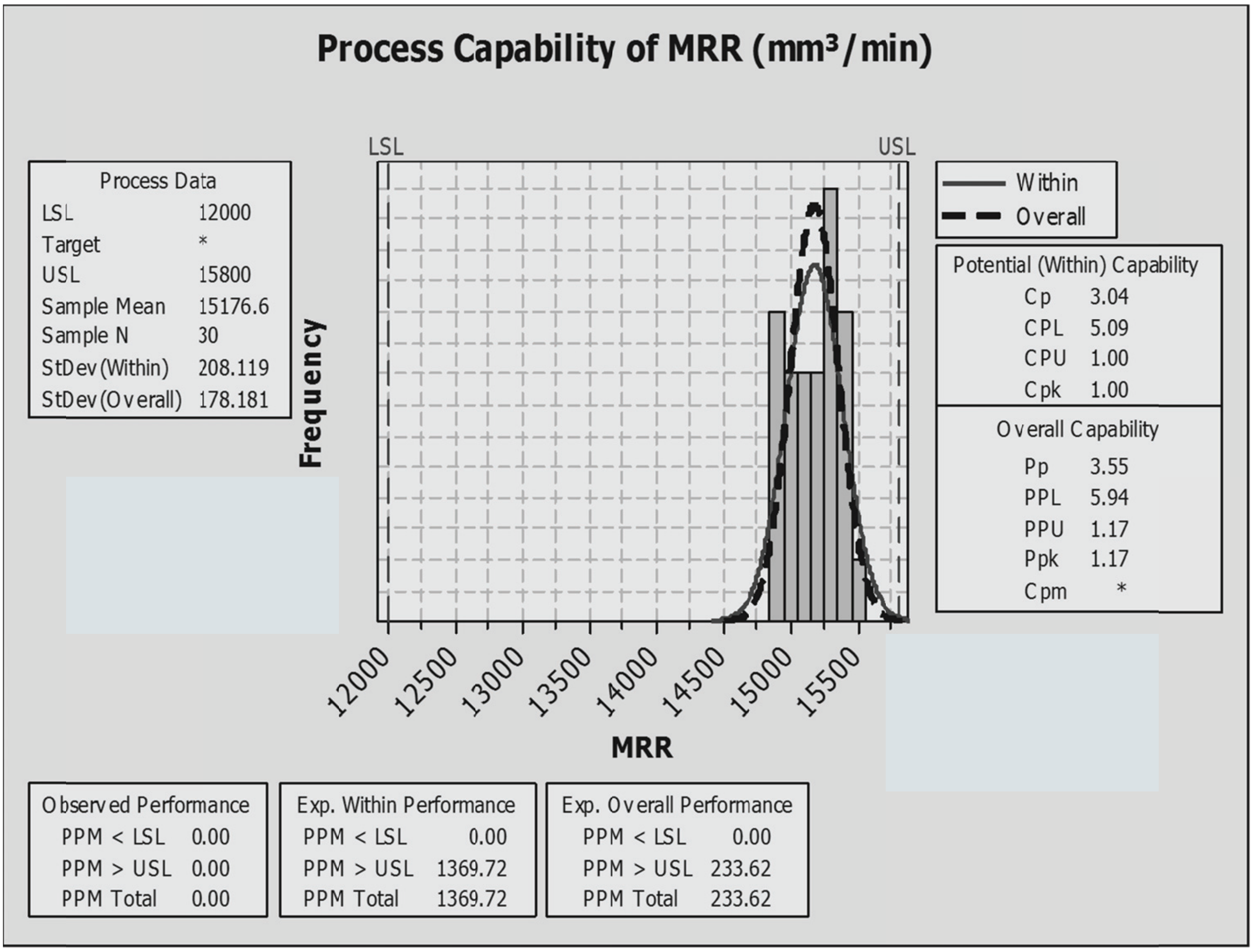


Figure 34 Process Capability w.r.t. MRR

The black dotted line describes that there will be a decrease in the standard deviation of material removal rate when the overall population will be considered (large sample size) as related spread of curve is less. So we can conclude that there is a decrease in the standard deviation from 208.119 to 178.181 when large sample size will be taken during machine setting 2.

Similarly the red curve in the figure 37 shows the standard deviation and spread within the samples of surface roughness when M/c is running at optimized settings.

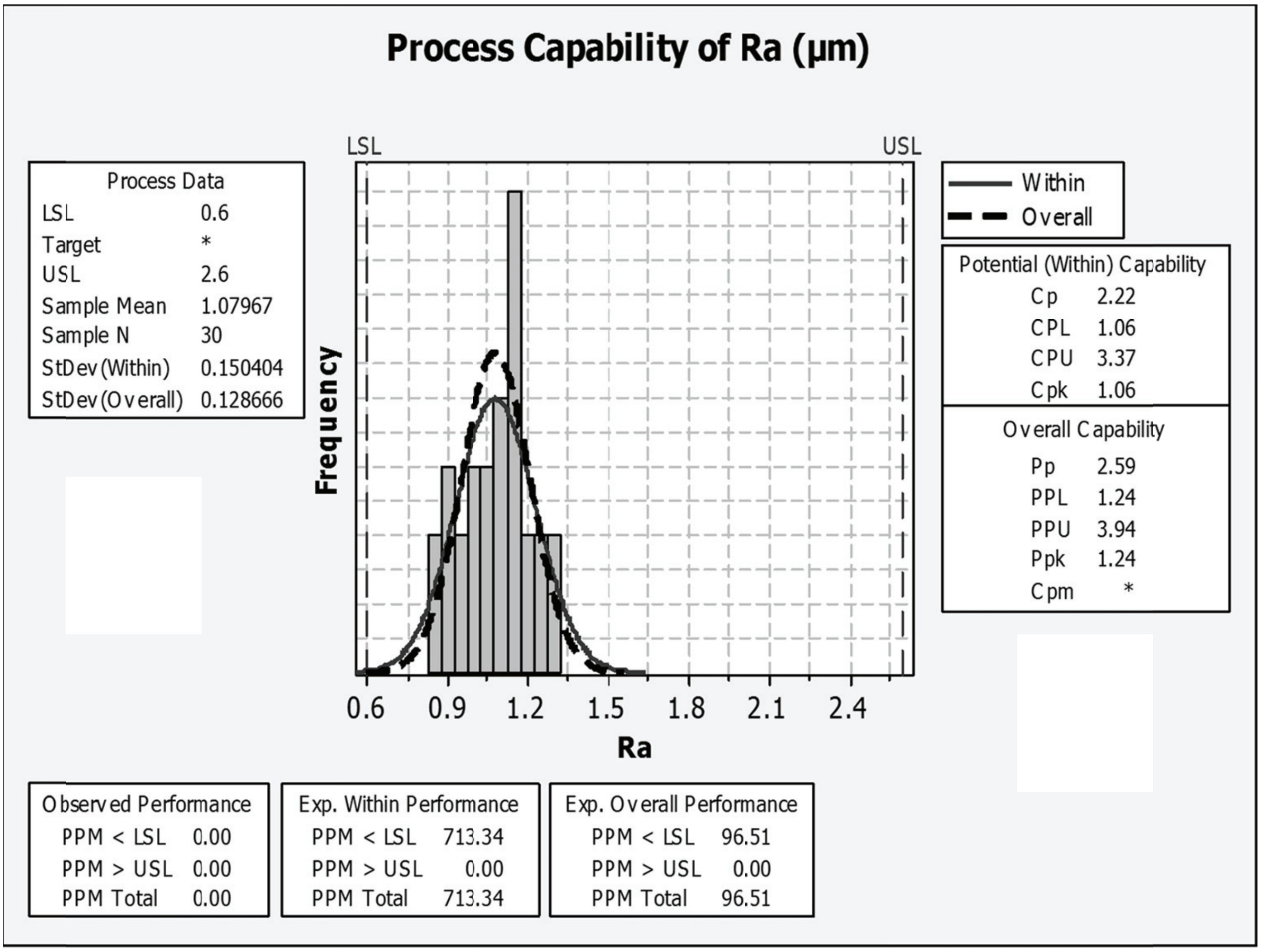


Figure 35 Process Capability w.r.t. Ra

Black dotted line demonstrates that there will be a decrease in the standard deviation and spread of surface roughness when the overall population will be considered (large sample size). So we can conclude that there is a decrease in the standard deviation from 0.150 to 0.128 when large sample size will be taken while machine will run at settings 2. It will give consistent output (distributed along the mean) as far as Ra is in question.

7.10 Relation In Between Responses

From the data it has been felt that there will be an inverse relation between MRR and Ra and to further explore this fact Co-relation tool has been used on both generated responses at optimized turning conditions. Carl Pearson Coefficient has come out to be -0.371 between MRR and Ra (look at figure 38 for details).

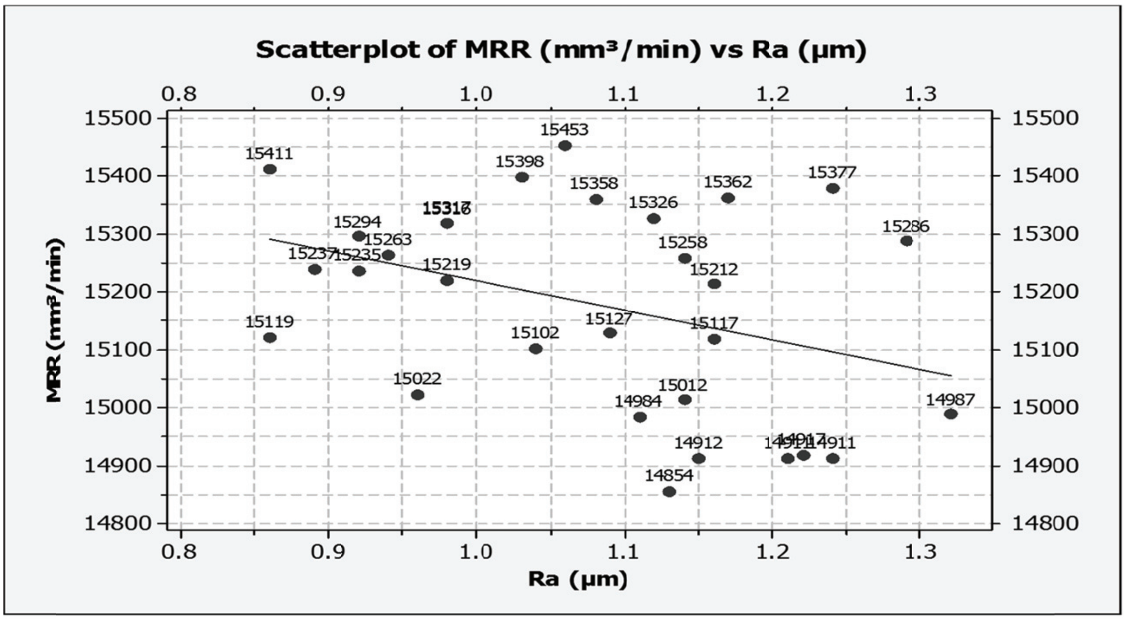
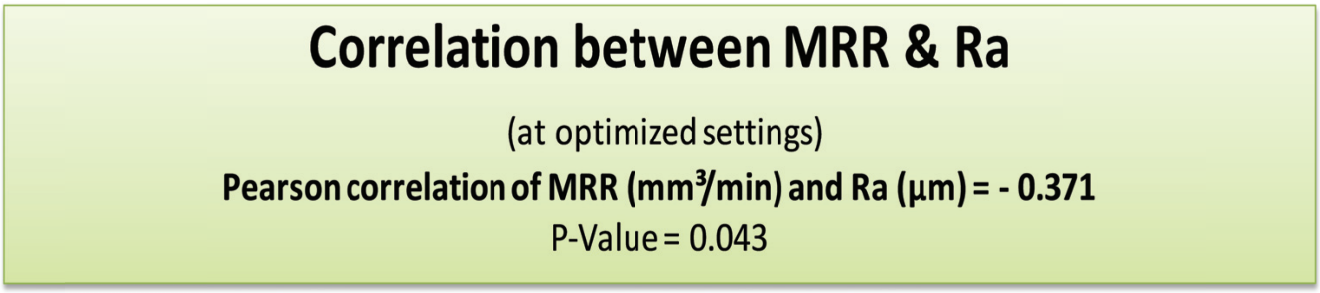


Figure 36 Correlations Between MRR and Ra



Correlation between MRR & Ra

(at optimized settings)

Pearson correlation of MRR (mm³/min) and Ra (µm) = - 0.371

P-Value = 0.043

The negative sign is due to inverse relation which implies as MRR will increase Ra would simultaneously decrease. All values of MRR and Ra have been plotted on scatter plot and regression line has been drawn. Pearson coefficient 1 signifies perfect relation, so it implies numeric term (0.371) demonstrates intensity of relation. It can also be judged from the slope of regression line.

CHAPTER 8

CONCLUSIONS & SCOPE

8.1 Conclusion

Generally, Tanguchi's method has been utilized for machining optimality but in present case, Central Composite Design of RSM is being applied on CNC turning parameters for Al-7020 alloys, successfully. The optimized results obtained by RSM are closely matched with actual ones and further verified by ANOVA. Best turning parameters found for maximum MRR and minimum Ra for Al-7020 alloys are;

Cutting Speed=167 m/min
Feed= 0.1 mm/rev and
Depth of Cut= 2.0 mm.

It has been un-folded that the individual parameters; Cutting Speed and Feed are more influencing than Depth of Cut as far as non-ferrous machining is under focus. This study has not only formulated statistical optimizing equations for MRR and Ra (for Al-7020), but also tries hard to define relation between them through co-relation. The important conclusions drawn from the present research are summarized as ahead. The Material removal rate and surface roughness could be effectively predicted by using spindle speed, feed rate and depth of cut as the input variables. Considering the individual parameters, Cutting speed and feed rate had been found to be the most influencing parameter, followed by depth of cut. The average actual Material removal rate value had been obtained as 15,177 mm^3/min and the corresponding predicted MRR value is 15,600 mm^3/min. The average actual roughness Ra value had been obtained as 1.07 µm and the corresponding predicted surface roughness value is 0.7 µm through RSM.

8.2 Scope for Future

RSM shows good compatibility in the optimization of CNC turning parameters therefore in future, optimization of CNC grinding parameters and CNC milling parameters can also be done for Aluminium alloys and other non ferrous materials by using this technique. Other RSM models such as central composite half, central composite quarter, Box – Behnken can be utilized for effective optimization. High speed steel cutting tools can also be used in further experiment works. Tool wear can also be considered as an influencing factor. Minimal quantity of lubrication can be found to get higher surface finish with lesser usage of cooling fluids. Parametric optimization of non-traditional machining techniques such as; Electric Discharge Machining or Ultrasonic Machining etc. can also be feasible through response surface methodology (RSM).

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